Food and Agriculture
Organization of the
United Nations

Contribution of terrestrial animal source food to healthy diets for improved nutrition and health outcomes

An evidence and policy overview on the state of knowledge and gaps

Draft (not for citation)

This is the first component document of a comprehensive, science and evidence-based global assessment of the contribution of livestock to food security, sustainable food systems, nutrition and healthy diets. An overview of the approach, scope, timeline and stakeholder involvement in the Assessment is provided in discussion document COAG:LI/2022/2 *Contribution of livestock to food security, sustainable agrifood systems, nutrition and healthy diets* .

The development of this component document was guided by a multidisciplinary Scientific Advisory Committee consisting of 23 experts which reviewed both an annotated outline and a first draft. In addition, an extended group of interested people was also invited to review those.

The review of the first draft of this component document resulted in more than 1 400 comments received from members of the Scientific Advisory Committee, experts across several disciplines, organizations representing: civil society organisations, the private sector, multi-stakeholders partnerships (GASL), research and academia and other United Nations Organisations (World Health Organization).

This unedited component document will be finalized following review by the Sub-Committee on Livestock of FAO's Committee on Agriculture.

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1 Abbreviations and acronyms

AIDS	Acquired Immunodeficiency Syndrome
AMR	Antimicrobial resistance
BMI	Body mass index
CAC	Codex Alimentarius Commission
CI	Confidence interval
COVID-19	Coronavirus disease 2019
DFD	Dark firm dry
ºC	Degree celsius
DNA	Deoxyribonucleic acid
DIAAS	Digestible Indispensable Amino Acid Score
DALY	Disability-adjusted life year
DHA	Docosahexaenoic acid
DPA	Docosapentaenoic acid
EPA	Eicosapentaenoic acid
ECDC	European Centre for Disease Prevention and Control
EFSA	European Food Safety Authority
FAPDA	FAO Food and Agriculture Policy Decision Analysis
FAO	Food and Agriculture Organization
FBDG	Food-based dietary guideline
FBD	Food-borne disease
GM	Genetically modified
GMO	Genetically modified organism
g	Gram
HR	Hazard ratio
HIV	Human Immunodeficiency Virus
IFAD	International Fund for Agricultural Development
kcal	kilocalorie
kg	kilogram
LMIC	Low- and middle-income countries
µg	microgram
ml	milliliter
MUFA	Monounsaturated fatty acids
INRAE	National Research Institute for Agriculture, Food and Environment, France
NCD	Noncommunicable disease
OR	Odds ratio
PBF	Plant-based food
PCB	Polychlorinated biphenyl
PDCAAS	Protein Digestibility-Corrected Amino Acid Score
PSE	Pale soft exudative
PUFA	Polyunsaturated fatty acids
RCT	Randomized Control Trial
RNI	Recommended Nutrient Intake
RR	Relative risk
RE	Retinol equivalents
RNA	Ribonucleic acid
SPS	Sanitary and Phytosanitary

SARS	Severe acute respiratory syndrome
SIDS	Small Island Developing States
spp.	multiple species
SDG	Sustainable Development Goal
TASF	Terrestrial animal source food
FERG	The Foodborne Disease Burden Epidemiology Reference Group of the World Health Organization
TMAO	Trimethylamine-N-oxide
UI	Uncertainty interval
UN	United Nations
UNICEF	United Nations Children's Fund
UNDP	United Nations Development Progamme
USDA	United States Department of Agriculture
USD	United States Dollar
GINA	WHO Global Database on the Implementation of Nutrition Action
WFP	World Food Programme
WHO	World Health Organization
OIE	World Organisation for Animal Health
YLD	Years lived with disability
YLL	Years of life lost

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Summary

About this document

The Assessment arose from the mandate from the Committee on Agriculture (COAG) at its twenty-seventh session in October 2020, requesting FAO to produce a "comprehensive, science and evidence-based global assessment of the contribution of livestock to food security, sustainable agrifood systems, nutrition and healthy diets." Four component documents will build the basis of the Assessment prepared for consideration of governing body sessions. Based on those four component documents a synthesis document will be prepared. Component Document 1 represents the first in the Assessment, focused on the downstream impacts of animal source food (TASF) on healthy diets for improved nutrition and health.

Component Document 1 serves as the technical, scientific synthesis of evidence for TASF contributions to human nutrition and health. The report focuses on specific contributions of terrestrial TASF in line with the COAG mandate. This does not dispute the recognized importance of healthy diets and the related full array of foods and food groups, including aquatic animal foods. The review was carried out through a consultative process with the FAO team, the Scientific Advisory Committee, and a wider group of technical experts. Three major themes were identified and included as sections: 1. Nutrient and bioactive composition and value of TASF; 2. Effects of TASF on health and nutrition in the life course; and 3. Food safety and food-borne issues of TASF. A fourth section focuses on emerging topics related to TASF, describes novel themes with prospects for growth in the literature and salience in the public discourse for TASF and human nutrition and health.

TASF and world nutrition situation

TASF within the context of healthy diets from efficient, inclusive, sustainable and resilient agrifood systems can make important contributions to meeting the 2025 World Health Assembly and 2030 Sustainable Development Goal (SDG) nutrition targets. Trends for nutrition indicators show the world is currently not on track to attain several milestones. This part of the Assessment gives evidence that TASF within appropriate dietary patterns can make vital contributions to milestones aimed at reducing: stunting among children under five years of age; low birthweight; anaemia in women of reproductive age (15 – 49 years); overweight among children under five years of age; and obesity in adults.

Evidence from the evolutionary past of *Homo sapiens* shows higher levels of TASF intakes in dietary patterns were associated with increased stature, brain size, and longevity, likely establishing metabolic needs in the human body into the present. Today, TASF dietary patterns vary across different agrifood systems, with some regions showing high intakes and over-consumption, and others under-consuming. There is increasing attention in the public domain for how TASF affects chronic disease and contributes to environmental impacts arising from livestock production, thus compelling the assessment of evidence to inform policy decision-makers.

Nutrient and bioactive composition and value of TASF

Several macronutrients, micronutrients, and bioactive compounds found in TASF play unique and important roles in human health. TASF can provide large proportions of RNI across the life course. The food matrix and overall diet of individuals modulates the digestibility including absorption and metabolism of TASF nutrients in human health. TASF provide high quality proteins, as indicated by the Digestible Indispensable Amino Acid Score (DIAAS), relative to other foods. Some amino acids and other compounds (carnitine, creatine, taurine, 4-hydroxyproline, and anserine) are only largely available in human nutrition through consumption of TASF. They contribute vital functions in immune defence, anti-inflammatory pathways, memory, and cognition. TASF are also dense in dietary fats, that can both either promote or compromise health. Consuming diverse diets and the appropriate levels of TASF can achieve the necessary ratios of essential fatty acids (linoleic-to-α-linolenic acids) and blood cholesterols (high-density lipoprotein-to-low-density lipoprotein) and enable the absorption of fat-soluble vitamins to ensure human health. Dietary intakes of long-chain fatty acids from terrestrial TASF are important for brain development and cognition across the life course, particularly in the absence of aquatic TASF.

TASF can also provide critical micronutrients (minerals and vitamins) in bioavailable forms. Iron and zinc deficiencies are highly prevalent in populations around the world, contributing significantly to global burden of disease. Animal meats offer these minerals in compounds that are more efficiently metabolized than from plant-based food (PBF). However, evidence suggests that iron availability from eggs and insects is reduced compared to meats. TASF are also a rich source for selenium, playing crucial roles in anti-inflammatory and genome-level processes. Vitamin B12, necessary for growth, neurodevelopment function and maintenance, is uniquely sourced from TASF in human nutrition with only a few exceptions in PBF (e.g. some seaweeds). Choline, also concentrated in some TASF, has garnered recent attention for its vital roles in human growth, neurotransmission, and cell membrane integrity and function, among other roles. Vitamin C, necessary for growth, development and repair of all body tissues, is partly found in TASF milk and some type of meats but is absent in eggs thus necessitating sourcing mainly from PBF.

Phytates, tannins, and oxalates, found in some foods such as legumes or cereals, can interfere with mineral and other nutrient absorption in human health. Consumption of TASF has been shown to counteract these effects of anti-nutrients in PBF.

Lipid and fat-soluble vitamins in TASF were shown to be most responsive to animal diets, with implications for decision-making around animal feeding. In populations who do not consume significant quantities of fish, meat can contribute to dietary needs of omega-3, especially when the animal diets include PUFA-dense plants.

Effects of TASF on nutrition and health in the life course

This section summarizes the evidence for the role of TASF in human biology through the life course and the associated impacts of dietary intakes: nutrition (nutrient status, anthropometry), health (infectious disease, chronic disease, bone health), and cognition (development, neuroprotection, and neurological disease prevention). Differential effects are revealed by life course phase: women during pregnancy and breastfeeding (including mothers, fetus, and breastfeeding child); infants and young child; school age children and adolescents; adults; and older adults. Overall, most evidence comes from trials assessing milk and dairy products, followed by beef and eggs. There is generally good regional representation in sampled populations, except in the life course phase of older adults in which evidence comes predominantly from high-income countries.

A robust evidence base shows milk and dairy consumption during pregnancy increases birth weight in the offspring, and may also enhance birth length and fetal head circumference outcomes. Among infants and young children, eggs, milk, and meat consumption have been studied with mixed findings depending on overall diet and environmental exposures. Evidence for school-age children and adolescents again focused on milk and dairy products showing positive effects for increased height and reduced adiposity and overweight and obesity. Beef consumption during this phase has been shown to improve cognitive outcomes.

In adults, findings largely point to positive effects from milk and dairy products specifically yoghurt for reducing risks for all-cause mortality, hypertension, stroke, type 2 diabetes, colorectal cancer, breast cancer, obesity, osteoporosis and fractures. However, findings for an association between milk consumption and coronary heart disease are equivocal. Evidence shows egg consumption in adults does not increase risks for stroke or coronary heart disease. Epidemiological evidence surrounding the effects of unprocessed and processed meat intakes and human health outcomes has been evaluated to be of low certainty given heterogenity in design and risk of bias. Synthesized findings from risk analyses show that modest amounts of unprocessed red meat (ranging from 9-71g/d) holds minimal health risk. For processed red meat, however, very low levels of consumption can elevate risk for mortality and chronic disease outcomes including cardiovascular disease and colorectal cancer. Robust evidence shows animal flesh intake (85-300g/d) is positively associated with iron status in adults. Poultry meat has been studied to a limited extent relative to beef, but findings suggest non-significant effects on stroke risk with sub-group analyses suggesting protective effect in women.

Among the older adults, epidemiological evidence for the health effects of TASF comes primarily from HIC. A fairly strong evidence-base shows positive effects for lean red meat consumption on muscle health. Other evidence suggests the potential for milk and dairy products and other TASF in mitigating impacts on sarcopenia (muscle loss), fractures, frailty, dementia and Alzheimer's disease.

Cow's milk and poultry eggs are among the eight food groups that pose allergenic risks to consumers and it is therefore mandatory to state their presence in foods as part of precautionary allergen labeling. However, there is no evidence that avoiding such foods during infancy can delay or prevent reactions. Lactose malabsorption is widespread, but does not automatically lead to lactose intolerance, which also greatly varies in severity.

Policy recommendations on TASF

Food based dietary guidelines from 95 countries provide recommendations related to TASF consumption, primarily linked to micronutrient intakes followed by diet-related noncommunicable diseases (NCDs). Most dietary guidelines are provided for the general public, although many make recommendations for specific groups according to the life course cycle. NCD-related documents were reviewed from 51 countries, showing recommendations related to TASF mostly linked to the prevention of diet-related NCDs with only ten recommendations related with micronutrient intake and three linked to environmental sustainability.Food and agriculture legislations and nutrition policies and programmes are reviewed revealing 50 recommendations related to TASF, primarily qualitive and targeting the general public.

Most recommendations are for TASF consumption generally, followed by recommendations on meat (in general), milk and dairy products, eggs and red meat. In the red meat category most recommendations refer to beef while others such as pork, goat, sheep are less covered. There is also less coverage on poultry, white meat (in general), offal, meat from wild animals and insects. Micronutrient-related recommendations tend to be more detailed compared with NCD related recommendations, providing quantitative indications in terms of daily or weekly intake of TASF. Consumption of TASF above or below recommendations is rarely addressed. This is a pertinent gap given the co-existence of micronutrient deficiencies with both undernutrition and overweight, obesity and NCD. Environmental sustainability considerations were only included in documents from eight middle-high income countries and mostly provided qualitative recommendations. Animal welfare was only mentioned in the Food based dietary guideline (FBDG).

Food safety and food-borne issues of TASF

One third of the food-borne disease burden is associated with the consumption of contaminated TASF mainly linked with bacterial causes and diarrhoea. While evidence on food-borne disease hazards and health outcomes as well as risk analysis methods are well documented, knowledge of the national burden (incidence and severity) is lacking. For example, main transmission routes along the value chain are crucial to target national policies, yet not well understood.

Changing agricultural practices, especially related to the intensification of livestock production and inputs use, lengthening and broadening of value chains and shifts towards consumption of processed food, contribute to increasing exposure to foodborne disease hazards. Antimicrobial resistance presents additional challenges beyond nutrition and food safety. Food safety burden needs to be alleviated by enhanced sanitation and mitigated health risks at the interfaces between animals, humans, and the environment through a One Health approach. Strengthening of national food control systems is key in ensuring food safety for better health and nutritional outcomes.

Emerging topics

Additional topics pertaining to TASF, nutrition and health have emerged more recently and merit consideration. Fortified, blended foods containing TASF, most commonly milk powder, have been studied globally with indications for positive effects on child growth and development outcomes. The independent effects of the TASF ingredients, however, cannot be directly linked to outcomes. Early findings for TASF alternatives including cell-derived and plant-based alternative "meats" suggest some products can mimic taste and texture, but evidence is lacking on their human nutrition and health outcomes. Insects and insect powders offer promise as nutritious, sustainable food sources. Issues of preference and culture remain in product development and marketing.

Major developments in microbiology offer insights into the relationship between TASF and human health. First are the methodological advances in ‘omics’ spanning genomics, nutrigenomics, metabolomics, proteomics, and transcriptomics. These new fields yield discoveries for the pathways and metabolites participating in TASF, nutrition, and health. Second is the rapidly expanding science for the microbiome, essentially showing a mediating role of the microbiome in the TASF and human health relationship. Species diversity, the abundance of short chain fatty acids, and pathogenic presence are among the factors driving the association. Animal models and trials in humans demonstrate red and processed meats and animal fats can induce deleterious effects on human health via microbial metabolites such as Trimethylamine-N-oxide or hydrogen sulfide, while fermented dairy products produce positive impacts.

Connections to other component documents

Component document 1 has summarized the evidence for the downstream effects of TASF to human nutrition and health outcomes. Building from this analysis, Component Document 2 examines factors influencing supply, demand, and consumption of TASF, historically and into the future. It will illuminate explanatory factors driving TASF access and affordability, quantity, quality, safety and diversity of TASF within dietary patterns. Moving further upstream, Component Document 3 will assess the contribution of the livestock sector to food security and sustainable agrifood systems. Component Document 4 will then present options to sustainably change the livestock sector towards achieving more sustainable agrifood systems, healthy diets, and nutrition. Ultimately, all four documents will then be combined into a high-level synthesis for the contribution of livestock to food security, sustainable agrifood systems, nutrition and healthy diets.

Key findings

TASF within adequate dietary patterns can make vital contributions to meeting the Global nutrition targets 2025 endorsed by the World Health Assembly[2] and the Sustainable Development Goals (SDGs) that aim to reduce: stunting among children under five years; low birthweight; anaemia in women of reproductive age (15–49 years); overweight among children under five years; and obesity and diet-related NCDs in adults.[3]

Nutrient and bioactive composition and value of TASF

- TASF provide high-quality proteins compared with other foods, with some nuanced differences in digestibility. Specific amino acids and bioactive factors with roles in human health may only be found in TASF (i.e. carnitine, creatine, taurine, hydroxyproline and anserine). Long-chain fatty acids and the ratios of essential fatty acids found in TASF are important for cognition, particularly across the human life course.
- Iron and zinc are bound in more bioavailable compounds in red meat and may be more easily digested than compounds found in plant-based foods. Milk is well recognized for its concentration and bioavailability of calcium among other nutrients. Eggs are highly concentrated in choline and some long-chain fatty acids. Generally, TASF are also a rich source of selenium, vitamin B12 and choline. Consumption of TASF has been shown to counteract effects of anti-nutrients in plant-based foods.
- Nutrition quality (especially the fat composition) of TASF can be influenced in order of priority by choice of animal species and feeding system, followed by breed and production environment.

Effects of TASF on nutrition and health over the life course

- Dietary intakes of TASF can affect nutrition (nutrient status, anthropometry), health (infectious disease, chronic disease, bone health) and cognition (development, neuroprotection, neurological disease prevention).
- Across all life course phases – which include women during pregnancy and when breastfeeding, infants and young children, school-age children and adolescents, adults and older adults – the concentration of evidence comes from trials assessing milk and dairy products. Beef and eggs follow in terms of availability of evidence, with fewer studies available on pig and poultry meat, meat from wild animals, insects and meat from other minor species. In sum, the evidence suggests beneficial effects of TASF intakes at appropriate levels for several health outcomes, and non-significant increases in chronic diseases, among apparently healthy individuals. A robust evidence base shows that milk and dairy consumption during pregnancy was found to increase infant weight at birth and may also increase birth length and fetal head circumference. Among infants and young children, eggs, milk and meat consumption has been studied with mixed findings depending on overall diet and environmental exposures. Evidence for school-age children and adolescents consuming milk and dairy products show positive effects for increased height and reduced adiposity, overweight and obesity. Beef consumption in this life course phase has been shown to improve cognitive outcomes.
- In adults, findings largely point to positive effects from milk and dairy products (such as yoghurt) for reducing risks for all-cause mortality, hypertension, stroke, type 2 diabetes, colorectal cancer, breast cancer, obesity, osteoporosis and fractures. Relatively robust evidence shows that egg consumption among adults does not increase risks for stroke or coronary heart disease. Compelling evidence suggests that in adults meat intake between 85–300 g/day can protect against iron deficiency. Poultry meat has not been studied as much as beef, but findings suggest non-significant effects on stroke risk with subgroup analysis suggesting a protective effect in women.
- The evidence base for red meat consumption in adults has been thoroughly assessed by the Global Burden of Disease Study, showing some increased risk of chronic disease associated with 23g

[2] Global nutrition targets 2025 (https://apps.who.int/nutrition/global-target-2025/en/).
[3] WHO. 2014. *Global nutrition targets 2025: Policy brief series (WHO/NMH/NHD/14.2)*. Geneva, WHO. (also available at https://apps.who.int/iris/bitstream/handle/10665/149018/WHO_NMH_NHD_14.2_eng.pdf).

(18–27 g) per day of red meat, and 2g (0–4 g) per day of processed meats. However, other studies have shown non-significant effects of beef on chronic disease biomarkers.

- Significant gaps remain in the evidence base for the older adults. Preliminary evidence, however, suggests the potential for milk and dairy products and possibly other TASF in mitigating impacts on sarcopenia, fractures, frailty, dementia and Alzheimer's disease
- Cow's milk and poultry eggs are among the eight food groups that pose allergenic risks to consumers and it is therefore mandatory to state their presence in foods as part of precautionary allergen labeling. However, there is no evidence that avoiding such foods during infancy can delay or prevent reactions. Lactose malabsorption is widespread, but does not automatically lead to lactose intolerance, which also greatly varies in severity.

Policy recommendations on TASF

- Most recommendations are for TASF in general, followed by recommendations on meat, milk and dairy products and eggs. There is significantly less coverage on offal, poultry, pig meat, meat from wild animals and insects.
- Most recommendations are linked to human micronutrient needs and NCDs and targeted to the entire population. Micronutrient-related recommendations tend to be more detailed compared with NCD-related recommendations, providing quantitative indications in terms of daily or weekly TASF intake. Most recommendations do not consider the implications of under- and overconsumption of TASF, a pertinent gap given the coexistence of micronutrient deficiencies with both underweight, overweight, obesity and NCDs.
- In total, there were 378 recommendations that follow a life course approach, 282 in FBDGs, irrespective of the income class of the countries. While the recommendations in the FBDG of high-income countries were more detailed, overall, there was a good distribution of both qualitative and quantitative recommendations.
- Environmental sustainability considerations were only included in documents from eight middle-high-income countries and mostly provided qualitative recommendations. Animal welfare was only mentioned in the FBDG of Denmark and Sweden, with a specific reference to animal welfare labels to inform consumers.

Food safety and food-borne issues of TASF

- One third of the food-borne disease burden is associated with the consumption of contaminated TASF, mainly linked with bacterial causes and diarrhoea. While evidence on food-borne disease hazards and health outcomes as well as risk analysis methods are well documented, knowledge of the national burden (incidence and severity) is lacking. For example, main transmission routes along the value chain are crucial to target national policies, but are not well understood.
- Changing agricultural practices, especially related to the intensification of livestock production and inputs use, lengthening and broadening of value chains and shifts towards consumption of processed food, contribute to increasing exposure to food-borne disease hazards. Antimicrobial resistance presents additional challenges beyond nutrition and food safety.
- Food safety burdens must be alleviated by enhanced sanitation and mitigated health risks at the interfaces between animals, humans and the environment through a One Health approach. Strengthening national food control systems is key to ensuring food safety for better health and nutritional outcomes.

Emerging topics

- While cost and access remain a barrier, milk powder has been used extensively as ingredient in fortified and blended foods with evidence for effectiveness in management of severe acute malnutrition when used in ready-to-use therapeutic food and nutrition outcomes among mothers, infants and young children when used in supplements. Egg powder and fish powder have been used to a significant lesser extent as ingredients in fortified and blended foods likely due to palatability, shelf life and involved processing techniques.

- The science is relative new for TASF alternatives, including plant-based food and cell-cultured 'meat'. Evidence suggests that these products cannot replace TASF in terms of nutritional composition. Microalgae is a TASF alternative highly considered for its rich nutritional composition and also the advantages algae may offer in terms of the environment as a natural carbon sink. Nevertheless, plant-based meat alternatives that are largely available in the market, have been found to be deficient in some essential nutrients and rich in saturated fat, sodium and sugar. Further research is also needed to complete the food safety risk assessment for cell-cultured 'meat' within a context of industrial production scale.
- While insects can provide many essential nutrients and there is some evidence on nutrition outcomes, cultural barriers and individual preferences interfere with current consumer acceptability. The environmental sustainability appeal for use of insects as human food seems compelling and may drive up demand in coming years. Nevertheless, food safety concerns should be considered in the scaling up of insects as food or animal feed.
- Current 'omics' applications are promising to characterize nutritional quality and safety, develop precision or personalized nutrition especially for defined targeted groups of people (e.g. young children) and compare nutritional composition of alternatives to TASF.
- Microbiome science has recently revealed that some of the effects of the diet on health might be mediated by the gut microbiome – trillions of micro-organisms living in the human gut. Diverse TASF, including meat and fermented dairy products, have an impact on the gut microbiome composition and functions and subsequently human health via the production of microbial metabolites. High intake of red and processed meat as well as animal saturated fats could induce deleterious effects when fermented dairy products seem to be associated with reduced inflammation. Positive or negative impacts on health might be modulated by the overall quality of the diet (as fats, sugars and fibers).
- The assessment of the contribution of TASF in sustainable healthy diets needs to consider regional variation in natural resources, background health and nutrition, nutritional needs over the life course, availability and accessibility of food and the ecosystem role of livestock. Emerging evidence on the sustainability of diets shows that the diversity of species (plants-based food, terrestrial animal source food and aquatic food) in the diet contributes to higher nutrient adequacy.

Preliminary gaps

In conclusion, these findings of this component document of the Assessment reveal some gaps in the evidence and in the policy as summarized below:

- A deeper understanding is required of the interactions of TASF nutrients and bioactive compounds in dietary patterns to further characterize the role of TASF in terms of nutrition, health and cognitive outcomes over humans' life course.
- Gaps remain in the literature for nutritional composition and health effects for several types of ASF including: poultry species, goat, sheep, pig, rabbit, wild animals and insects.
- More robust evidence is needed for the health effects of ASF consumption (under- and overconsumption) from studies with consistent design and methods and implemented across different contexts (LMIC and HIC).
- While this is beyond the scope of the Assessment, additional evidence may be merited for examining TASF in unhealthy populations (diabetic, overweight and obese) given the high prevalence of these medical conditions.
- National FBDGs should be updated with recommendations that provide ranges for daily intake based on different stages of the life course phases. These recommendations should consider the implications of under consumption and over consumption of TASF given the increasing coexistence of micronutrient deficiencies and NCD.
- National FBDG should be used to better inform livestock policies, programmes and legislative frameworks on nutrition outcomes

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Setting the scene

The Committee on Agriculture (COAG), an FAO governing body, at its 27th session in October 2020 requested FAO to produce a "comprehensive, science and evidence-based global assessment of the contribution of livestock to food security, sustainable agrifood systems, nutrition and healthy diets" (the Assessment). At the same session, the Committee on Agriculture established a Sub-Committee on Livestock to provide targeted guidance to stakeholders for this specific sector of agriculture.

The Assessment of the contribution of livestock to food security, sustainable agrifood systems[4], nutrition and healthy diets will be based on four component documents that will be prepared for consideration of governing body sessions. The process will be accompanied and guided by a multi-disciplinary Scientific Advisory Committee.

This document represents the first component document of the Assessment and focuses on the contribution of terrestrial animal source food (TASF) (see Box 1) to healthy diets for improved nutrition and health. Although the focus of the document is TASF arising from the COAG mandate, the report recognizes the need in human nutrition for dietary diversity and a full spectrum of healthy foods and food groups, including aquatic food, to promote and maintain health. While the importance of these foods in healthy diets is well recognized, it is beyond the scope of this report. This document builds on *Livestock-derived foods and sustainable healthy diets*, a consensus document among members of UN Nutrition (UN Nutrition, 2021). The UN Nutrition paper addressed topics across the four components of this Assessment at higher levels. The UN Nutrition paper provided an overview of the major health benefits, opportunities and potential trade-offs associated with sustainable production and consumption.

Box 1 What is terrestrial animal source food?

In this Assessment, terrestrial animal source food (TASF) comprise all food products from terrestrial animals. The Assessment covers TASF derived from animal production systems of any scale, including: integrated plant-animal production systems, specialized livestock production systems and grazing systems and pastoralism. TASF include food derived from hunting of wild animals and wild life farming.

Food products are included derived from mammalian species, avian species and insects. They are classified into the following food groups of:

- eggs and egg products;
- milk and dairy products;
- meat and meat products;
- food from hunting and wildlife farming; and
- insects and insect products.

Each group includes sub-groups (e.g. red meat, poultry) and multiple food items coming from different species (e.g. beef, chicken) or processing techniques within the same sub-group. The Assessment mostly focusses on unprocessed TASF as there is a myriad of processed TASF. However, the health consequences of processed TASF is presented in Section C where evidence is available, and processed blended food products containing TASF ingredients are introduced in Section E. The vast array of aquatic food is beyond the scope of the report.

In this document, the analyses is being deepened by conducting a systematic review focused only on the nutrition and health outcomes related to TASF intake. This first component document, in

[4] The 166th FAO Council defined in its report (http://www.fao.org/3/nf693en/nf693en.pdf) agrifood systems: The agrifood system covers the journey of food from farm to table – including when it is grown, fished, harvested, processed, packaged, transported, distributed, traded, bought, prepared, eaten and disposed of. It also encompasses non-food products that also constitute livelihoods and all of the people as well as the activities, investments and choices that play a part in getting us these food and agricultural products. In the FAO Constitution, the term "agriculture" and its derivatives include fisheries, marine products, forestry and primary forestry products.

particular, will build consensus on the role of TASF in healthy diets by taking into account the vulnerability of different target groups from an economic, health and contextual perspective.

Healthy diets are fundamental to maintaining the health and well-being of humans. TASF are among a mix of food groups (see Box 2) that can contribute to diverse and balanced dietary patterns. This component document is the first of four component documents building the basis of the Assessment of the contribution of livestock to food security, sustainable agrifood systems, nutrition, and healthy diets. It focuses on the endpoints of the conceptual framework for agrifood systems, specifically how TASF in diets lead to nutrition and health outcomes (see Figure 1). The other three component documents will move upstream in the framework to examine the factors determining demand, supply, and consumption of TASF (Document 2), the livestock sector benefits, trade-offs, and synergies to food security and sustainable agrifood systems (Document 3), and opportunities for transforming the livestock sector sustainably to optimize food and nutrition security (Document 4). It should be noted that the scope of this first component document is to assess the contribution of TASF at appropriate levels among apparently healthy individuals and not to assess risks among individuals suffering from medical conditions.

Box 2 Definition of food groups and sub-groups related to terrestrial animal source food

A **food group** is a set of foods that share similar nutritional properties or biological characteristics.

Food groups and sub-groups related to terrestrial animal source food based on FAO/WHO Global Individual Food consumption data Tool (FAO and WHO, 2022):

Eggs and egg products: mainly from poultry (chicken, duck, geese, quail and turkey) including fresh and processed food such as dried eggs.

Milk and dairy products: fresh and processed, from mammalian livestock species, most commonly: cattle, water buffalo, goat, sheep, dromedary and Bactrian camels, including:
- Fresh and processed: milk and products derived from milk by reducing water or/and increasing sugar content and isolating milk protein such as evaporated, condensed and powdered milk and milk protein;
- Cheese such as cured and uncured cheese, brined cheese, ripened cheese (soft and hard), cheese rind and processed cheese such as spreads;
- Cream, whey and any other milk products: derived from milk by isolating its different fractions, including dried products such as powdered whey, cream and sour cream and isolated whey protein, and manufactured products such as flavoured whey, cream and sour cream;
- Fermented milk products such as yoghurt, kefir, kumis, sour and fermented milk, including flavoured and non-flavoured products;

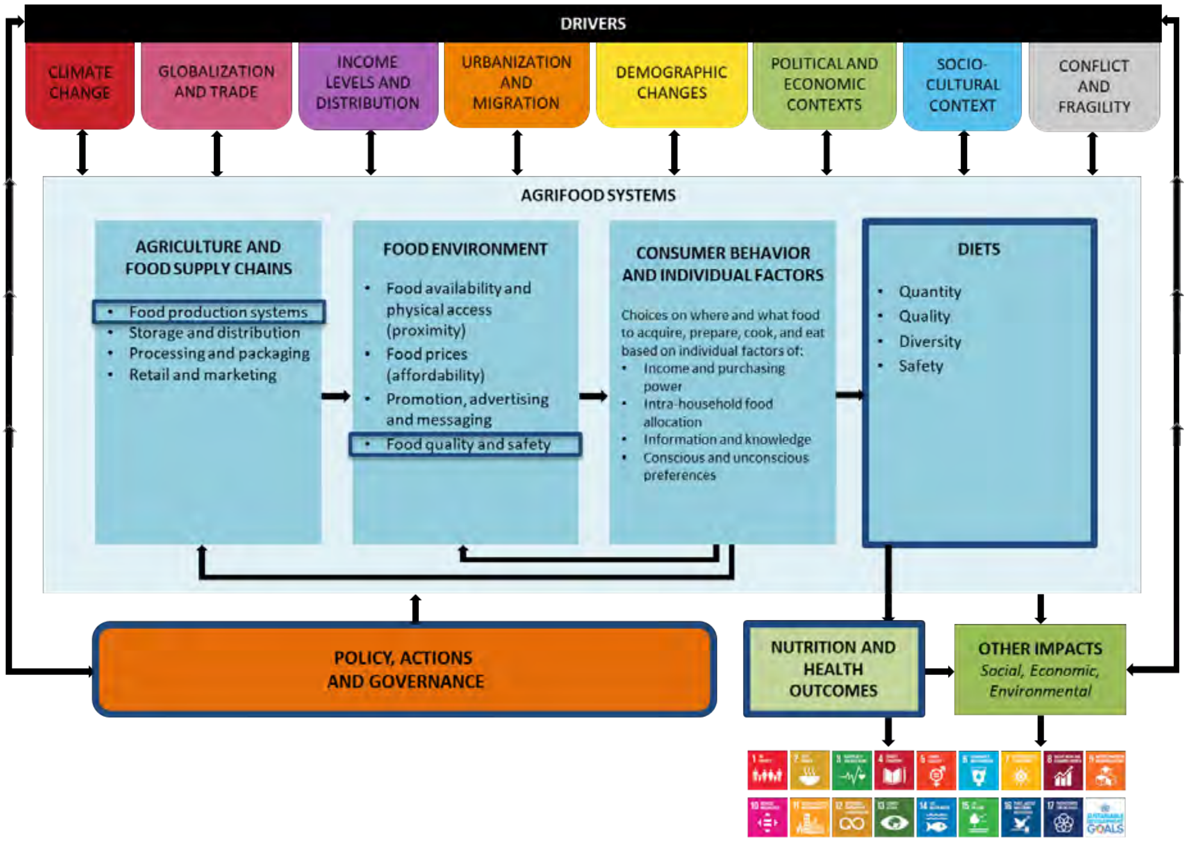
Meat and meat products: red and white meat, from livestock, both ruminants and monogastrics, including offals and processed meat:
- Red meat: meat from animals used as food derived from cattle, buffalo, goat, sheep, pig, dromedary, Bactrian camel, horse, donkey;
- White meat: meat from animals used as food derived from rabbits, chicken and other avian species, and characterised by their paleness;
- Poultry meat: meat of domesticated avian species including chicken, duck, Muscovy duck, goose, guinea fowl, turkey, quail, pigeon, pheasant, ostrich;
- Processed meat: range of meat products (including offals) that have undergone treatment such as salting, curing, smoking, marinating, drying, cooking;
- Offals: organ meat from mammalian and avian species such as liver, kidney, heart, lungs, intestines, blood;

Food from hunting and wildlife farming: food obtained from hunting of wild animals and non-domesticated animals raised on farms.

Insects and insect products: insects such as spiders, mites, ticks, beetles, flies, bugs, ants and grubs such as earthworms, including processed products such as dried insects and manufactured products such as powdered insects and grubs.

Source: FAO and WHO, 2022.

Figure 1 Agrifood systems for healthy diets



Note: Blue frames indicate elements assessed in this component document. Contextual information on different food production systems was provided to explain differences in the quality and consumption of TASF. However, food production systems were not the subject of this component document and will be covered in Component Document 3.

Source:(FAO, 2021c, 2021d)

Section A INTRODUCTION

Key findings

- Trends for nutrition indicators show the world is currently not on track to attain several of the 2025 World Health Assembly[5] and 2030 SDG nutrition targets.
- TASF within appropriate dietary patterns can make important contributions to reducing: under-five years childhood stunting and wasting; low birthweight; anaemia in women of reproductive age (15 – 49 years); under-five years childhood overweight; and obesity and diet-related noncommunicable diseases (NCDs) in adults.
- Evidence from the evolutionary past of *Homo sapiens* shows higher levels of TASF intakes in dietary patterns were associated with increased stature, brain size, and longevity, likely establishing metabolic needs in the human body into the present.
- Globally, 21 percent of total caloric supply is comprised of TASF. Regions showing higher percentages are Europe (37 percent) and the Americas (30), while Africa is only 11 percent on average. The highest level of TASF relative to total caloric supply is in Northern America (43 percent), followed by Australia and New Zealand, and Northern Europe (both 41 percent). The lowest levels are observed in Eastern Africa and Middle Africa (6 percent) and Western Africa (4 percent).
- Globally, 47 percent of children between 6-23 months consume dairy and eggs respectively. and 22 percent. However, this masks a significant disparity between the poorest and wealthiest quintile.
- Certain typologies of agrifood systems may be particularly salient in the consideration of the TASF role in human nutrition, for example among pastoralist populations and Indigenous Peoples. On the other side of the consumption spectrum, there are populations that practice vegetarianism for cultural or religious reasons.

Summary

This section summarized the most recent data on the world nutrition situation focusing on the progress towards the global nutrition targets set by the World Health Assembly and Sustainable Development Goals (SDG) by 2030. It also provides an overview of the trends in nutrition indicators by region showing the geographical variation of different forms of malnutrition.

An overview of TASF dietary patterns using data from the Food Balance Sheets was provided. This section showed trends in the global and regional supply of TASF again highlighting great disparities across regions and subregions as highlighted in the key findings. An overview was provided on the contribution of TASF to caloric supply and on energy and protein supply from plants and animal source food (including both terrestrial and aquatic sources) differentiated by region. A snapshot was provided on the percentage of children between 6-23 months consuming TASF such as dairy, eggs and flesh foods (including both terrestrial and aquatic sources) showing the high discrepancy by wealthiest quintile. The section also included a brief evidence-based overview of the role that TASF played in hominin evolution over the last two million years and introduces the importance livestock and TASF play in given agrifood systems for both food security and nutrition. It emphasizes the extent to which certain typologies of agrifood systems may be particularly salient in the consideration of the TASF role in human nutrition. For example, pastoralist populations whose livelihoods have traditionally depended on livestock have historically consumed more TASF and some Indigenous People's food system incorporate TASF through hunting, gathering or livestock production. It presents the results from a study examining the inclusion of wild foods in the diets of eigth Indigenous Peoples'groups across the world. On the other side of the consumption spectrum, there are populations that practice vegetarianism for cultural or religious reasons.

[5] Global nutrition targets 2025 (https://apps.who.int/nutrition/global-target-2025/en/).

1 World nutrition situation

Diets that are of adequate quantity and quality to achieve optimal growth and development of all individuals and support functioning and physical, mental and social wellbeing at all life stages and physiological needs. Healthy diets are safe, diverse, balanced, and based on nutritious foods. They help to protect against malnutrition in all its forms, including undernutrition, micronutrient deficiencies, overweight and obesity and lower the risk of diet-related noncommunicable diseases (see Box A1).

The Committee on Food Security Voluntary Guidelines on Food Systems and Nutrition also recognizes that healthy diets may vary by individual's characteristics (e.g. age, sex, health status, economic security, lifestyle and level of physical activity), geography, culture and customs, food preferences, and availability of foods. There can be tremendous diversity and variation in dietary preferences with the range of what may be a healthy diet.

The review provided here also embraces a perspective of variability in TASF in dietary patterns globally, both arising by choice and circumstance. The review considers TASF within the context of a diverse and varied diet and the health consequences of TASF intake levels acting synergistically in the diet matrix and in response to external factors.

The world is not on track to meet the World Health Assembly or SDG nutrition targets by 2030 (see Figure A1). Large gaps remain for several milestones including exclusive breastfeeding from zero to six months and anaemia in women of reproductive age (15-49 years). Anaemia affects nearly one in three women worldwide. The world is not on track to meet the 3 percent target for 2030 in terms of prevalence of child wasting and to ensure that there is no increase in overweight among children less than five years. Overweight affects 14.6 percent of children and adolescents, and obesity 4.3 percent (WHO, 2021a). Similarly, low birthweight in 2015 was 14.6 percent, only a small reduction from 2012 and unlikely to achieve the 10.5 percent target.

In regional trends, stunting is the only indicator showing substantial improvements in the last two decades, although estimates from the 2021 *State of Food Security and Nutrition in the World* predict that the COVID-19 pandemic may reverse this trend for the first time (see Figure A2). Anaemia among women of reproductive age persists at very high levels across multiple regions, again showing limited progress towards reaching the set target of a 50 percent reduction. Adult obesity has also risen sharply across many regions. Globally, there were 39 percent (1.9 billion) adults 18 years or older overweight, 13 percent (650 million) of whom were obese in 2016 (WHO, 2021e). Annually, 41 million people die from noncommunicable diseases (NCDs), comprising approximately 71 percent of all deaths globally. The majority of these deaths occur in low- and middle-income countries (WHO, 2021c). Four conditions are responsible for over 80 percent of premature NCD deaths annually: cardiovascular diseases (17.9 million); cancers (9.3 million); respiratory diseases (4.1 million); and diabetes (1.5 million). Unhealthy diets are among the leading risk factors for NCD morbidity and mortality (Afshin *et al.*, 2019a).

The recent *State of the World Food Security and Nutrition* (2021) reports that the percent of undernourishment increased from 8.4-9.9 percent from 2019 to 2020, globally. This translates into an estimated 118 million more people experiencing hunger for a total of around 811 million people worldwide.

Box A1 Definitions of different forms of malnutrition

Malnutrition is an abnormal physiological condition caused by inadequate, unbalanced, or excessive intake of macronutrients and/or micronutrients. Malnutrition is also characterised by physiological inefficiencies in the utilization of nutrients. It may manifest in a variety of ways depending on nutritional status, and different forms of malnutrition can co-occur.

Stunting or chronic malnutrition

Stunted growth is defined as height-for-age Z score < -2 SD (WHO, 2021b). This form of malnutrition may be associated with both physical and cognitive delays in growth and development as well as an elevated risk of death. It occurs particularly in the first 1 000 days from conception until the age of two years due to inadequate maternal and/or child nutrition. Lack of access to adequate and poor quality foods and/ or disease can cause stunting.

Wasting or acute malnutrition

Wasting is defined as weight-for-height < -2 SD (WHO Growth Standards). It may also be indicated by mid-upper arm circumference (MUAC) < -2 SD. This form of undernutrition indicates recent and severe weight loss, which is often associated with infectious disease and acute starvation. Children under five years of age are most vulnerable to wasting, in particular when transitioning from exclusive breastfeeding to complementary feeding. The occurrence of wasting often varies seasonally or increases as result of emergencies such as droughts or floods. Stunting and wasting often coexist.

Underweight

Underweight is defined as weight-for-age Z score < -2 SD (WHO Child Growth Standards). A child who is underweight may be stunted, wasted or both. Mortality risk increased in children even with moderated underweight.

Micronutrient deficiencies or hidden hunger

Lack of essential vitamins and minerals that the human body requires in small amounts. Most micronutrients come from dietary sources as the body does not produce them or not in adequate quantities. There are some micronutrients that cannot be stored in the body for long periods; this is the case with water-soluble vitamins. Due to this fact, the regular consumption of foodis rich in those micronutrients is necessary to avoid deficiency. Micronutrient deficiency can cause severe and even life-threatening conditions such as anaemia, xerophthalmia, osteoporosis or impaired immune function.

Anaemia

Anaemia is a condition in which the number of red blood cells or the hemoglobin concentration within them is lower than normal decreasing the capacity of the blood to carry oxygen to the body's tissues. This results in symptoms such as fatigue, weakness, dizziness and shortness of breath, among others. The optimal hemoglobin concentration needed to meet physiologic needs varies by age, sex, elevation of residence, smoking habits and pregnancy status. The most common causes of anaemia include nutritional deficiencies, particularly iron deficiency, though deficiencies in folate, vitamins B12 and A are also important causes; hemoglobinopathies; and infectious diseases, such as malaria, tuberculosis, HIV and parasitic infections. Anaemia is a serious global public health problem that particularly affects young children and pregnant women. WHO estimates that 42 percent of children less than five years of age and 40 percent of pregnant women worldwide are anaemic (WHO, 2021d).

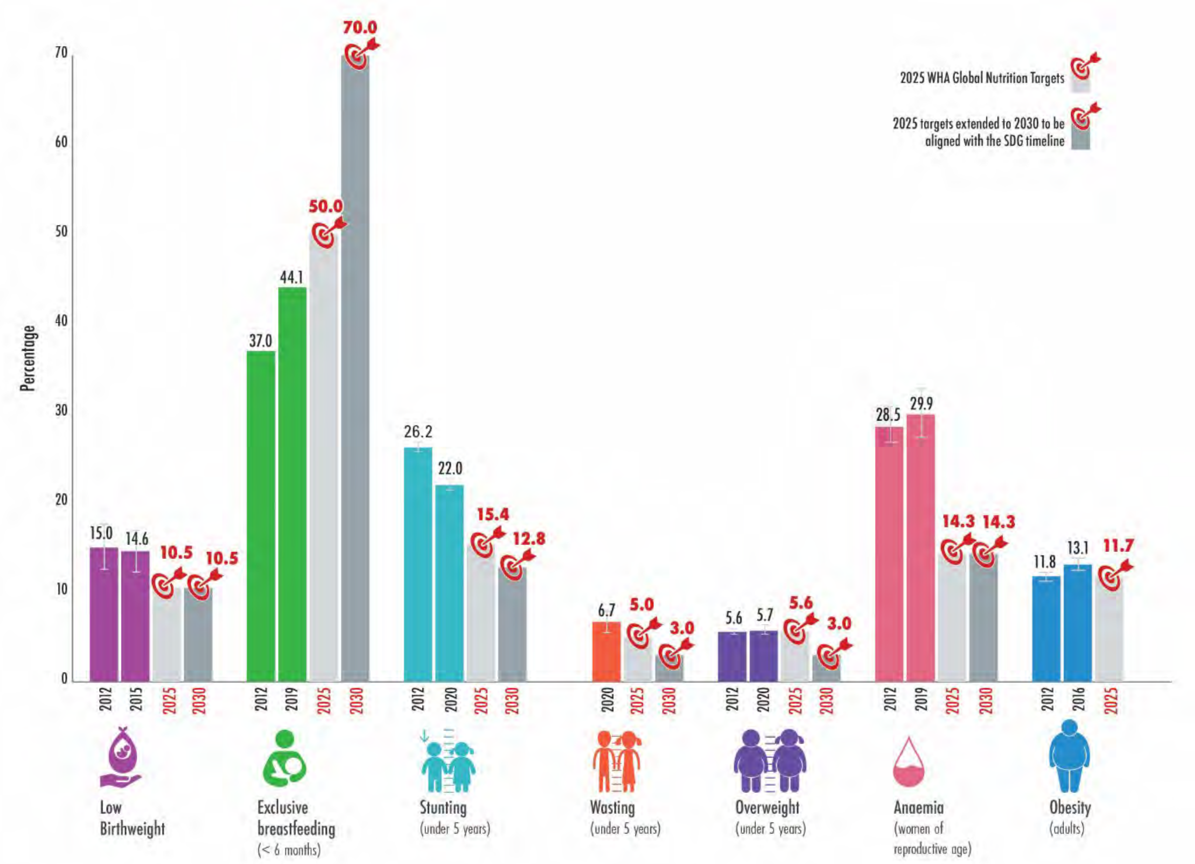
Overweight and Obesity

In children less than five years, overweight is defined as weight-for-age Z score greater than 2, and obesity greater than 3, while in children 5–19 years, overweight is defined as BMI-for-age greater than 1 SD above the WHO Growth Reference median and obesity as greater than 2 SD. In adults, overweight is BMI (kg/m^2) greater than or equal to 25, and obesity is greater than or equal to 30. Overweight is characterized by body weight that is above normal for height and is generally a result of an excessive accumulation of fat. It is usually a manifestation of expending fewer calories than are consumed. In obesity, body weight is pathologically above normal as a result of an excessive accumulation of fat in adipose tissue to the extent that health may be impaired.

Diet-related noncommunicable diseases

Noncommunicable diseases (NCDs), also known as chronic diseases, tend to be of long duration and are the result of a combination of genetic, physiological, environmental and behavioural factors. Unhealthy diets and a lack of physical activity may show up in people as raised blood pressure, increased blood glucose, elevated blood lipids and obesity. These are called metabolic risk factors that can lead to cardiovascular disease, the leading NCD in terms of premature deaths (WHO, 2021c). The NCDs that are most commonly studied in association with consumption of red and processed meat include colorectal cancer, type 2 diabetes and ischemic heart disease.

Figure A1 Progress towards World Health Assembly global nutrition targets



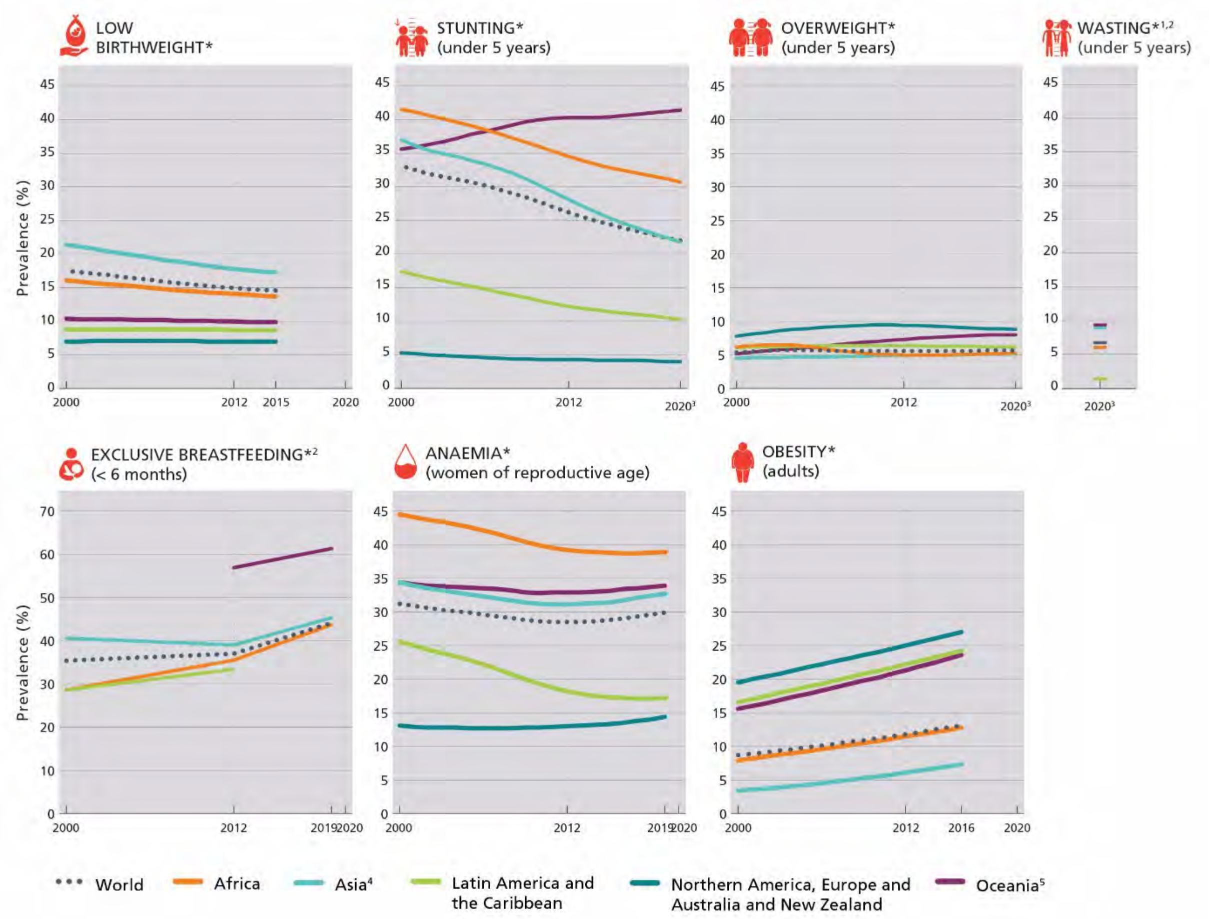
Source:(FAO, IFAD, UNICEF, WFP and WHO, 2021a)

Notes: The potential impact of the COVID-19 pandemic is not reflected in the estimates. Wasting is an acute condition that can change frequently and rapidly over the course of a calendar year. This makes it difficult to generate reliable trends over time with the input data available – as such, this report provides only the most recent global and regional estimates.

Data sources: Data for stunting, wasting and overweight are based on UNICEF, WHO & World Bank. 2021. UNICEF-WHO-World Bank: Joint child malnutrition estimates - Levels and trends (2021 edition) [online]. https://data.unicef.org/resources/jme-report-2021, www.who.int/data/gho/data/themes/topics/jointchild-malnutrition-estimates-unicef-who-wb, https://datatopics.worldbank.org/child-malnutrition; data for exclusive breastfeeding are based on UNICEF. 2020. UNICEF Global Database on Infant and Young Child Feeding. In: UNICEF [online]. New York, USA. [Cited 19 April 2021]. data.unicef.org/topic/ nutrition/infant-and-young-child-feeding; data for anaemia are based on WHO. 2021. Global Health Observatory (GHO). In: WHO [online]. Geneva, Switzerland. [Cited 26 April 2021]. www.who.int/data/gho/data/themes/topics/anaemia_in_women_and_children; data for adult obesity are based on WHO. 2017. Global Health Observatory (GHO). In: WHO [online]. Geneva, Switzerland. [Cited 2 May 2019]. www.who.int/data/gho/data/indicators/ indicator-details/GHO/prevalence-of-obesity-among-adults-bmi-=-30-(age-standardized-estimate)-(-); data for low birthweight are based on UNICEF & WHO. 2019. UNICEF-WHO Low Birthweight

Estimates: Levels and trends 2000–2015 [online]. [Cited 4 May 2021]. data.unicef.org/resources/lowbirthweight-report-2019.

Figure A2 Trends in nutrition indicators by region



Source: (FAO, IFAD, UNICEF, WFP and WHO, 2021a)

Notes: 1. Wasting is an acute condition that can change frequently and rapidly over the course of a calendar year. This makes it difficult to generate reliable trends over time with the input data available and, as such, this report provides only the most recent global and regional estimates. 2. For wasting and exclusive breastfeeding, estimates are not shown for regions/years where population coverage was below 50 percent. 3. The collection of household survey data on child height and weight were limited in 2020 due to the physical distancing measures required to prevent the spread of COVID-19. Only four national surveys included in the database were carried out (at least partially) in 2020. The estimates on child stunting, wasting and overweight are therefore based almost entirely on data collected before 2020 and do not take into account the impact of the COVID-19 pandemic. 4. For wasting and low birthweight, the Asia estimate excludes Japan.

Data sources: Data for low birthweight are based on UNICEF & WHO. 2019. UNICEF-WHO Low Birthweight Estimates: levels and trends 2000–2015, May 2019. In: UNICEF data [online]. New York, USA, UNICEF [Cited 19 April 2021]. data.unicef.org/resources/unicef-who-low-birthweight-estimates-levels-and-trends-2000-2015; data for stunting, wasting and overweight are based on UNICEF, WHO & World Bank. 2021. UNICEF-WHO-World Bank: Joint child malnutrition estimates - Levels and trends (2021 edition) [online]. https://data.unicef.org/resources/jme-report-2021, www.who.int/data/gho/data/themes/topics/joint-child-malnutrition-estimates-unicef-who-wb, https://datatopics.worldbank.org/child-malnutrition; data for exclusive breastfeeding are based on UNICEF. 2020. UNICEF Global Database on Infant and Young Child Feeding. In: UNICEF [online]. New York, USA. [Cited 19 April 2021]. data.unicef.org/topic/nutrition/infant-and-young-child-feeding; data for anaemia are based on WHO. 2021. Global Health Observatory (GHO). In: WHO [online]. Geneva, Switzerland. [Cited 26 April 2021]. www.who.int/data/gho/data/themes/topics/anaemia_in_women_and_children; data for adult obesity are based on WHO. 2017. Global Health Observatory (GHO). In: WHO [online]. Geneva, Switzerland. [Cited 19 April 2021]. www.who.int/data/gho/data/indicators/indicator-details/GHO/prevalence-of-obesity-among-adults-bmi-=-30-(age-standardized-estimate)-(-).

Stunted growth and development, affecting 149.2 million (22 percent) children less than five years of age globally, results from poor quality diets, inadequate feeding practices, infectious diseases and an unsanitary environment. Children who do not meet their full growth are at risk of compromised brain development, infectious and chronic diseases, other longer-term health challenges, and mortality. Wasting, a marker of more acute lack of food and likely infection, affected 45.4 million of young children under the age of five (6.7 percent), while on the other end of the spectrum, 38.9 million children in the same age category (5.7 percent) were overweight in 2020 (FAO, IFAD, UNICEF, WFP and WHO, 2021). Overweight and obesity in particular are known to develop in later phases of the life course. The most recent global data from 2016 on children of school-going age and adolescents (ages 5-19) estimate that 340 million were classified as overweight or obese in 2016 (WHO, 2021e). Additional data from 2020 indicate that anaemia affected 29.9 percent of women of reproductive age, equivalent to over half a billion women, and 39.8 percent or 269 million children under 5 years of age globally (FAO, IFAD, UNICEF, WFP and WHO, 2021).

2 TASF dietary patterns and agrifood systems: historic legacy and current challenges

This assessment considers TASF within the context of dietary patterns and broader agrifood systems. As discussed following in Section B and C, nutrition and related health outcomes depend on the interactions of TASF intakes with other foods, environmental exposures, and the metabolic processes in human biology. This subsection discusses how dietary patterns have evolved as part of human evolution, followed by an overview of the diversity of current dietary patterns incorporating TASF and of agrifood systems, locally and regionally. Other component documents of the Assessment will go into greater detail on subject matter covered here.

3.1 Hominin evolution and TASF

Evidence suggests that TASF played an important role in hominin evolution over the last two million years. Information from isotope studies, archaeological assemblages, dental wear analyses, and ethnographies of contemporary gatherer-hunter-fisher groups suggest TASF were present in hominin diets in relatively high proportions and that TASF were among the factors driving important physiological changes (Kuipers, Joordens and Muskiet, 2012; Larsen, 2003; Stanford and Bunn, 2001). Dietary patterns today diverged from those of our ancestors only in recent history, precipitated by changes in climate conditions, agriculture, and technological advances. The discordance theory posited by Konner and Eaton suggests this sudden change in diets resulted in chronic disease (Eaton and Konner, 1985), while others building on the discordance theory suggest a broader array of poor health outcomes (Eaton and Iannotti, 2017). Dietary diversity and a higher proportion of energy from TASF were among the key characteristics of the ancient gatherer-hunter-fisher diet distinguishing it from modern *Homo sapiens* (Kuipers, Joordens and Muskiet, 2012).

Some studies have used contemporary gather-hunter-fisher groups to examine diets in human evolution. One recent analysis approximated one-third to nearly all dietary energy intakes coming from meat consumption (Pontzer and Wood, 2021). An older analysis reviewed ethnographies from 229 gather-hunter-fisher groups showing TASF comprised between 45-65 percent of total energy intakes (Cordain *et al.*, 2000). These estimates may have limitations, however, including a potential gender bias (data from more men than women), modern hunter-gather populations do not exclusively rely on this foraging, and the large diversity of patterns across groups (Milton, 2003). Others have estimated wide ranges in macronutrient intakes as a proportion of total calories depending on ecological zone: protein (10-35 percent); carbohydrates (20-50 percent); and fat (20-70 percent) (Kuipers *et al.*, 2010). Many scholars agree TASF were part of, overall, very diverse diets that allowed for flexibility and adaptation to different environments for migrating groups (Turner and Thompson, 2013; Marlowe, 2005).

There were several types of TASF documented in hominin diets depending on the environment as well as period in hominin evolution. Archaeological assemblages from early hominin species suggest TASF from lacustrine ecosystems and drawing from a diverse range of both terrestrial animal source food and aquatic food such as crocodiles, turtles, and fish (Braun *et al.*, 2010). Although some evidence points to scavenging of meat in early Pleistocene species, predation and hunting was likely more common for sourcing meat (Domínguez-Rodrigo *et al.*, 2021). The use of tools appears to be connected to very early carnivorous behaviours, including the consumption of animal tissue and intake of nutrients from bone marrow (Pante *et al.*, 2018; Thompson *et al.*, 2019). One study applied paleobiologic and paleoecology approaches to analyse trophic level consumption patterns over time (Ben-Dor, Sirtoli and Barkai, 2021). They showed that *Homo sapiens* evolved from a low to high carnivorous base levels from *Homo habilis* to *Homo erectus* during the Pleistocene era and then there was a reversal of this trend occurring from Upper Palaeolithic through Neolithic eras and emergence of agricultural practices.

Consensus exists for the junctures in hominin evolution when significant anatomical and physiological changes occurred, and there is some evidence on the role of TASF in driving the shifts (Aiello and Wheeler, 1995; Milton, 2003). The first juncture occurred around two million years ago with the emergence of *Homo erectus*. Evidence suggests marked increases in stature, body mass and brain size that some have linked to increased TASF in the diet (Kuipers *et al.*, 2010). Others have described early habitats near aquatic ecosystems and improved dietary quality including TASF explaining in part larger brain sizes compared to other primates (Broadhurst *et al.*, 2002; Burini and Leonard, 2018; Cunnane and Crawford, 2014; Mann, 2018). Other physiological changes arose in human evolution that mark a divergence from other primates and suggest dietary requirements for TASF (Mann, 2018): inability to absorb vitamin B12 produced by gut bacteria (Domínguez-Rodrigo *et al.*, 2012); preferential absorption of hem iron over ionic forms (Henneberg, Sarafis and Mathers, 1998; Lönnerdal and Hernell, 2013); a greater dependency on dietary choline (Domínguez-Rodrigo *et al.*, 2012; Wiedeman *et al.*, 2018); reduction in taurine production from amino acid precursors (Chesney *et al.*, 1998; Ripps and Shen, 2012); and reduced conversion of alpha-linolenic acid into EPA/DHA (Emken *et al.*, 1993).

Multiple lines of evidence show the greatest dietary shifts away from TASF to plant-based food followed widespread adoption of agriculture (crop and livestock production) during the Neolithic era and industrialization. Skeletal evidence suggests that for many populations, agriculture was associated with poorer quality diets, a reduction in stature and life span, increased infectious disease burden (arising from population density), increased dental caries, among other health deficits (Armelagos *et al.*, 2014).

In summary, evidence shows that TASF have been integral to shifting dietary patterns and anatomical features during hominin evolution. The ancestral gatherer-hunter-fisher diet likely had high proportions of energy derived from TASF with wide ranging types and embedded within diverse diets determined by ecosystem habitat. Critical anatomic and physiological evolution such as stature, brain size, and longevity were associated with patterns of TASF consumption. This evolutionary history linking TASF and health suggests the importance for TASF in diets today.

3.2 TASF dietary patterns around the world today

FAO and WHO define sustainable, healthy diets as:

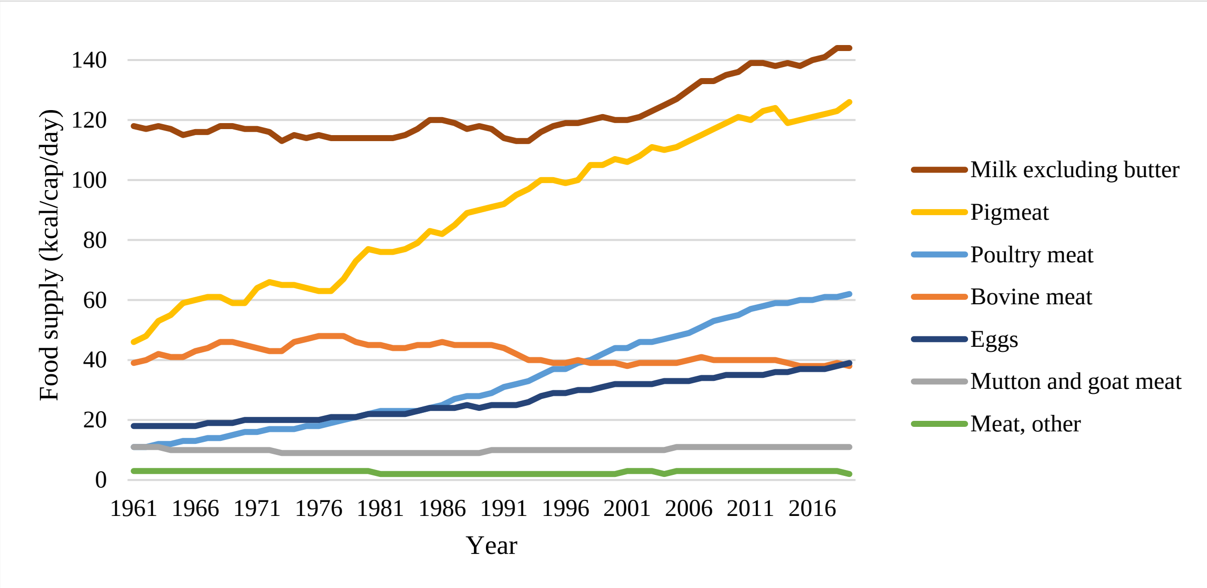
> *dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable. The aims of Sustainable Healthy Diets are to achieve optimal growth and development of all individuals and support functioning and physical, mental, and social wellbeing at all life stages for present and future generations; contribute to preventing all forms of malnutrition (i.e. undernutrition, micronutrient deficiency, overweight and obesity); reduce the risk of diet-related NCDs; and support the preservation of biodiversity and planetary health. Sustainable healthy diets must combine all the dimensions of sustainability to avoid unintended consequences. (FAO & WHO, 2019)*

The 20th century was an era of rapid industrialisation and significant advances in public health interventions such as vaccines, antibiotics and improved sanitation and hygiene in some parts of the world. It has been suggested that these factors, along with consumption of TASF during this period for some populations, were associated with increased stature and other improvements in health (Roser and Appel, 2013). At the start of the 21st century, a “nutrition transition” was occurring in tandem with rapid urbanization and access to processed food (Popkin, 2006). Common dietary patterns in this nutrition transition generally include increased fat intakes, increased refined sugar and processed food consumption, and reduced fibre intakes.

During the past six decades, from 1961-2016, there have been increasing trends in per capita supply for most types of TASF – likely arising from growing stability and wealth (see Figure A3). Bovine meat is one exception, showing a steady supply pattern in the first four decades and around 1990, per capita supply levels began to decrease. Pork has shown the greatest increases in this period with relatively steady rate, while eggs and milk have increased more notably since 1990. These trends are not shared by all regions and subregions, however, with evident disparities in TASF supply (see Figure A4). Regionally, Europe, North America, and Oceania show the highest supply levels, particularly marked by high milk consumption relative to other TASF and regions. The combined Americas regions shows the largest increases in poultry meat since 1990 while other TASF intakes have been relatively stable. In Asia, there are large differences by subregion, with Eastern Asia showing steep increases in pig meat, Central Asia consuming higher levels of milk than the other subregions, and South-eastern and Southern Asia indicating fairly low levels for all TASF except pig meat and milk, in subregions respectively. In Africa, levels of all TASF are low and stable except in Southern Africa where there are increasing supplies of poultry meat and slightly higher supplies of milk and bovine meat. Within regions, there are also stark differences in country-level TASF supply patterns.

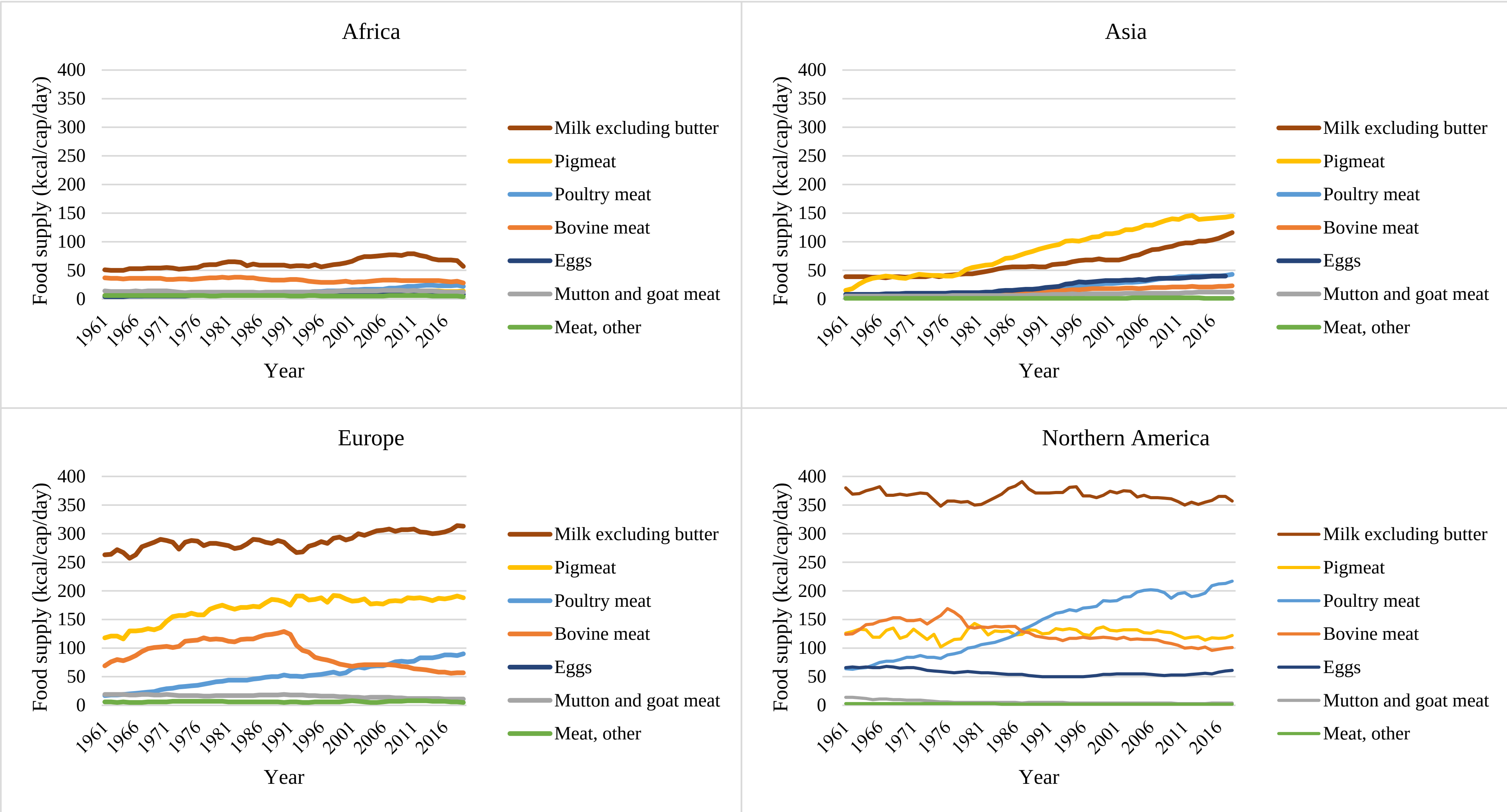
While the energy density from global cereal supply remained constant between 1961-2013, the nutritional content has decreased due to less production of highly nutritious cereals (e.g. millet, sorghum) favouring the production of less nutritious high yielding cereals like rice and maize (DeFries *et al.*, 2015). For example, the iron content in global cereal supply decreased by 19 percent.

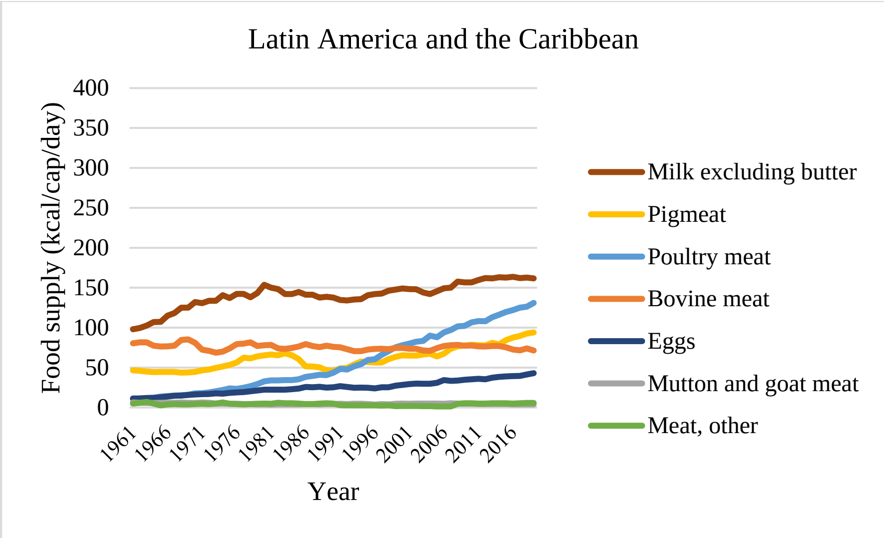
Figure A3 Trends in global food supply of TASF

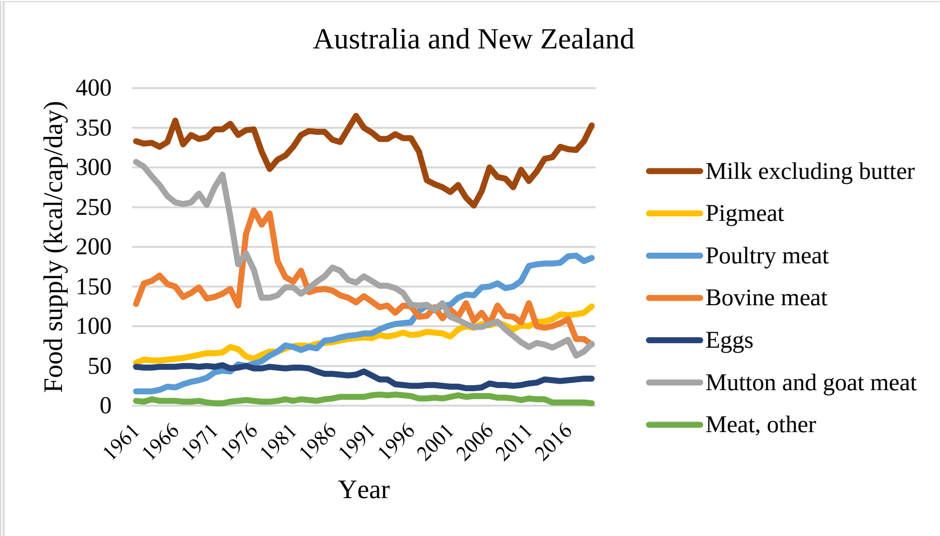


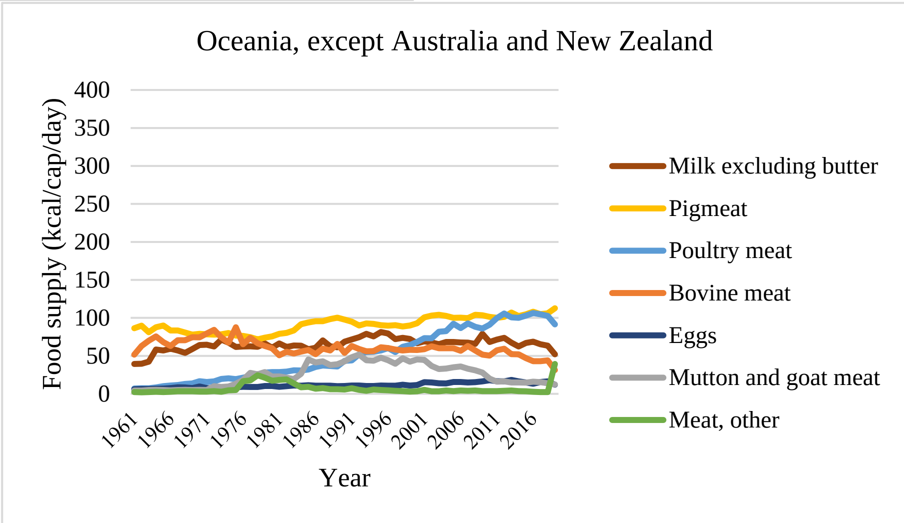
Source: FAO, 2022.

Figure A4 Trends in food supply of TASF by region and subregion







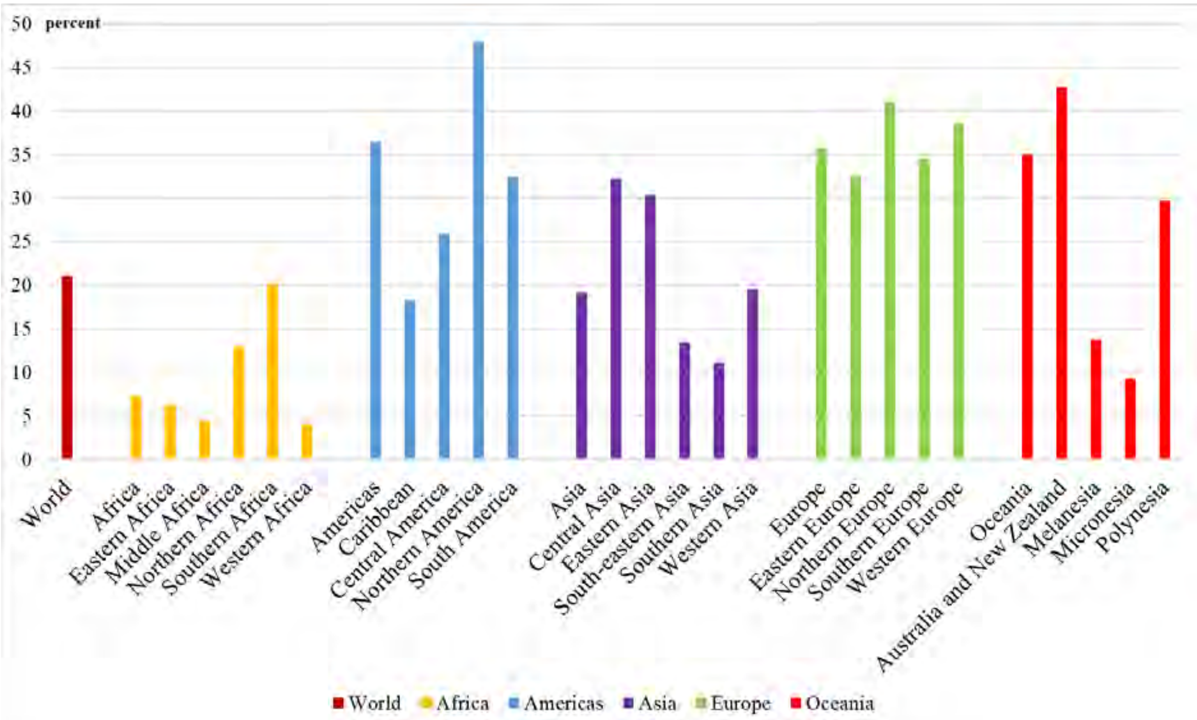


Source: FAO, 2022..

Regional differences are also evident in the percent contribution of TASF to total calorie supply (see Figure A5). Globally, 21 percent of total caloric supply is comprised of TASF. Regions showing higher percentages are Europe (37 percent) and the Americas (30 percent), while Africa is only 11 percent on average. The highest level of TASF relative to total caloric supply is in Northern America (43 percent), followed by Australia and New Zealand, and Northern Europe (both 41 percent). The levels are observed in Eastern Africa and Middle Africa (6 percent) and Western Africa (4 percent) (Tables A1 and A2). Diet and lifestyle patterns in populations with higher caloric proportionality of TASF often include unhealthy dietary patterns, sedentary lifestyles and high levels of overweight/obesity, NCD burden, though in some countries such as Australia, red meat consumption is associated with healthy patterns such as vegetable consumption (Sui, Raubenheimer and Rangan, 2017). Country level disparities in supplies of TASF and TASF types are also evident (Figure A5). Australia, Sweden and the United States of America show relatively greater quantities compared to other countries.

Note that estimates used for Figures A3-6 were derived only from Food Balance Sheets and do not account for food loss and waste and thus may overestimate to a certain degree supply patterns. The estimates presented do not include individual dietary consumption given the current limitations with data availability.

Figure A5 Contribution of TASF to caloric supply by region and subregion



Note: Included: Bovine meat, mutton and goat meat, pig meat, poultry meat, meat other, eggs, milk-excluding butter. 2000 kcal/day considered as average of the total calories consumed per day.
Source: FAO, 2021b.

Table A1 Protein supply from plants and animals by region

Region/Subregion	Eggs (g/cap/day)	Fish, seafood (g/cap/day)	Meat (g/cap/day)	Milk, excluding butter (g/cap/day)	Vegetal products (g/cap/day)	Total (g/cap/day)
World	3	5	15	9	50	82
Africa	1	3	6	3	51	64
Eastern Africa	0	2	4	3	49	58
Middle Africa	0	3	6	1	34	44
Northern Africa	1	4	10	7	67	90
Western Africa	1	3	4	1	52	62
Americas	4	4	32	15	40	95
Northern America	5	5	42	22	40	114
Central America	5	4	20	9	46	84
Caribbean	2	3	16	7	40	67
South America	3	3	29	11	38	85
Asia	3	6	11	7	53	81
Central Asia	2	1	17	21	53	93
Eastern Asia	6	10	20	3	61	100
Southern Asia	1	2	3	11	49	65
South-eastern Asia	3	12	10	2	44	71
Western Asia	3	2	14	12	57	87
Europe	4	6	26	20	45	102
Eastern Europe	4	5	24	16	47	97
Northern Europe	4	7	29	21	46	107
Southern Europe	4	9	28	18	45	104
Western Europe	4	6	25	26	42	104
Oceania	2	6	34	15	35	92
Australia and New Zealand	3	6	36	20	36	101
Melanesia	0	6	27	1	31	65
Micronesia	1	23	10	1	35	70
Polynesia	2	13	34	7	35	91
Southern Africa	2	2	23	4	45	76

Source: FAO, 2022.

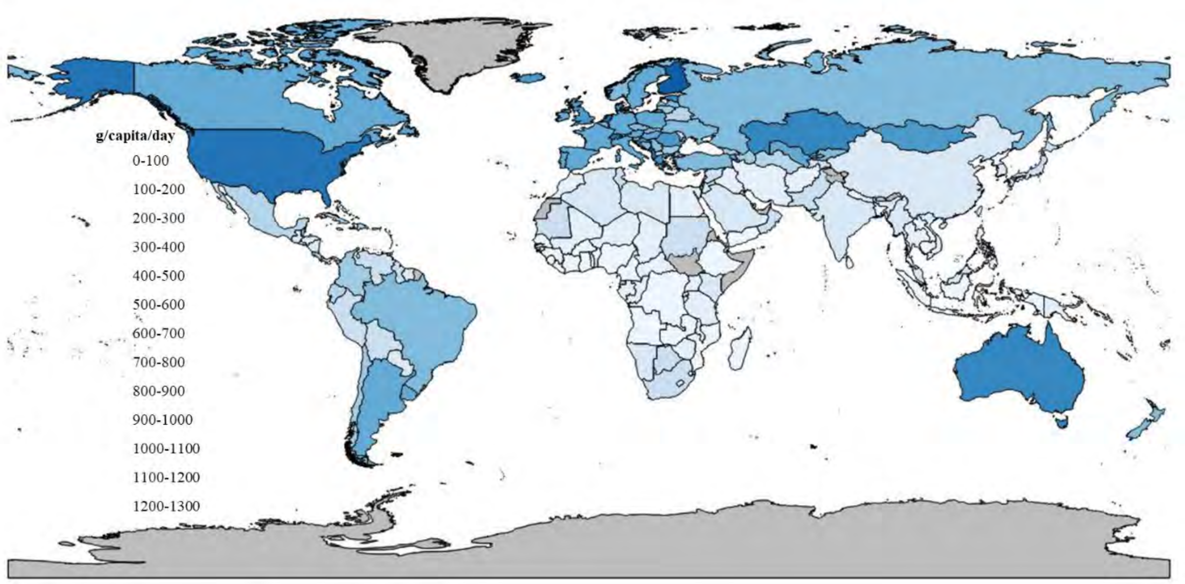
Table A2 Energy supply from plants and animals by region

Area	Eggs (kcal/cap/day)	Fish, seafood (kcal/cap/day)	Meat (kcal/cap/day)	Milk, excluding butter (kcal/cap/day)	Vegetal products (kcal/cap/day)	Total (kcal/cap/day)
World	39	35	240	144	2431	2889
Africa	8	18	81	57	2403	2567
Eastern Africa	3	10	63	59	2110	2245
Middle Africa	1	20	73	14	2070	2178
Northern Africa	16	27	111	132	2901	3187
Southern Africa	25	11	305	74	2395	2810
Western Africa	7	21	47	26	2547	2648
Americas	53	25	422	252	2479	3231
Northern America	62	35	528	369	2720	3714
Central America	62	23	303	154	2417	2959
Caribbean	24	18	214	126	2403	2785
South America	43	17	400	205	2304	2969
Asia	43	40	225	116	2428	2852
Central Asia	22	4	256	368	2361	3011
Eastern Asia	81	61	467	58	2545	3212
Southern Asia	13	15	32	176	2280	2516
South-eastern Asia	43	74	193	31	2484	2825
Western Asia	33	12	153	205	2650	3053
Europe	50	47	351	313	2444	3205

Area	Eggs (kcal/cap/day)	Fish, seafood (kcal/cap/day)	Meat (kcal/cap/day)	Milk, excluding butter (kcal/cap/day)	Vegetal products (kcal/cap/day)	Total (kcal/cap/day)
Eastern Europe	56	36	322	275	2440	3129
Northern Europe	46	54	418	356	2360	3234
Southern Europe	44	62	357	287	2519	3269
Western Europe	49	46	353	368	2439	3255
Oceania	26	42	411	261	2222	2962
Australia and New Zealand	34	41	470	353	2308	3206
Melanesia	5	41	253	17	1980	2296
Micronesia	10	154	160	14	2715	3053
Polynesia	21	99	449	125	2174	2868

Source:FAO, 2022.

Figure A6 Terrestrial animal source food in national food supply



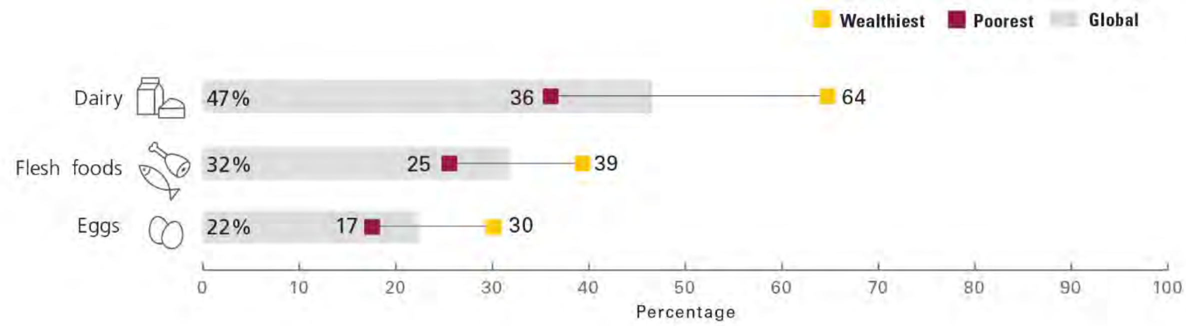
Note: World average per capita supply of terrestrial animal source food per day is 383 g.Terrestrial animal source food include bovine meat, mutton and goat meat, pig meat, poultry meat, meat other, eggs and milk-excluding butter.
Source: FAO, 2021a.

FAO defines food security as the conditions in which "all people, at all times, have the physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Two additional dimensions are now recognized as fundamental aspects of food security: agency that includes empowerment, the capacity to act independently to reducing inequality; and sustainability that includes respect and protection of ecosystems over the long term in their interaction with economic and social systems (HLPE, 2020). The four components are conceptually linked to food security are availability, access, utilization, and stability. In Component Document 1, the focus is primarily on utilization and the vital importance of TASF in certain life course phases to providing bioavailable nutrients as part of healthy diets.

Moderate and severe forms of household food insecurity correlate with poor quality diets in many contexts. One study across four countries (Kenya, Mexico, Samoa and Sudan) examined dietary patterns in relation to food insecurity as measured by global Food Insecurity Experience Scale (Alvarez-Sanchez, 2021). Their analyses of household food consumption and expenditure surveys revealed that in the four countries, those households experiencing moderate or severe food insecurity consume less meat and dairy products. Consuming less fruits and vegetables was also associated with food insecurity in Kenya and Sudan. Authors concluded that the more food insecure households are, the larger the share of staples in the diet and the smaller the presence of nutritious food groups such as fruits and vegetables, pulses and TASF. A significant disparity in consumption of TASF between the poorest and weathiest quintiles among children between 6-23 months is showed in Figure A7.

TASF and dietary patterns should be viewed within the larger context of agrifood systems. Though again, this web of factors influencing livestock production and agrifood systems more broadly will be handled in following component documents.

Figure A7 Percentage of children between 6-23 months consuming TASF by poorest and wealthiest quintile relative to the global average



Note: Flesh food in the figure refers to meat, fish, poultry and organ meats. Source: UNICEF global databases, 2021, based on MICS, DHS and other nationally representative sources. Adapted from UNICEF, 2021.

3.3 Agrifood systems, locally and regionally

Food security components undergird the structural elements of an agrifood system, spanning food supply chains (availability) to food environments (access), individual factors and consumer behaviour, ultimately leading to diets that translate into nutrition and health outcomes (Figure 1) (FAO, 2018; Food Systems Dashboard, 2021). Food supply chains encompass TASF production systems, storage and distribution, processing and packing, and retail and marketing. Food safety and food-borne diseases are covered under Section D and address different aspects of the food supply chains. Food environments include important factors driving access to TASF such as food availability and affordability but as well product and vendor properties, food messaging and accessibility of convenience food. Conditions at the level of the individual (economic, cognitive, aspiration, and situational) and consumer behaviour (food acquisition, preparation, meal practices and storage) components in an agrifood system may also drive TASF access and ultimately consumption.

External drivers of the agrifood system can play a powerful role in its dynamics. Some of these factors may contribute differentially in the role of TASF and livestock production in agrifood systems such as environment and climate change; globalization and trade; income growth and distribution; urbanization; population growth and migration; politics and leadership; socio-cultural context; infrastructure including electricity and access to refrigeration; among others. Environmental conditions such as water, sanitation, and hygiene (WASH) are especially important drivers of nutritional status through enteric disease and can either challenge or enable TASF effects on health. Similarly, the environmental and climatic conditions may influence how TASF are produced, stored, distributed, processed, marketed and even consumed. While these factors are covered in the following component documents of the Assessment, we acknowledge the multidimensionality of agrifood systems leading ultimately to how TASF are integrated in diets and associated with nutrition and health outcomes.

Policy makers globally are increasingly recognizing the need to transform agrifood systems for livelihoods, human and planetary health. In September 2021, key stakeholders from around the world convened for the UN Food Systems Summit to come to a consensus around crucial changes needed in agrifood systems to achieve the Sustainable Development Goals by 2030 (see Box A2).

Box A2 Livestock-related policy in the 2021 United Nations Food System Summit

In 2021, the United Nations Food System Summit was convened as part of the Decade of Action to achieve the Sustainable Development Goals by 2030. The Summit process included multistakeholders dialogues based on structured discussions between governments and stakeholders, and supported the development and shaping of national pathways towards sustainable food systems by countries.

An analysis of the national pathways was conducted to identify national priorities and plans for action relevant to the livestock sector that emerged from the Summit (FAO, 2022[6]). Livestock policy issues were covered in 90 out of 106 national pathways (Food Systems Summit Dialogues Gateway, accessed 18 October 2021). A general concern was the need to increase livestock productivity as a way to address environmental issues and/or enhance food and nutrition security and healthy diets. In particular, enhancing terrestrial animal source food consumption and their role in nutrition and food security, diverse and healthy diets were outlined in 42 and 37 percent of African and Asian's national pathways, respectively. Thematic areas emerged within regions. In Europe, 44 percent of the national pathways engaged in further developing the One Health approach, 28 percent in supporting animal welfare and 22 percent in reducing consumption of meat, milk and dairy products and eggs. Animal welfare and reduction of consumption were not raised in other regions.

Analysis of livestock-related themes in national pathways by region

Region	Self-sufficiency	Productivity	Animal welfare	Environ-mental sustainability	Food safety	One Health	Increase consumption	Decrease consumption	Total
Africa	0	20	0	13	0	0	14	0	47
Asia	2	10	0	7	3	2	7	0	31
Europe	0	5	5	7	1	8	2	4	31
LAC	0	2	0	5	1	1	3	0	12
Near East	1	4	0	2	0	1	1	0	9
North America	0	0	0	1	0	0	0	0	1
South West Pacific	0	2	0	6	0	0	1	0	9
World	3	43	5	41	5	12	28	4	141

Note: Number of national pathways covering livestock-related theme published by 18 October 2021. LAC = Latin America and the Caribbean.
Source: Food Systems Summit Dialogues Gateway (accessed 18 October 2021)
https://summitdialogues.org/overview/member-state-food-systems-summit-dialogues/convenors/.

Certain typologies of agrifood systems may be particularly salient in the consideration of the TASF role in human nutrition. For example, Indigenous Peoples' food systems have been recognized for the knowledge base and practices around resilience and sustainability (FAO, Alliance of Bioversity International and CIAT, 2021). A study examining eight different Indigenous Peoples' groups globally showed animal source food were present in balance with plant-based food across all the food systems for nutrition and livelihoods (FAO, Alliance of Bioversity International and CIAT, 2021). Among those featured were the Inari Sámi people in Nellim, Finland who practice reindeer herding, the nomadic herders and pastoralist food system of Aratène, Mali and agro-pastoralism combined with gathering in the Bhotia and Anwal peoples of Uttarakhand, India. Fishing contributed in two other groups, the Melanesians of Solomon Islands and Tikuna, Cocam and Yagua peoples of Puerto Nariño, Colombia. The study found a wide variety of wild hunting species and wild products more broadly in the diets of Indigenous Peoples with the potential for nutritional advantages conferred (see Table A3).

[6] FAO. 2022. Livestock-related outcomes of the 2021 UN Food Systems Summit. Information Document, COAG Sub-Committee on Livestock, First Session, Rome 16–18 March 2022 (COAG:LI/2022/INF/11). Rome (available at http://www.fao.org/3/ni117en/ni117en.pdf).

Table A3 Indigenous Peoples' wild food

Indigenous Peoples	Geographic area	Wild food in diet (in percent)	Wild species hunted for consumption (number)	Example of edible hunted species and biological classification
Baka	Cameroon	37	60	Nightjar (bird) Water chevrotain (mammal)
Inari Sámi	Finland	5	7	Capercaillie (bird) Moose (mammal)
Khasi	India	10	13	Red wild fowl (bird) Leopard cat (mammal)
Melanesians	Solomon Islands	15	11	Pacific reef heron (bird) Flying fox (mammal)
Tikuna, Cocama and Yagua	Colombia	25	26	Ruddy ground dove (bird) Palm weevil (insect)
Maya Ch’orti’	Guatemala	10	9	Rock dove (poultry) Pelibuey sheep (mammal)

Note: Wild food include animal source food and plant-based food.
Source: Adapted from (FAO, Alliance of Bioversity International and CIAT, 2021).

The Indigenous Peoples’ food systems point to the notion of territorial diets. The French word “terroir” symbolically represents the origins of food or other products arising from a geographic area but also encompassing sociocultural elements. The geographic indication may be assigned to food arising from interactions between local population and local environment (FAO, 2021a). Others have described the Mediterranean, Traditional and New Nordic, and Japanese diets as territorial diets emerging from local agrifood systems (FAO and WHO, 2019). The TASF within these diets are produced within the region and are integral to the cultural element of the whole diet.

In certain populations, TASF play a more or less prominent role. For example, pastoralist populations whose livelihoods have traditionally depended on livestock have historically consumed more TASF. However, with increased marginalization, diminishing land tenure, and climate change there have been losses in TASF intake and consequent health repercussions (Iannotti *et al.*, 2014). As described above, some Indigenous People’s agrifood systems incorporate TASF through hunting, gathering or livestock production (see also Box A3). There may be greater or lesser diversity of TASF consumed depending on groups. On the other side of the consumption spectrum, there are populations that practice vegetarianism for cultural or religious reasons. In India, Hinduism encourages lacto-vegetarianism to uphold the principle of nonviolence towards animals but as well to protect the mind and spirit.

Climate change has negatively affected many communities around the world. For example, rising temperatures and drought conditions have impacted many pastoralist communities resulting in severe food insecurity for populations already at risk of low consumption of healthy diets (Herrero *et al.*, 2016; Inman, Hobbs and Tsvuura, 2020). Other extreme weather events such as floods and tropical storms are causing irreparable damage to production systems, and there is evidence for increases in vector-borne diseases in animals resulting from climate change (Kimaro, Toribio and Mor, 2017).

The production of TASF in some agrifood systems has garnered the public’s attention in the dialogue on issues related to climate change and environmental sustainability. While this topic is covered in Component Document 3, we introduce important sustainability issues in consideration of TASF as consumed within healthy diets. Overconsumption of TASF and rising demand for TASF in some populations are likely contributing to environmental impacts and climate change effects associated with production. Agriculture, forestry and other land use broadly contribute approximately 21 percent of greenhouse gas emissions and livestock production, an estimated 14.5 percent (Clark *et al.*, 2019; Gerber and FAO, 2013). Greenhouse gas emissions in livestock systems arise primarily from feed production, enteric fermentation by ruminants and manure storage. Fresh water use and biodiversity losses have also been documented in livestock production systems. Comprehensive Life Cycle

Assessments are needed to fully encompass all stages of production and adequately compare food group contributions to climate change and the environment.

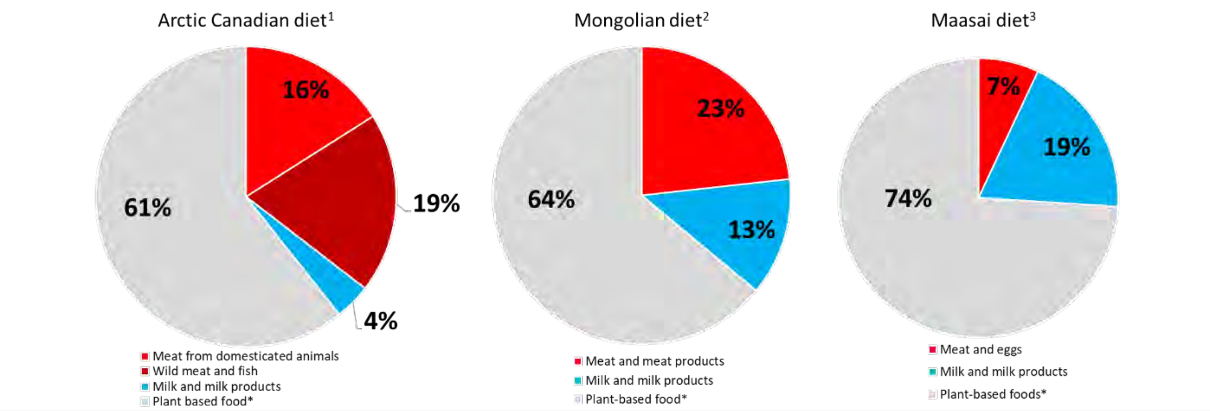
Box A3 Animal source food in dietary patterns - some examples of traditional diets

Arctic Canadian: The Arctic Canadian Tundra is characterized by low temperatures and short growing season which does not allow crop production. Thus, hunting and fishing activities play a central role in the culture of arctic communities. Their traditional diet includes a diversity of hunted meat and fish and is particularly high in protein and micronutrient content (e.g. vitamins, iron, zinc). TASF—comprising meat, meat from wild animals, fish and dairy— represent around 40 percent of total calories consumed (Kuhnlein and Receveur, 2007).

Maasai: The Maasai live in southern Kenya and northern Tanzania along the Great Rift Valley on semi-arid and arid lands with limited potential for crop production. These agro-pastoral communities depend mostly on cattle, sheep, goats and dromedaries. TASF represent 26 percent of the total energy intake in the diet of a Maasai community in Kenya (Transmara district) i.e. meat, poultry, eggs, milk and milk products. In particular, 19 percent of total calories come from milk and milk products (Hansen *et al.*, 2011).

Mongolian: Nearly 36 percent of total calories consumed in the Mongolian diet come from TASF. Within this group, 20 percent correspond to meat and meat products and 11 percent to milk and milk products. However, cereals are still the main source of energy providing in average 55 percent of the daily intake (FAO/UNICEF/UNDP, 2007). The extreme weather conditions and the high proportion of grassland (80 percent of total land area) compared to available arable land (<1 percent) explain the major role of livestock products in the Mongolian diet.

Total energy obtained from different food groups in some traditional diets



[1] Adapted from Kuhnlein and Receveur, 2007. * Plant- based food: Grain, fruits and vegetables provide around 30 percent of total energy.
[2] Adapted from FAO/UNICEF/UNDP, 2007. Plant-based food*: Only near 1 percent are vegetables.
[3] Adapted from Hansen *et al.*, 2011. * Plant- based food: cereals and grain products represent 45 percent of total energy.
Source: FAO, UNICEF and UNDP, 2007; Hansen *et al.*, 2011; Kuhnlein and Receveur, 2007.

In sum, the global nutrition situation points to the important role played by TASF across different dietary patterns for meeting global milestones. Evidence from the evolutionary history of our species indicates that there was a wide variety of TASF consumed in our ancient past, and that its introduction into hominin diets approximately two million years ago was associated significant anatomical and physiological changes. TASF should be viewed within larger multidimensional agrifood systems comprised of: their contribution to healthy diets for nutrition and health outcomes (Component Document 1); factors determining supply, demand, and consumption of TASF (covered in Component Document 2); the role of livestock and impacts on the environment and climate change (covered in Component Document 3) and; an overview of benefits, opportunities and trade-offs associated with livestock and TASF (covered in Component Document 4).

4 Structure of this document

First, nutrient composition and value of five types of TASF are covered (Section B) as a precursor to a review of the evidence for TASF effects on nutrition and health outcomes in different phases of the life course, which is covered in Section C. Section D assesses food safety and food-borne disease issue related to TASF. Then an overview of emerging topics is provided that extend beyond the gaps identified in each section (Section E). Each Section is being commences with key findings and a summary.

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Section B NUTRIENT COMPOSITION AND VALUE OF TERRESTRIAL ANIMAL SOURCE FOOD

Key findings

- TASF provide high-quality proteins compared with other foods, with some nuanced differences in digestibility. Specific amino acids and bioactive compounds with roles in human health may only be found in TASF (i.e. carnitine, creatine, taurine, hydroxyproline and anserine). Long-chain fatty acids and the ratios of essential fatty acids found in TASF are important for cognition, particularly across the human life course.
- Iron and zinc are bound in more bioavailable compounds in red meat and may be more easily digested than compounds found in plant-based foods. Milk is well recognized for its concentration and bioavailability of calcium among other nutrients. Eggs are highly concentrated in choline and some long-chain fatty acids. Generally, TASF are also a rich source of selenium, vitamin B12 and choline. Consumption of TASF has been shown to counteract effects of antinutritional compounds in plant-based foods.
- Nutrition quality (especially the fat composition) of TASF can be influenced in order of priority by choice of animal species and feeding system, followed by breed and production environment.
- Husbandry practices barely impact on protein composition and amino acid profile of TASF.
- Feed and feeding systems impacting mostly nutritional quality of TASF, especially fat and fatty acids content and especially in monogastric livestock (such as poultry and pigs). High PUFA-dense plants intake in the diet of both ruminants and monogastrics results in higher amount of beneficial fatty acids (omega-3) in resulting eggs, meat and milk. Feed and feeding systems impact in particular technological and organoleptic quality and commercial value of TASF.
- Genetic selection programmes are predominantly focusing on increasing production and productivity, improving economic performance and demand by food processing industry. A few initiatives aim at improving nutritional quality.
- Placing animals in conditions of stress before slaughter impacts on TASF quality.
- Drivers of livestock production include consumer demand and market opportunities.

Summary

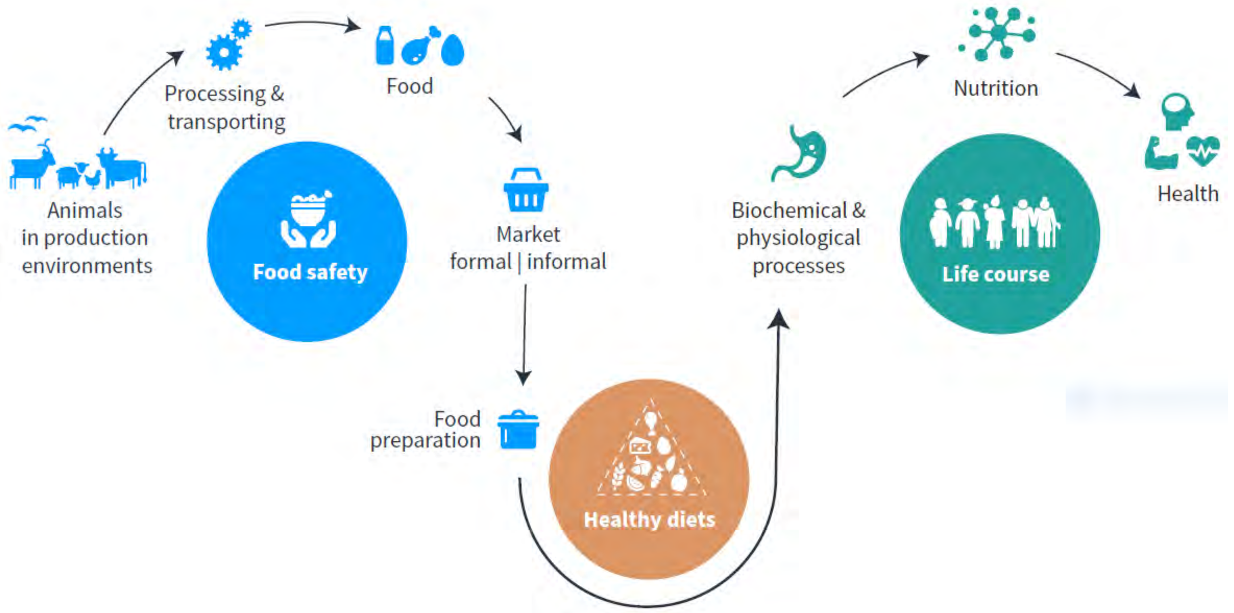
This section summarized the evidence base for TASF nutrient and bioactive composition. Several highlighted nutrients and bioactive compounds play important roles in human nutrition and health. TASF digestibility is modulated by both the food matrix and the overall diet of an individual. TASF can provide large proportions of macro- and micronutrient RNI throughout the life course. Across all TASF, we found evidence pointing to the provision of high quality proteins as indicated by DIAAS scores. Some amino acids and bioactive compounds were highlighted for being predominantly found in TASF: carnitine, creatine, taurine, hydroxyproline, and anserine. Lipid and fat-soluble vitamins in TASF are highly responsive to animal diets, with implications for decision-making around animal feeding. The ratio of high-density lipoprotein and low-density lipoprotein cholesterol matters for human health. Excess low-density lipoprotein cholesterol, which is caused especially by high transfat in the diets, can build up “plaque” in blood vessels and increase the risk for heart disease and stroke. Some carbohydrates identified in TASF were found to be potentially beneficial to human health: β-lactoglobulin in animal milk; oligosaccharides in animal milk and honey; and fibre in insects.

Evidence shows that TASF are micronutrient-dense and deliver several limiting micronutrients in bioavailable matrices that are more easily absorbed and metabolized. TASF are an especially important source of vitamin B12, not found in bioavailable forms in PBF. The entire vitamin B complex was also confirmed in the evidence base as richly provided by TASF. Choline more recently recognized for health and development is found concentrated in eggs and other TASF. Very high proportions of RNI can be met by consuming animal livers, but as well other TASF. Animal meats and insects are important dietary sources of iron and zinc. Deficiencies in these two nutrients remain highly prevalent across multiple populations globally. Selenium also emerged repeatedly as a concentrated mineral found in TASF. Milk and dairy products and other TASF offer calcium, vital for bone health among other biological processes, in high proportions of RNI. Across several TASF, the review highlighted bioactive compounds that have been associated with anti-inflammatory and antioxidative processes.

1 Introduction

This section reviews the literature for the nutrient composition and value of TASF. It also describes the evidence base for distinct nutrients found in various TASF and their products and the pathways leading to human health outcomes (see Figure B1). In the first subsection, concepts, definitions, and methods used are described. Next, the section highlights particular nutrients that may be more bioavailable and/or more highly concentrated in TASF compared to PBF, as well as their respective roles in selected aspects of human biology and public health. The evidence base for food chemistry and composition of TASF and their products is also summarized in this section. Factors that affect the variation of TASF nutritional quality at the production level are detailed, and finally, the section is summarized and gaps/needs are presented.

Figure B1 Pathway from animal production to human health



2 Concepts, definitions, and methods

Essential nutrients are compounds or single elements that are required from dietary consumption because the human body either does not endogenously produce at all or does not produce a sufficient supply to sustain optimal health. Deficiencies in essential nutrients may lead to serious health problems and even death. There are approximately 150 nutrients or components that are included in global food composition databases and studied in human health and nutrition. Generally, these nutrients are categorized into macronutrients (proteins, fats, carbohydrates) that provide energy among other functions and micronutrients (vitamins and minerals and trace elements) necessary for healthy development, disease prevention and well-being.

Human nutrient requirements established by FAO and WHO are used to guide recommendations on nutrient intakes to consumers and are periodically updated based on the evidence base. These values provide guidance on the amount of nutrients needed to maintain health in an otherwise healthy individual or group of people (WHO and FAO, 2004). Nutrient requirements are used by Member Countries and international bodies including the Codex Alimentarius Commission for the development of practical applications, and tools for improving nutrition, such as food labelling. Nutrient requirements are also established at regional and national level such as the Dietary Reference Values established by the European Food Safety Authority (EFSA) the comprehensive set of Dietary Reference Intakes that includes Recommended Dietary

Allowances, Adequate Intakes, and Upper Limits from the United States of America (USDA, 2021) (Dietary reference values EFSA)[1].

Evidence shows that beyond macro- and micronutrients there are biochemical compounds exceeding 26 000 present in foods and likely influencing human health (Barabási, Menichetti and Loscalzo, 2020a, 2020b). These compounds can be either positive or negative in physiological pathways, acting to enhance or interfere with metabolism, respectively. Furthermore, there is also documented evidence for food synergies that argue for consideration of dietary patterns and the interaction of food compounds within the context of the diet (Jacobs, Gross and Tapsell, 2009). This section of the Assessment of TASF considers nutrient composition across different edible portions of the animals or their products (milk, eggs) but as well, bioavailability of nutrients in the food and diet.

Nutrients and other bioactive compounds within various foods may be absorbed, metabolized, transported, stored, and ultimately excreted in differing manners depending on nutrient density and bioavailability. The food and diet matrices with interacting nutrients and bioactive compounds are important determinants of the mechanical and biochemical processes of human nutrition (Capuano and Janssen, 2021). Nutrient density refers to the relative amount of nutrients per: calories (e.g. per 100 kcal); food volume (e.g. per 100 gram); or serving size (Drewnowski and Fulgoni, 2014). Nutrient bioavailability refers to the proportion of nutrient intake that is absorbed and metabolized. Bioavailability can depend on the food chemistry of the TASF composition and synergies with other foods consumed in the diet. For example, the absorption of iron is enhanced when consumed with meat or vitamin C-rich foods (Gropper, Smith and Carr, 2021). There may also be compounds that interfere with absorption such as phytates in the case of iron. These antinutritional compounds will also be highlighted in this section.

Nutrient and food quality is being assessed (see definition below and in subsection 5) which impacts absorption, metabolism, storage, and excretion processes as well as acceptability. The DIAAS, defined as the percentage of digestible indispensable amino acids compared with a reference protein, is one example of a metric used to rate protein quality (FAO, 2013a) (see Box B1). The Global Diet Quality Score (GDQS) was recently developed to measure nutrient adequacy in association with NCDs, with comparable findings to other metrics including the Minimum Dietary Diversity-Women and Alternative Healthy Eating Index-2010 scores (Bromage *et al.*, 2021). Some TASF improve the score (e.g. eggs, chicken meat, game meat, low-fat dairy products), while contributing positively only in moderate amounts (e.g. red meat), and others negatively affect the score (processed meat, high-fat dairy products).

Box B1 Amino acids digestibility: Digestible Indispensable Amino Acid Score (DIAAS)

Protein quality is closely associated with the capability of different food sources to supply amino acids and nitrogen required to support multiple functions in the human body. High quality proteins comprise high digestibility and contain all the indispensable (dietary essential) amino acids in an adequate level and pattern. Accuracy in the measurement of protein quality is crucial to understand food security. For example, in India between 4-26 percent of the population of various groups is at risk of quality protein deficiency (Minocha *et al.*, 2017).

FAO/WHO adapted in 1990, PDCAAS (Protein Digestibility-corrected Amino Acid Score) relating protein quality to indispensable amino acid profile and digestibility. In 2011, a revised system was proposed by FAO to express protein quality, the DIAAS (Digestible Indispensable Amino Acid Score) (FAO, 2013b). There are differences between both methods: while in PDCAAS amino acid digestibility is related to rat crude protein nitrogen faecal digestibility, DIAAS examines ileal digestibility of each individual amino acid. PDCAAS overvalues low quality protein sources that are limited in indispensable amino acids and undervalues high quality protein sources (Rutherfurd *et al.*, 2015).

In addition, PDCAAS does not adequately take into consideration the bioavailability of specific amino acids. For example, lysine, that can be modified in the Maillard reaction during food processing. DIAAS measures the digestibility of individual amino acids and provides a means of determining bioavailable lysine.

[1] https://www.efsa.europa.eu/en/topics/topic/dietary-reference-values

FAO advice for individual foods or food ingredients is not to truncate the values above 100. This fact penalizes proteins with high concentrations of the indispensable amino acids, which is of particular interest from a nutrition security perspective. A score over 100 indicates potential to complement protein of lower quality. Not truncating the score allows the calculation of the protein quality of individual foods or food ingredients. However, for the calculation of a mixed diet itself it should be done using truncation.

PDCAAS truncated (PDCAASt) or without truncation (PDCAAS) and DIAAS for individual protein sources

Protein source	Protein quality score (in percent)			PDCAASt-DIAAS (in percent points)
	PDCAASt	PDCAAS	DIAAS	
Whole milk powder	100.0	116.1	115.6	-15.9
Egg	100.0	105	113	-13
Beef	100.0	114.0	111.6	-11.6
Chicken breast	100.0	101	108	-8
Soybean	100.0	102.0	99.6	0.4
Peas	78.2	78.2	64.7	13.6
Barley	59.1	59.1	47.2	11.8
Wheat	46.3	46.3	40.2	6.1

Source: Adapted from Ertl et al., 2016.

Conceptually DIAAS may be superior, but there is a lack of published amino acid digestibility datasets for a wide range of human foods (FAO, 2014). Therefore, it should be noted that PDCAAS remains the validated method to determine protein quality. In recent years, new data have become available on ileal amino acid digestibility of individual amino acids for foods and diets from various regions through the Proteos Phase III project undertaken by the Riddet Institute (Massey University), the University of Illinois, AgroParisTech, and Wageningen University.

Source:(Ertl, Knaus and Zollitsch, 2016; FAO, 2013a; Minocha, Thomas and Kurpad, 2017; Rutherfurd *et al.*, 2015a; FAO, 2014)

The definition of food quality refers to the attributes of a food that influence its nutritional value and that make it acceptable or desirable for the consumer (FAO and WHO, 2003). The factors impacting food quality are presented in Subsection 5.

Table B1 Types of food processing

Category of process	Examples of type of processes
Heating to destroy enzymes and micro-organisms	Boiling, blanching, roasting, grilling, pasteurization, baking, smoking
Removing water from the food	Drying, concentrating by boiling, filtering, pressing
Removing heat from the food	Cooling, chilling, freezing
Increasing acidity of foods	Fermentation, adding citric acid or vinegar
Using chemicals to prevent enzyme and microbial activity	Salting, syruping, smoking, adding chemical preservatives such as sodium metabisulphite or sodium benzoate
Excluding air, light, moisture, micro-organisms and pests	Packaging

Adapted from Trager, 1996 and FAO Basic facts about food preparation and processing[2].

This document covers TASF, primarily raw though to a lesser extent processed products. Processing methods are grouped into six categories that serve to preserve the food and protect from contamination (FAO, accessed in 2021). Other forms of food preparation may include among others, mixing, grinding, and

[2] https://www.fao.org/3/y5113e/y5113e04.htm

cutting. Processing food may not only serve to preserve, but also change the quality of food in terms of palatability and nutritional quality. Ultra-processed food has been described and a classification scheme developed called NOVA that ranks foods according to the extent and purpose of industrial processing (Monteiro *et al.*, 2019). The following table (Table B1) lists types of processing.

The following synthesis of the literature is presented as a narrative review. The literature search for this section included studies examining the nutrient composition of TASF in their original form and TASF products. Information on aquatic foods, studies examining foods with TASF as ingredients only and fortified TASF were excluded. Literature describing the health implications of common nutrients and bioactive compounds found across TASF was also summarized. The databases and search terms applied are listed in Box B2.

Box B2 Search terms by database used for Section B

Search terms using Academic Search Complete via EBSCO
(“animal source food” OR “livestock derived food” OR “animal derived food” OR “meat” OR “red meat” OR “dairy product”) AND (“nutrient”) OR (“nutritional composition”) OR (“nutrient composition”) OR (“nutritional content”) OR (“macronutrient”) OR (“micronutrient”) OR (“nutritional value”)

Search terms using PubMed
(“animal source food” OR animal source food* OR “animal sourced food” OR “animal based food” OR “livestock derived food” OR “TASF”) AND (“macronutrient” OR “protein” OR “amino acid” OR “lipid” OR “DHA” OR “EPA” OR “carbohydrate” OR “protein quality” OR “micronutrient” OR “vitamin A” OR “calcium” OR “iron” OR “bioactive compound” OR “taurine” OR “carnosine” OR “creatine”) OR ((“eggs”) AND (“poultry” OR “duck” OR “emu” OR “muscovy duck” OR “ostrich” OR “partridge” OR “peafowl” OR “pheasant” OR OR “pig” “pigeon”) OR (“Milk” OR “dairy product”)) OR (“lactose” OR “buffalo” OR “camel” OR “cow” OR “cattle” * OR “donkey” OR “goat” OR “mare” OR “mithan” OR “sheep”) OR (“red meat” OR “meat” AND “alpaca” OR “beef" OR “goat” OR “guinea pig” OR “llama” OR “pheasant” OR “pig” OR “poultry” OR “sheep”) OR (“Insects”) OR (“honey” OR “Bee products” OR “apis” OR “bees”) OR (“Game meat” OR “bushmeat” OR “wildlife food”) AND (“nutrient composition” OR “nutrient value” OR “nutritional value” OR “nutrient density” OR “nutrient content”) NOT (“aquatic animal food” OR “fortified” AND “animal source food” OR “ingredient” AND “animal source food”).

Search terms using ScienceDirect
(“animal source food” OR animal source food* OR “animal sourced food” OR “animal based food”* OR “livestock derived food” OR “TASF”) AND (“macronutrient” OR “protein” OR “amino acid” OR “lipid” OR “DHA” OR “EPA” OR “carbohydrate” OR “protein quality” OR “micronutrient” OR “vitamin A” OR “calcium” OR “iron” OR “bioactive compound” OR “taurine” OR “carnosine” OR “creatine”) OR ((“eggs”) AND (“poultry” OR “duck” OR “emu” OR “muscovy duck” OR “ostrich” OR “partridge” OR “peafowl” OR “pheasant” OR OR “pig” “pigeon”) OR (“milk” OR “dairy product”)) OR (“lactose” OR “buffalo” OR “camel” OR “cow” OR “cattle” * OR “donkey” OR “goat” OR “mare” OR “mithan” OR “sheep”) OR (“red meat” OR “meat” AND “alpaca” OR “beef" OR “goat” OR “guinea pig” OR “llama” OR “pheasant” OR “pig” OR “poultry” OR “sheep”) OR (“insects”) OR (“honey” OR “bee products” OR “apis” OR “bees”) OR (“game meat” OR “bushmeat” OR “wildlife food”) AND (“Nutrient composition” OR “nutrient value” OR “nutritional value” OR “nutrient density” OR “nutrient content”) NOT (“aquatic animal food” OR “fortified” AND “animal source food” OR “ingredient” AND “animal source food”

3 Nutrients in TASF and importance for human nutrition

This subsection examines the nutrients and bioactive compounds found in TASF that have been associated with health and nutrition indirectly (see Box B3). Additionally, this subsection covers key macro- and micronutrients and bioactive compounds that are highly concentrated in and/or more bioavailable in TASF, compared to other food.

Box B3 Food components: nutrients, bioactive compounds and antinutritional compounds

Nutrients
A nutrient is a substance that is required by the body for optimal growth, development, and maintenance of good health.

Nutrients are classified according to quantitative requirement:
Macronutrients: calorie-containing components of food needed in substantial quantities, typically above 10g per day. These include carbohydrates, proteins, and fats.
Micronutrients: nutrients required by the body in small amounts, usually below 2g per day. These include vitamins and minerals.

Nutrients can be also classified according to their essentiality. Their deficiency causes specific symptoms that can lead to health problems:
Essential nutrients: nutrients required through nutrition that cannot be synthesized by the human body.
Conditionally essential nutrients: nutrients that are produced by the body in sufficient amounts to meet the bodies' physiological requirements, but for which intake via food may be essential under certain conditions when biosynthesis is inadequate.
Non-essential nutrients: nutrients required by the human body that can be synthesized by the human body under normal conditions and are thus not required in the food.

Classification of nutrients by essentiality

Classification	Nutrients
Essential nutrients	Amino acids: histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine;
	Fatty acids: alpha-linolenic acid, linoleic acid
	Water-soluble vitamins: Vitamin B1 (Thiamin); Vitamin B2 (Riboflavin); Vitamin B3 (Niacin); Vitamin B5 (Pantothenic acid); Vitamin B6 (Pyridoxine); Vitamin B7 (Biotin); Vitamin B9 (Folate); Vitamin B12 (Cobalamin); Vitamin C;
	Fat-soluble vitamins: Vitamin A; Vitamin E; Vitamin K;
	Minerals: calcium, chlorine, chromium, cobalt, copper, iron, iodine, manganese, magnesium, molybdenum, phosphorus, potassium, selenium, sodium, zinc;
	Choline;
Conditionally essential nutrients	Vitamins: Vitamin D;
Non-essential nutrients	Amino acids: alanine, arginine, asparagine, creatine, cystine, glutamine, glycine, proline, serine, taurine, tyrosine;
	All digestible carbohydrates;
	All fatty acids except for linolenic acid, linoleic acid;

Bioactive compounds are substances that are able to modulate metabolic functions leading to beneficial outcomes. In TASF there are different bioactive compounds that are being studied such as carnitine, anserine, creatine, and anersine.

There are other components to consider when analysing the nutritional aspects of food that can interact with the bioavailability of a specific nutrient. This is the case for antinutritional compounds. These are substances that naturally occur in plants and TASF and interfere with the absorption of nutrients. Antinutritional compounds occur predominately in plant-based food. Examples of antinutritional compounds that interfere with mineral uptakes from TASF include phytates (phytic acid) and oxalates (oxalic acid).

3.1 Macronutrients

TASF are most often associated with protein content and quality. Proteins are found throughout the human body with over 40 percent in skeletal muscle, 25 percent in body organs and the remaining in skin and bones (Gropper, Smith and Carr, 2021). Living cells in the body depend on proteins for architecture and various functions used to categorize proteins: catalysts (e.g. enzymes); messengers (e.g. hormones); structural elements; immunoprotectors; transporters; buffers among others. In general, balanced protein intake optimises human health outcomes such as increasing muscle mass throughout the life course (Tagawa *et al.*, 2021). There are particular phases of the life course, however, where higher intakes of protein are important, for example in pregnant and lactating women or in the older adults to prevent sarcopenia (Paddon-Jones and Rasmussen, 2009; Wolfe, Miller and Miller, 2008). Though not covered in this Assessment, populations who are chronically or acutely ill may also require additional protein intakes (Phillips, Paddon-Jones and Layman, 2020).

TASF are an important source of high quality proteins containing digestible and indispensable (essential) amino acids. In recent years, there has been renewed focus on high quality proteins for the prevention of stunted growth. One study with observational design in 116 LMICs found that utilizable protein (total protein corrected for biological value and digestibility) was negatively associated with stunting after adjusting for energy and gross domestic product (Ghosh, Suri and Uauy, 2012). In another study among children aged 12-59 months in Malawi, lower serum concentrations of specific essential amino acids (tryptophan, isoleucine, valine, methionine, threonine, histidine, phenylalanine, lysine) and conditionally essential amino acids (arginine, glycine, glutamine) were found associated with child stunting (Semba *et al.*, 2016). A recent narrative review discussed the importance of TASF for the essential amino acids needed for young child growth and neurocognitive development, point to the amino acid sensing rapamycin complex 1 (mTORC1) as a key regulator of these processes (Parikh *et al.*, 2022).

Some amino acids and their metabolites are notably present in TASF and absent or found in low levels in PBF. These compounds have been classified as bioactives and many have been studied for their association with human health outcomes. Taurine, creatine, carnosine, 4-hydroxyproline, and anserine were all discovered in cattle and found concentrated in beef, while lacking in PBF (Wu, 2020). They play key roles in anti-inflammatory and immunological defence pathways, as well in memory and cognition (Avgerinos *et al.*, 2018; Benton and Donohoe, 2011) and brain fat comand eye health and cardiovascular maintenance (Ripps and Shen, 2012). Some TASF may be more concentrated in the essential amino acid, tryptophan, a precursor for serotonin recently connected to brain function via the microbiome (Gao *et al.*, 2020) and depression in older adults (Klimova, Novotny and Valis, 2020) and postnatal women (Trujillo *et al.*, 2018). Diets consisting primarily of the staple food maize are deficient in tryptophan and may also interfere with absorption of minerals found in TASF.

Box B4 Important fat compounds provided by terrestrial animal source food

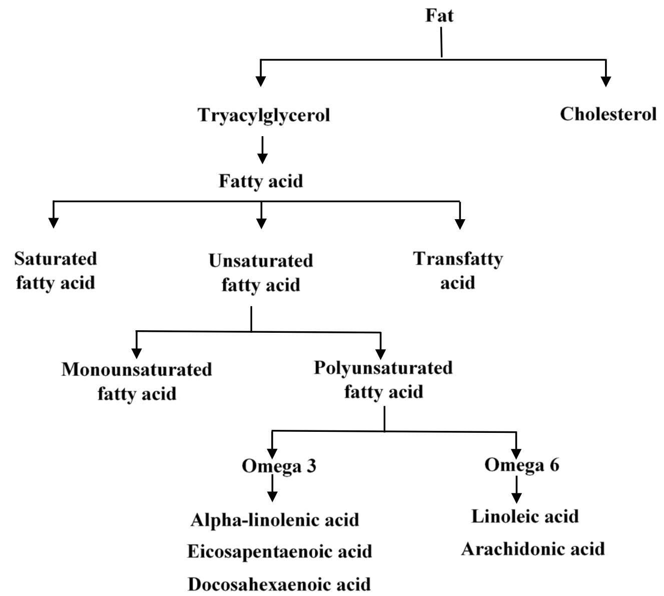
TASF are rich in a variety of fats. Dietary fats not only provide essential fatty acids but also help in the absorption of fat-soluble vitamins. In the human body, they are usually presented as triacylglycerols. One of the components of triacylglycerols are fatty acids. Depending on the source of food, fatty acids can be found in different conformations, abundance and may also influence a wide number of health outcomes. They can be divided in three large groups: saturated fatty acids, unsaturated fatty acids and transfatty acids. Within the unsaturated fatty acids category, there are monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA). The group of PUFA is especially important as it contains two essential fatty acids: alpha-linolenic acid and linoleic acid. The aforementioned are required nutrients that cannot be synthesized by the human body, and so, dietary sources are the only way to obtain them.

Another important component from the family of fats is cholesterol. Cholesterol is made in the liver or can be found in food. Cholesterol is transported in human blood on two types of lipoproteins: low-density lipoprotein; and high-density lipoprotein. The ratio of high-density lipoprotein and low-density lipoprotein matters for human health. Excess low-density lipoprotein cholesterol can build up “plaque” in blood vessels and increase the risk for heart disease and stroke, while high-density lipoprotein, the “good” cholesterol, serves to remove low-density lipoprotein from the blood by transporting it to the liver to flush out of the body (CDC, 2020).

Examples of fatty acids and their health outcomes

Fatty acid	Health outcome
Arachidonic acid Docosahexaenoic acid Eicosatetraenoic acid	Vital roles in neuro development, anti-inflammatory processes and cell membrane integrity;
Docosapentaenoic acid Omega-6	Potential reduction of NCD risk;
Ratio of omega-6 to Omega-3 fatty acids	Low ratio enables endonegous production of long-chain fatty acids DHA and EPA, important for neurodevelopment
Transfatty acids	High levels in the diet can increase the risk of death and coronary heart disease;

Classification of main dietary fats



The composition of essential fatty acids in TASF matters for human health outcomes (see Box B4 for details on classification and importance of fat coumpunds). For example, the ratio of linoleic acid to alpha-linolenic acid will influence how efficiently these fatty acids are endogenously converted into the longer chain fatty acids of arachidonic acid, aminopenicillanic acid and DHA (Bernard *et al.*, 2013). The elongation and desaturation of alpha-linolenic acid to long chain omega-3 PUFA may be limited if there excess dietary linoleic acid. The long-chain fatty acids have known benefits to human health, playing vital roles throughout the life course in neurodevelopment, anti-inflammatory processes, cell membrane integrity, among others (Hadley *et al.*, 2016; Swanson, Block and Mousa, 2012). There is some evidence for positive effects of docosahexaenoic acid (DHA) supplementation on young child cognitive outcomes (Drover *et al.*, 2011), but systematic and narrative reviews have shown supplementation trials have only minimal effects on health outcomes throughout the life course (Abdelhamid *et al.*, 2018; Jiao *et al.*, 2014). Dietary TASF intervention trials to be discussed in Section C have shown demonstrated impacts on DHA status.

Some fats such as saturated fatty acids and transfat have been implicated in negative human health outcomes. Dietary guidelines generally recommend limiting saturated fats, to approximately 10 percent of total energy intakes (FAO, 2010). Recent reviews suggest the observational studies linking the saturated fats in meat with risk of disease have not fully considered the overall diet or type of cooking methods used that may serve to modulate the effects on disease (Geiker *et al.*, 2021; Martínez Góngora *et al.*, 2019; Tárraga López, Albero and Rodríguez-Montes, 2014; Ward *et al.*, 2016). High transfat in the diet can increase the risk of death and coronary heart disease likely through by increasing low-density lipoprotein and lowing high-density lipoprotein (de Souza *et al.*, 2015; Te Morenga and Montez, 2017).Transfats may occur naturally from ruminants or from processing by adding hydrogen to vegetable oil to convert liquid to solid (WHO, 2018).

3.2 Micronutrients

Vitamins can occur in differing forms and play different roles in human nutrition. Forms may vary across TASF and PBF, and recommended nutrient intake of vitamins varies by life cycle phase (see Annex Table B1). Vitamin B12 also known as cobalamin is an important nutrient to be considered in relation to TASF and human health, because it is largely absent in PBF; Vitamin B12 can be found in some PBF like seaweed, mushrooms (technically fungi) and tempeh, though in forms that may not be as bioavailable as vitamin B12 in TASF (Watanabe *et al.*, 2013; Zugravu *et al.*, 2021). Vitamin B12 plays an important role in cellular metabolic processes such as DNA synthesis and methylation. Deficiencies may result in pernicious anaemia and compromised neurodevelopment and functioning (Green *et al.*, 2017). Other B vitamins serve as cofactors in enzyme systems throughout the human body. Riboflavin or vitamin B2, is necessary to produce two coenzymes, flavin mononucleotide and flavin adenine dinucleotide that function in multiple pathways namely cellular respiration, growth, development and maintenance of epithelial tissue. The vitamin B6 in its phosphorylated form of pyridoxine is found largely in plants and must be dephosphorylated to be absorbed, while vitamin B6 in meat appears as esters that are more bioavailable (Brown, Ameer and Beier, 2021). Pyridoxine serves as a coenzyme for synthesis of amino acids, sphingolipids, neurotransmitters, haemoglobin, among other bioactives, as well as metabolism of glycogen.[3] Other B vitamins such as B1 and B3 are also contained in TASF and important in human health (Gropper, Smith and Carr, 2021).

Choline has gained increasing attention in recent years for its importance in growth, brain function, and gene interactions (Leermakers *et al.*, 2015; Smallwood, Allayee and Bennett, 2016). In human physiology, choline serves as a precursor for phospholipids (phosphatidylcholine and sphingomyelin) that are integral in cell membrane integrity and signalling, acetylcholine, which influences neurotransmission, neurogenesis, myelination and synapse formation; and betaine, which donates a methyl group in the homocysteine production pathway (Caudill, 2010; Zeisel and da Costa, 2009). Recent systematic and narrative reviews point to the importance of choline in the first 1 000 days of life for growth and neurodevelopment (Bragg, Prado and Stewart, 2021; Derbyshire and Obeid, 2020). Eggs (and beef to a lesser extent) are highly concentrated in this nutrient. Another essential nutrient found in TASF is vitamin K (the form K2 is only found in TASF), important for blood coagulation and calcium binding pathways in human health (Halder *et al.*, 2019).

The minerals zinc and iron are found highly bioavailable in the muscle tissue of meats. Iron plays multiple roles in the human body, most notably for oxygen transport in the haemoglobin blood protein, but as well for other pathways involved in growth, neurodevelopment, and immunity (Gropper, Smith and Carr, 2021; McCann, Perapoch Amadó and Moore, 2020). Iron is especially important during pregnancy when there is significant plasma volume expansion (Georgieff, 2020) (see Annex Table B2 for more information on recommended nutrient intake of minerals by life cycle phase). Zinc is necessary for the activity of over 300 enzymes in the human body, and also serves vital functions in growth, development, and immunity (Gropper, Smith and Carr, 2021). Deficiencies in iron and zinc contribute substantially to global burden of disease (Black *et al.*, 2013). Although selenium is not recognized to be widely deficient in populations, it does play important roles in human health (Gashu *et al.*, 2016; Speckmann and Grune, 2015). The trace mineral is important for immune function and for its antioxidant and epigenetic effects. Selenium is among the nutrients known to be influenced by environmental factors such as soil concentration (Gibson *et al.*, 2011). Calcium and phosphorous are considered macro-minerals found in TASF and important for bone health among other roles (Gropper, Smith and Carr, 2021).

[3] https://pubchem.ncbi.nlm.nih.gov/compound/1054

4 Evidence for nutrient composition of different TASF

The evidence for five categories of TASF was reviewed for the nutrient composition with potential implications for human health:

- eggs and egg products;
- milk and dairy products;
- meat and meat products;
- TASF from hunting and wildlife farming; and
- Insects inluding grubs and their products.

TASF from hunting and wildlife farming were included as a separate group because of the consistent findings for the composition of some nutrients diverging from livestock-derived meats. Insects and insect products are not generally included in food-based dietary guidelines. However, they are explored in this subsection because there is a growing literature on their value in human health and nutrition.

4.1 Eggs and egg products

Chicken eggs are the most widely consumed though the diets of many populations also contain eggs from other poultry such as turkey, duck, quail and geese (FAO, 2015b). Egg in shell is the predominant exported product, though others include liquid eggs and egg powder. Eggs provide a range of different nutrients but are especially concentrated in high quality proteins, essential fatty acids, DHA, choline, selenium, riboflavin, and vitamin B12 (Iannotti *et al.*, 2014) (see Tables B2, B3, Annex Tables B3 and B4). The literature for egg nutrient composition often differentiates nutrient content in the yolk and white. These constituents originate in the hen during different phases of egg production and serve separate functions for the developing chick; the egg yolk derived from hepatic tissue is primarily nutritive, and the white secreted in the oviduct serves largely as a defence system (Nys and Guyot, 2011).

Table B2 Amino acid composition of poultry eggs

Nutrient (in gram)	Chicken	Duck	Chicken egg yolk		Chicken egg white		Geese	Quail	Turkey
	average	average	Average	range	average	range	average	average	average
Protein	12.6	12.8	15.8	15.6-15.9	11.1	10.9-11.2	13.9	13.0	13.7
Alanine	0.74	0.63	0.82	0.81-0.84	0.70	0.69-0.70	0.68	0.76	0.80
Arginine	0.82	0.77	1.11	1.1-1.13	0.66	0.65-0.66	0.83	0.84	0.88
Aspartic acid	1.33	0.78	1.5	1.45-1.55	1.22	1.21-1.22	0.84	1.29	1.36
Cystine	0.27	0.29	0.29	0.26-0.29	0.32	0.29-0.34	0.31	0.31	0.33
Glutamic acid	1.67	1.79	1.92	1.87-1.97	1.54	1.55-1.53	1.94	1.66	1.74
Glycine	0.43	0.42	0.48	0.47-0.48	0.41	0.41-0.41	0.46	0.43	0.46
Histidine	0.31	0.32	0.45	0.42-0.48	0.28	0.27-0.28	0.35	0.32	0.33
Isoleucine	0.67	0.6	0.89	0.87-0.91	0.70	0.66-0.74	0.65	0.82	0.86
Leucine	1.09	1.10	0.89	0.37-1.4	1.03	1.92-1.04	1.19	1.15	1.20
Lysine	0.91	0.95	1.19	1.16-1.22	0.81	0.81-0.807	1.03	0.88	0.92
Methionine	0.38	0.58	0.40	0.38-0.43	0.42	0.40-0.43	0.62	0.42	0.44
Phenylalanine	0.68	0.84	0.68	0.68-0.69	0.7	0.69-0.71	0.91	0.74	0.77
Proline	0.51	0.48	0.57	0.49-0.64	0.39	0.34-0.44	0.52	0.52	0.54
Serine	0.97	0.96	1.34	1.33-1.34	0.83	0.80-0.86	1.04	0.99	1.04
Threonine	0.56	0.74	0.81	0.87-0.94	0.58	0.45-0.71	0.80	0.64	0.67
Tryptophan	0.16	0.26	0.21	0.18-0.23	0.16	0.13-0.18	0.28	0.21	0.22
Tyrosine	0.5	0.61	0.47	0.27-0.68	0.45	0.45-0.46	0.66	0.54	0.57
Valine	0.86	0.89	0.97	0.95-0.95	0.84	0.81-0.87	0.96	0.94	0.99

Note: All nutrient values are expressed per 100g edible portion on fresh weight basis (EP).
Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

The combination of amino acids and proteins in eggs is considered a gold standard against which other proteins are compared (see Table B2). The concentration of proteins does not vary greatly across bird species with slightly higher levels in turkey (13.7/100g) and geese (13.9/100g) eggs compared to chicken (12.6/100g) (see Table B2). One study found a higher quantity of essential and total amino acids in the albumen of turkey eggs compared to chicken, duck, goose, quail, and pigeon, though higher ratio of essential to total amino acids in duck and goose eggs relative to chicken, turkey goose, quail, and pigeon eggs (Sun *et al.*, 2019).

Egg proteins broadly are noted for their high digestibility – further enhanced through heating and the denaturation of some structural proteins (Réhault-Godbert, Guyot and Nys, 2019). Egg yolks contain a mix of low-and high-density lipoproteins, livetins, and phosvitins. Phosvitins have been shown to interfere with iron absorption (Yilmaz and Ağagündüz, 2020). The vitelline membrane proteins and lipids separate the egg yolk from egg white. Ovoalbumin and ovomucoid, proteinase inhibitors that can resist thermal heating, are the primary proteins contained in the egg white. Antibacterial proteins such as lysozyme, peptides, ovotransferrin, ovoglobulin, cystatin, avidin, and ovoflavin are also present in the egg white likely contributing to human nutrition (Guha, Majumder and Mine, 2018). One older review summarized evidence indicating the proteins and peptides contained in eggs have been associated with multiple health promoting biological processes: antimicrobial activities; immunomodulatory; antiadhesive properties; antioxidative processes; anticancer and antihypertensive activities, among others (Kovacs-Nolan, Phillips and Mine, 2005).

Table B3 Composition of fats and fatty acids of poultry eggs

Nutrient	Chicken		Chicken egg yolk		Chicken egg white		Duck	Geese	Quail	Turkey
	avg	range	avg	range	avg	range	avg	avg	avg	avg
Fat (g)	8.5	8.5-9.5	27.4	26.5-28.2	0.09	0-0.2	13.8	13.3	11.1	11.9
SFA (g)	2.76	2.3-3.1	9.1	8.6-9.6	0	0	3.7	3.6	3.6	3.6
SFA 4:0 (g)	0	0	0	nd	0	0	0	0	0	0
SFA 6:0 (g)	0	0	0	nd	0	0	0	0	0	0
SFA 8:0 (g)	0	0	0	0- 0.14	0	0	0	0	0	0
SFA 10:0 (g)	0	0	0	0-0.01	0	0	0	0	0	0
SFA 12:0 (g)	0.01	0-0.02	0	0-0.01	0	0	0	0	0	0
SFA 14:0 (g)	0.04	0.03-0.05	0.11	0.10-0.12	0	0	0.05	0.05	0.053	0.04
SFA 16:0 (g)	1.95	1.66-2.23	6.50	6.13-6.86	0	0	3.00	2.85	2.67	2.72
SFA 18:0 (g)	0.68	0.54-0.81	2.24	2.06-2.42	0	0	0.63	0.70	0.84	0.88
MUFA (g)	3.61	3.55-3.66	12	11.7-12.03	0	0	6.52	5.75	4.32	4.57
MUFA 16:1 (g)	0.21	0.20-0.22	0.74	0.57-0.92	0	0	0.44	0.39	0.47	0.67
MUFA 18:1 (g)	3.35	3.28-3.41	11.00	10.70-11.39	0	0	6.08	5.35	3.85	3.90
MUFA 20:1 (g)	0.019	0.01-0.03	0.08	0.07	0	0	0	0	0	nd
MUFA 22:1 (g)	0	0	0	0-0.01	0	0	0	0	0	nd
PUFA (g)	1.55	1.19-1.91	3.56	2.92-4.20	0	0	1.22	1.67	1.32	1.66
PUFA 18:2 (g)	1.26	0.96-1.56	2.9	2.25-3.54	0	0	0.56	0.68	0.94	1.17
PUFA 18:3 (g)	0.05	0.05-0.05	0.09	0.07-0.10	0	0	0.102	0.55	0.04	0.08
PUFA 18:4 (g)	0	0	0	0	nd	0	0	0	0	nd
PUFA 20:4 (g)	0.14	0.08-0.18	0.22	0-0.44	0	0	0.32	0.28	0.12	0.13
PUFA 2:5 n-3 (EPA) (g)	0	0	0.01	0	0	0	0	0	0	nd
PUFA 22:5 n-3 (DPA) (g)	0.08	0.08	0	0	0	0	0	0	0	nd
PUFA 22:6 n-3 (DHA) (g)	0.06	0.06	0.11	0	0	0	0	0	0	nd
Fatty acids, total trans (g)	0.02	0.01-0.04	0.03	0	0	0	nd	nd	nd	nd
Cholesterol (mg)	430	372-488	1065	1050-1080	0	0	884	852	844	933
Choline (mg)	294	294	820	820	1.1	1.1	nd	263	nd	nd

Note: All nutrient values are expressed per 100g edible portion on fresh weight basis (EP); SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; RAE = retinol activity equivalents. Slaughter weight and degree of maturity at slaughter weight influence nutrient composition; nd = not available (no values found); avg = average. Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Eggs of all poultry species contain a wide range of fatty acids (see Table B3). Lipids are highly concentrated in the egg yolk relative to the white (see Annex Table B3). Duck (13.8g) and geese (13.3g) eggs, on average, contain more lipids per 100 gram compared to chicken eggs (8.5g). One study showed that there is a higher ratio of unsaturated to saturated fats in eggs compared to other TASF (Réhault-Godbert, Guyot and Nys, 2019). Cholesterol concentrations are also relatively high in eggs compared to other TASF and food broadly, though there is some uncertainty in the evidence-base for correlation of intake levels with plasma cholesterol (Kim and Campbell, 2018). The lipid molecule has been associated with the development of cardiovascular disease (Kuang *et al.*, 2018). One systematic review and meta-analysis of randomized controlled trials comparing more egg consumption on different interventions showed higher low-density lipoprotein-cholesterol/high-density lipoprotein-cholesterol ratio than the control group (mean difference = 0.14, p = 0.001, I2 = 25%) (Li *et al.*, 2020).

Eggs contain several bioavailable vitamins and some minerals at higher concentrations (see Annex Table B4 and below Table B4). Eggs are among the richest dietary sources of choline, containing both lipid- forms and water-soluble forms. Similar to other TASF, eggs contain vitamin B12 (eggs from different poultry species can provide greater than 50 percent of age- and sex-specific recommended nutrient intake), as well as significant concentrations of other B vitamins. Eggs have been noted for the carotenoids of lutein and zeaxanthin, important in anti-inflammatory pathways. Vitamin C is missing from eggs, likely explained by the capability of birds to produce this endogenously. Niacin is also found in very low levels. Some minerals and trace elements found limited in the diets of vulnerable populations may be provided by eggs at sufficient levels and in more available forms. Egg yolks are more highly concentrated in minerals compared to whites, and some variability exists across species. Egg shells are also a rich in highly bioavailable calcium—about 380mg of calcium is contained in 1 gram of chicken egg shell (Bartter *et al.*, 2018; Omer *et al.*, 2018). Turkey eggs are more highly concentrated relative to other birds in some important minerals including calcium (99.0mg per 100g), iron (4.1mg per 100g), and zinc (1.6mg per 100g; see Table B4). Evidence is equivocal for dietary egg intakes and human mineral nutrition.

Table B4 Mineral composition of poultry eggs

Nutrient	Chicken		Chicken egg yolk		Chicken egg white		Duck	Geese	Quail	Turkey
	avg	range	Avg	range	avg	range	avg	avg	avg	avg
Calcium (mg)	52	47-56	115	100-129	6	5-7	64	60	64	99
Magnesium (mg)	12	12	6.5	5-8	11	11	17	16	13	13
Phosphorus (mg)	189	180-198	394	390-398	12.5	10-15	220	208	226	170
Potassium (mg)	139	138-140	106.5	104-109	141	119-163	222	210	132	142
Sodium (mg)	146	142-150	53	48-58	175	166-175	146	138	141	151
Iron (mg)	1.8	1.6-1.9	3.4	2.7-4	0.1	0.2-0.1	3.9	3.6	3.7	4.1
Zinc (mg)	1.2	1.1-1.3	2.4	2.3-2.5	0	0	1.4	1.3	1.5	1.6
Copper (mg)	0.06	0.06-0.07	0.10	0.07-0.13	0.012	0-0.02	0.06	0.06	0.06	0.06
Manganese (mg)	0.027	0.03-0.028	0.07	0.05-0.08	0.01	0-0.01	0.04	0.04	0.04	0.04
Selenium (µg)	28.2	25.7-30.7	56.0	56.0	15.5	20.0-11	36.4	36.9	32.0	34.3
Iodine (µg)	57.6	57.6	80	80	0	0	n/a	nd	nd	nd

Note: nd = not available (no values found); avg = average.
Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Egg consumption by women of reproductive age was shown to be low in many LMIC, but particularly in Sub-Saharan Africa and India. Among all women of reproductive age in any context, two eggs per day can provide high levels of required nutrient intakes, particularly for choline, selenium, vitamin B12, vitamin B2 (riboflavin) and vitamin B5 (pantothenic acid), and phosphorous (Lutter, Iannotti and Stewart, 2018) with limited evidence showing elevated risk of blood cholesterol in associtation with coronary heart disease, stroke and hypertension in healthy adults (Kolahdouz-Mohammadi *et al.*, 2020; Rong *et al.*, 2013).

4.2 Milk and dairy products

Globally, humans consume the milk and dairy products from multiple animal species including cattle, buffalo, mithan, yak, goats, sheep, horse, alpaca, llama, reindeer and dromedary and Bactrian camel. The milk from these animal species varies in composition. Animal milk produced around parturition with the biological purpose of nourishing offspring is nutrient-dense and complete across many nutrients and bioactive compounds (Mozaffarian, 2019). The matrix contains complementary nutrients acting in synergy to optimize metabolism, for example lactose and casein acting to enhance calcium absorption (Chalupa-Krebzdak, Long and Bohrer, 2018). One recent study using chromatography-nuclear magnetic resonance spectroscopy and different types of mass spectrometry conducted an untargeted metabolomics study and identified 296 bovine milk metabolites and metabolite species that may or may not have health implications (Foroutan *et al.*, 2019). Sphingomyelin in animal milk may be protective against gut dysbiosis and inflammation (Norris *et al.*, 2019).

Similar to eggs, milk and dairy products have been recognized for their importance in terms of high quality proteins. The two primary protein categories in milk are casein (insoluble) and whey (soluble), approximately 80 percent and 20 percent, respectively. Whey proteins can act in concert with other nutrients, minerals specifically, to enhance absorption and metabolism. For example, the glycoprotein lactoferrin binds iron and may increase bioavailability of the mineral and play key roles in immunity and inflammatory processes (Hao *et al.*, 2019), though animal milk is generally not considered a good source of iron (Hurrell *et al.*, 1989; Ziegler, 2011). β-lactoglobulin has high affinity for retinol and other carotenoids may enhance vitamin A absorption and metabolism (Mensi *et al.*, 2013). Caseins serve as protein carriers for calcium and phosphorous. The protein insulin-like growth factor, IGF-1, in TASF milk has been linked to child growth though evidence is mixed for this effect (Grenov *et al.*, 2020; Hoppe, Mølgaard and Michaelsen, 2006). One recent analysis showed the protein content in plant-based alternatives to milk – soybean, oat, hemp, coconut, rice and nuts – was on average an estimated 48 percent of bovine milk proteins (Chalupa-Krebzdak, Long and Bohrer, 2018).

Milk lipids are primarily comprised of triacylglyerols (98 percent), and very small fractions of diacylglycerol (two percent), cholesterol (<0.5 percent), phospholipids (1 percent), and free fatty acids (0.1 percent) (Pereira, 2014). TASF milk fatty acids are a function of feed, stage of lactation and animal species (see also Subsection 5). Bovine milk contains approximately 70 percent saturated and 30 percent unsaturated fatty acids. Oleic acid, conjugated linoleic acid, and omega-3 fatty acids in bovine milk may promote positive human health outcomes (Haug, Høstmark and Harstad, 2007). Concerns about saturated fats and the association with cardiometabolic health have been raised but largely derive from observational studies (Poppitt, 2020). To be discussed in Section C, there is some evidence showing yogurt and high-fat cheese have an inverse association with risk of type 2 diabetes.

Comparing the nutrient concentration in the milk of various animal species, differences in macronutrient concentrations were evident (see Table B5). Animal milk protein levels per 100g are highest in: reindeer (10.4g); mithan (6.0g); sheep (6.0g); and alpaca (5.8g). The highest milk fat concentrations per 100g showed a similar pattern: reindeer (16.1g); mithan (8.9g); buffalo (7.5g); and sheep (7.0g). The amino acid and fatty acid compositions varied across animals as well (see Annex Tables B5 and B6).

In terms of micronutrients, milk and dairy products are especially well-recognized for its concentration and bioavailability of calcium, bound to casein in micellar form but also whey proteins and inorganic salts. Other macrominerals found concentrated in milk are phosphorous, magnesium, and potassium, and microminerals, zinc and selenium may also be provided by milk. Iodine may be found in bovine and buffalo milk (see Annex Table B7). Among the dairy products, dry milk powder unsurprisingly is most concentrated across several vitamins and minerals, though fresh buttermilk, crème, and sour cream also show higher micronutrient levels (see Annex Tables B8 and B9). Fat-soluble vitamins again depend on animal diets and milk product (whole, low-fat, and skim). Whole milk contains bioavailable vitamin A. Raw cow's milk contains low levels of vitamin D (0.06µg/100g) compared to some TASF, but may be fortified in commercially available products. In terms of water-soluble vitamins, TASF milk provides high levels of vitamin B complex and some vitamin C.

The nutrient composition of other TASF milks beyond bovine has been analysed and described in the literature. One review suggested non-cattle milks may be more easily digested compared to cow's milk, likely due to softer curds formed in the stomachs of these animals during gastric digestion (Roy *et al.*, 2020). This effect may be explained by varying composition in other species' milks for casein compounds, fat globules, and protein-to-fat ratio. Another study compared the nutrient composition of multiple animal milks, including human milk (Gantner *et al.*, 2015). Investigators found that fat content varied the most, with more commonalities in content found in non-ruminants and human milk than ruminant milks. For example, the structure of fat globules and triacylglycerol was significantly different in ruminant milk compared to non-ruminants and human milk. Non-ruminant milk also contained higher percentages of unsaturated and lower saturated and monounsaturated fatty acids compared to ruminants.

Table B5 Nutrient composition of milk from mammalian livestock species and humans

Species	Value	Energy (kcal/kJ)	Carbohydrates (g)	Fibre (g)	Lactose (g)	Protein (g)	Fat (g)
Human	avg	71/295	7.1	0	nd	1.2	4.3
	range	70-71/291-298	6.9-7.2	0	nd	1.03-1.4	4.1-4.4
Buffalo	avg	99/412	nd	0	4.4	4	7.5
	range	71-118/296-495	nd	0	3.2-4.9	2.7-4.6	5.3-9.0
Cattle	avg	64/270	5.0	0	5.2	3.35	3.5
	range	61-69/256-290	4.8-6.1	0	4.6-6.1	3.2-3.5	5.3-9.0
Mithan	avg	122/510	nd	nd	4.4	6.5	8.9
	range	nd	nd	nd	4.1-4.6	6.1-6.8	7.7-10.3
Yak	avg	100/417	nd	nd	4.8	5.2	6.8
	range	nd	nd	nd	3.3-6.2	4.2-5.9	5.6-9.5
Goat	avg	70.6/295	4.4	0	nd	3.7	4.3
	range	69-74/288-308	4.4	0	nd	3.6-3.9	4.1-4.5
Sheep	avg	108/451	5.4	0	nd	6.0	7
	range	nd	nd	nd	4.4-5.2	4.4-6.6	5.6-6.2
Alpaca	avg	71/299	5.1	nd	5.1	5.8	3.2
	range	nd	4.4-5.6	nd	4.4-5.6	3.9-6.9	2.6-3.8
Bactrian camel	avg	76/319	4.2	nd	4.2	3.9	5
	range	nd	nd	nd	nd	3.6-4.3	4.3-5.7
Dromedary	avg	56/234	nd	nd	4.3	3.1	3.2
	range	44-79/185-332	nd	nd	3.5-4.9	2.4-4.2	2.0-6.0
Llama	avg	78/326	nd	nd	6.3	4.1	4.2
	range	nd	nd	nd	5.9-6.5	3.4-4.3	2.7-4.7
Reindeer	avg	196/819	nd	nd	2.9	10.4	16.1
	range	nd	nd	nd	1.2-3.7	7.5-13.0	10.2-21.5
Donkey	avg	37/156	nd	nd	6.4	1.6	0.7
	range	nd	nd	nd	5.9-6.9	1.4-1.8	0.3-1.8
Horse	avg	48/199	nd	nd	6.6	2	1.6
	range	nd	nd	nd	5.6-7.2	1.4-3.2	0.5-4.2

Note: avg = average; nd = not available; all values per 100g of milk.
Source: Australian Food Composition Database, 2021; Balthazar et al., 2017; FoodData Central USDA, 2021; Frida, 2021; Medhammar et al., 2012; Tabla de Composición de Alimentos Colombianos, 2021.

Following some evidence is being summarized on the nutritional composition of other dairy animals. One review examined the milk of buffalo, mare and dromedary milks at the level of breed and species-level data for yak, mithan, musk ox, donkey, Bactrian camel, llama, alpaca, reindeer and moose milks, quantifying interspecies nutrient values (per 100g): 0.70-16.1 total fat; 1.6-10.5 protein; 2.6-6.6 for lactose; and 67.9-90.8 for water (Medhammar *et al.*, 2012). Notable differences were observed for reindeer and moose milks containing the greatest concentrations in fat and protein, and minerals (calcium, sodium, phosphorus) in moose milk only. By contrast, mare and donkey milks showed the lowest concentrations of protein and fat, though a fatty acid profile in closer alignment to human nutrition requirements. Donkey milk has been reviewed for its low allergenicity due to low casein levels and whey proteins serving as bioactive peptides (Vincenzetti *et al.*, 2017). TASF sensitivity and allergy issues are addressed in Section C.

Buffalo milk comprises 12 percent of global milk production and contributes greater than half of milk consumption in India and Pakistan (Arora, Sindhu and Khetra, 2020). While the composition varies by genetics, nutrition, season, stage of lactation (see Subsection 5), it contains 6-12 percent fat, 4-5 percent protein, 4-5.5 percent lactose, 0.8 percent ash and the remainder water 82-83 percent water (see Table B5 for comparison of milk from cattle and buffalo). Another study also compared buffalo milk to cow’s milk, showing higher levels of fat, protein, calcium, vitamins A and C, but lower levels of vitamin E, riboflavin and cholesterol (Abd El-Salam and El-Shibiny, 2011). Fermented buffalo milk showed increased bacterial viability compared to cow’s milk in an in vitro experiment (Simões da Silva *et al.*, 2020).

Camel milk offers high quality nutrient food for populations living in arid and semi-arid regions particularly (Rahmeh *et al.*, 2019). One review of the nutrient composition of camel milk, inclusive of dromedary, Bactrian, and other camelids, on average showed high concentrations of vitamin C (up to 10 times comparing to cow milk), higher proportions of total salts, calcium, oligoelements including iron, copper, and zinc and low cholesterol (Benmeziane-Derradji, 2021).

In the analyses of comparative micronutrient composition, this assessment found the highest levels of vitamin A in retinol equivalents per 100g in the milks of Bactrian camel (97µg); buffalo (69µg); and sheep (44µg); and cow (43µg) (see Annex Table B10). Vitamin B12 concentrations per 100g were highest in the milk of: sheep (0.71µg); cow (0.46µg); and buffalo (0.45µg). Yak and dromedary milks showed high iron and zinc mineral levels relative to other TASF milks. The highest concentration per 100g of iron were in the milks of: yak (0.57mg); and dromedary (0.21mg), and zinc were: yak (0.90mg), Bactrian camel (0.70mg); and dromedary (0.60mg).

4.3 Meat and meat products

Meat and meat products from the following animal species are reviewed in this subsection and in the subsection on food from hunting and wildlife farming: cattle, buffalo, sheep, goat, pig, horse, rabbit, deer, chicken, turkey, quail, pheasant, duck, goose, pigeon and guinea fowl. This subsection covers animal tissues consumed that include muscle and offal (organs and any other edible non-muscle tissues). Some evidence in public health nutrition distinguishes between red (from species such as cattle, buffalo, goat, sheep, pig, dromedary, Bactrian camel, horse, donkey) versus white meats (from rabbits and avian species).

Meat, similar to eggs and milk, is considered a high quality protein food. The protein and amino acid composition of meat muscle tissue aligns well with human nutrition requirements, in part because it is similar to human skeletal muscle (Geiker *et al.*, 2021). Meat from muscle tissue contains an array of amino acids, including all essential ones (see Annex Tables B11 and B15 for comparison between meat and offals). It is most highly concentrated in glutamic acid and glutamine, followed by arginine, alanine, and aspartic acid (Williams, 2007). Cooking practices have been shown to influence the ileal amino acid digestibility (DIAAS). Regardless of processing type, the DIAAS for meat generally exceeds 100; overcooking, however, can lower the digestibility and reduce the DIAAS (Bailey *et al.*, 2020). Overcooking may lessen DIAAS (Bailey *et al.*, 2020). Poultry meats have been highlighted for the low content of collagen, a structural protein, as a favourable characteristic that enables digestion (Marangoni *et al.*, 2015).

The bioactive compounds of carnitine, creatine, taurine, hydroxyproline, and anserine – all present in meat – have been shown to confer positive health effects on human health as described above (Wu, 2020). Meat is the most abundant dietary source of taurine, serving as an antioxidant among other roles in human health (Williams, 2007). There is evidence that carnitine levels and metabolism increases during pregnancy and lactation and in the infants, potentially playing a critical role during the first 1000-day period (Manta-Vogli *et al.*, 2020).

Depending on multiple factors (e.g. animal diet, tissue types, ruminant versus non-ruminant), meat contains approximately: 50 percent of monounsaturated fatty acids; 40 percent of saturated fatty acids; 5 percent transfatty acids; and 4 percent of polyunsaturated fatty acids (see Annex Tables B12 and B16 for comparison between meat and offals). Some fatty acids found in meat include oleic (C18:1), palmitic (C16:0), and stearic acid (C18:0) (Valsta, Tapanainen and Männistö, 2005). Meat is also the primary dietary source of docosapentaenoic acid (DPA, C22:5 omega-3), available from mammals and poultry, but not fish (De Smet & Vossen, 2016). The evidence suggests potential health benefits associated with DPA in reducing chronic disease risk (McAfee *et al.*, 2010). One review noted that once poultry skin was removed, its meat can be a good source of unsaturated fats (Marangoni *et al.*, 2015). Meat, more broadly, can provide important long-chain fatty acids for human health, DHA and EPA (Mann and Truswell, 2017).

Animal diet shows a stronger association to the fatty acid composition of meat in monogastric animals compared to ruminants, explained by the metabolic degradation of fatty acids in the rumen (one of the stomachs of ruminants), absent in monogastric animals. Fatty acid composition in the diet reflects that of monogastric meat (see Subsection 5.1). Meat from ruminants, influenced by fermentation, lipolysis and biohydrogenation processes in the rumen, contain conjugated linoleic acid and unique branched-chain fatty acids with positive health implications (Geiker *et al.*, 2021; Vahmani *et al.*, 2020). Cooking can also change fatty acid composition. In a study examining beef and lamb meat, there was an increased in omega-3 and omega-6 polyunsaturated fatty acids with cooking (Purchas *et al.*, 2014).

Macronutrient composition of meats showed some differences apparent particularly when comparing meats from livestock species versus meats from wild animals (see Tables B6 and B7). The meats from wild animals tended to have greater concentrations of protein while meats from livestock species showed higher total fats. This was reinforced by findings described below in the next subsection on foods from hunting and wildlife farming. Protein levels per 100g were highest in: pheasant (23.6g); turkey (22.6g); and rabbit (21.6g) meats, while fat levels per 100g were greatest in: pork (65.7g); sheep (61g); and cattle (33.99g).

Table B6 Nutrient composition of meat from mammalian and avian livestock species

Species	Value	Energy (kcal/kJ/per100g)	Carbohydrates (g/per100g)	Protein (g/per100g)	Fat (g/per100g)
Cattle	avg	443/1819	nd	13.6	34.0
	range	276-592/1160-2478	nd	12.1-15.0	23.5-61.4
Water buffalo	avg	99/414	0	20.4	1.4
Sheep	avg	577.5/2418	0	9.5	61.0
	range	553-577/2315-2522	nd	8.2-10.8	57.6-64.6
Goat	avg	276/1155.5	0	32.8	23.5
	range	109-443/456-1855	nd	12.2-20.6	2.31-44.6
Pig	avg	632/2640	0	9.3	65.7
Horse	avg	133/556	0	21.4	4.6
Rabbit	avg	124.5/520.5	0	21.6	3.6
	range	113-136/472-520.5	nd	20-23.2	2.1-5.6
Deer	avg	120/502	0	23.0	2.4
Chicken	avg	243/1020	0	14.7	20.0
Turkey	avg	115/479	0	22.6	1.9
Quail	avg	153/641.5	0	20.2	7.8
	range	134-172/561-722	nd	18.5-21.8	4.5-11.0
Pheasant	avg	133/556	0	23.6	3.6
Duck	avg	128/536	0.5	18.1	5.8
	range	121-135/506-566	0-0.1	17.8-18.3	5.5-6
Goose	avg	161/674	0	22.8	7.1
Pigeon	avg	216.5/906.5	0	16.9	16.7
	range	142-291/594-1219	nd	16.2-17.5	
Guinea fowl	avg	110/460	0	20.6	2.5

Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.
Note: nd = not available; avg = average.

Meat is among the most important food sources for the critical limiting minerals in diets globally, iron and zinc. Iron in meat is generally complexed as heme iron that is absorbed at higher rates, on average 25 percent (range 15-35 percent), when compared to non-haem iron predominantly found in plant-based food, 2-3 percent (Gropper, Smith and Carr, 2021). Older analyses have demonstrated comparable ranges of absorption, ranging from 15–25 percent from heme iron compared to 5–12 percent from non-heme iron (Carpenter and Mahoney, 1992; Hallberg, 1983; Hurrell and Egli, 2010). Zinc supplied by meat is also more bioavailable than from plant-based food (Gropper, Smith and Carr, 2021). Other important minerals in meat include selenium, copper, and phosphorous. Fresh or unprocessed meat is low in sodium. Similar to other TASF, meat provides vitamin B12 and a range of other B vitamins – primarily vitamin B3 (niacin) and vitamin B6 and secondarily vitamin B6 (riboflavin) and vitamin B5 (pantothenic acid). Poultry meat has been highlighted for its contents in vitamin B1 (thiamine), vitamin B6 and vitamin B5. All organ meats are rich in vitamin B12, except tripe (Williams, 2007). Choline and DHA are found in highest concentrations in the liver (Enser *et al.*, 1998). Liver also offers high concentrations of vitamin A in its bioavailable form of retinol, iron, and folate. The vitamin D metabolite, 25-hydroxycholecalciferol, is provided by meat with evidence for high biological activity (Williamson *et al.*, 2005).

In the analyses comparing the micronutrient concentrations of various meats (including some meats from wild animals), high concentrations are observed per 100g of iron in cattle (3.48mg); pigeon (3.45mg); deer (3.40mg); and turkey (3.45mg) (see Annex Tables B13 and B17). For zinc, the meats showing the highest concentrations per 100 g, were: horse (2.9mg); goat (2.6mg); cattle (2.4mg); and goose (2.34mg). More differences emerged for vitamins (see Annex Tables B14 and B18). Vitamin A in retinol equivalents per 100g was particularly high in pheasant (50µg) and pigeon (51µg), followed by sheep (42µg) and goat (33µg). Goose and pigeon meat showed highest concentrations per 100g of vitamin C, 7.2mg and 6.1mg, respectively. In terms of vitamin B12, deer (6.31µg) and horse (6.23µg) meats showed the highest concentrations per 100g.

Other studies have done comparative analyses of micronutrients among meats. One review of various meats consumed in Australia and New Zealand showed mutton was especially dense in nutrients with biological value compared to beef, veal and lamb (Williams, 2007). Recent reviews of the evidence present the characteristics of some lesser consumed meats such as sheep and goat processed meat (Teixeira *et al.*, 2020), pheasant, quail and guinea fowl (López-Pedrouso *et al.*, 2019) and camelids of South America (Popova *et al.*, 2021).

4.4 Food from hunting and wildlife farming

Consumption of meat from hunted animals (game) or meat from farmed wild animals has been increasing throughout the last two decades (Costa *et al.*, 2016). FAO defines the term wild meat as: "*terrestrial animal wildlife used for food in all parts of the world*" (FAO, 2019). The European Union defines wild game under the EU Regulation No. 853/2004 as being "*wild ungulates and lagomorphs, as well as other land mammals that are hunted for human consumption and are considered to be wild game under the applicable law in the Member State concerned, including mammals living in enclosed territory under conditions of freedom similar to those of wild game, and wild birds that are hunted for human consumption*".

Particularly in high-income countries, demand has increased for these food as perceived to be healthier leaner meat, free of antibiotics and hormones. In some LMICs, populations depend on hunting and wildlife farming for food security. Serious concerns have been raised about the environmental impacts of hunting practices (legal and illegal), as a factor of depletion of wildlife, largely driven by urban demand for wild meat and human encroachment of wildlife areas. It is estimated that 20 percent of the species (>300 mammals) on the IUCN Red List of threatened or near threatened are those hunted in the wild. A review reports 301 mammals threatened by hunting, all found in LMICs and only eight of these species were also found in HICs (Ripple *et al.*, 2016). Moreover, almost 72 percent of emerging infectious diseases transmitted by animals (zoonotic), originate from wildlife (Jones *et al.*, 2008).

Hunting increases the exposure to wildlife and the risk of zoonotic diseases, and the consumption of meat from wild animals is associated to food safety risks when handling and cooking do not follow food safety practices and as meat from wild animals may be contaminated by chemical residues (toxic metals and polycyclic aromatic hydrocarbons) (Van Vliet *et al.*, 2017) (see also Section D). However, many populations depend on hunting and wildlife farming for food security to supplement cultivation and livestock production or where these practices are not possible (Hoffman and Cawthorn, 2012). One recent study showed 15 countries at risk for food insecurity from prohibitions of meat from hunting and highlighted the trade-offs in terms of lost species with land-use for agricultural land (Booth *et al.*, 2021). In South America, an estimation of 5-8 million people regularly rely on meat from wild animals as a source of protein (Rushton *et al.*, 2005). Hunted animals range across multiple species: ungulates, rodents, rabbits and hares, kangaroos, reptiles, birds and bats. One study in the Congo Basin estimated that 40 million tonnes of bush meat are harvested each year (Van Vliet *et al.*, 2017).

One review of meat from wild animals examined nutrient compositional differences across representative species (Costa *et al.*, 2016). Total protein concentrations do not vary significantly, but some meats are higher on average – the common duiker (*Sylvicapra grimmia*), 25.0g/100g; hare (*Lepus europaeus*), 24.7g/100g; wild rabbit (*Oryctolagus cuniculus*), 23.7g/100g; elk (*Alces alces*), 22.7g/100g; red deer (*Capreolus capreolus*), 22.8-25.7g/100g; and fallow deer (*Dama dama*), 22.0g/100g (see Table B7**)** (Costa *et al.*, 2016). Fatty acids range with some species showing notably higher total fat concentrations: pigeon

(*Columba livia*), 4.32-7.85g/100g; and springbok (*Antidorcas marsupialis*), 2.5-5.3g/100g; and fallow deer (*Dama dama*), 2.5g/100g.

Table B7 Examples of protein and fat composition of meat from wild animals

Species		Protein (g/100g)	Fat (g/100g)
Ungulates			
Kudu	*Tragelaphus strepsiceros*	23.6-24,3	1,56–1,58
Impala	*Aepyceros melampus*	18.9–20.0	1,2–4,3
Springbok	*Antidorcas marsupialis*	17.4–18.4	2,5–5,3
Blesbok	*Damaliscus dorcas phillipsi*	19.3–22.4	0,21–6,8
Common duiker	*Sylvicapra grimmia*	25.7	2.12
Red reed	*Cervus elaphus*	21.7	0.6
Fallow deer	*Dama*	22.0	2.5
Roe deer	*Capreolus*	22.8–25.7	1,0–2,1
Elk	*Alces*	22.7	1.33
Mouflon	*Ovis ammon*	22.9–22.3	0.6 –1.0
Wild boar	*Sus scrofa*	21.4 – 23.6	1.1 – 4.4
Leporidae			
Wild rabbit	*Oryctolagus cuniculus*	23.7	0.2
Hare	*Lepus europaeus*	24.7	1.5
Game birds			
Quail	*Coturnix japonica*	22.9–22.9	2.3–2.3
Pheasant	*Phasianus colchicus*	22.2–25.3	0.1–0.4
Pigeon	*Columba livia*	20.6–23.6	4.3–7.9

Source: Adapted from Costa et al. (2016)

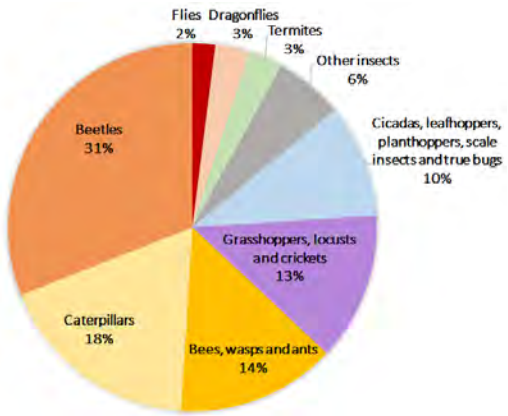
Other studies have examined differences in nutrient concentrations across meat from wild animals or comparatively with livestock species. Meat from wild animals from Europe including red and fallow deer, wild boar, hare and wild rabbit, were reviewed for nutritional characteristics (Soriano and Sánchez-García, 2021). These meat were found to have high protein and low fat content. Compared to other meat from livestock species, the wild sources showed higher proportions of omega-3 and polyunsaturated fats generally, and lower omega-6/omega-3 ratios (around 4) in the wild ruminants. High nutrient densities were found for phosphorous, potassium, zinc, and iron as well vitamin E and the vitamin B complex. Another study compared meat from red and fallow deer with Aberdeen Angus and Holstein cattle (Bureš *et al.*, 2015). They found lower total levels of crude fat and collagen and higher polyunsaturated to saturated fatty acid ratios in the venison meat comparatively. The atherogenic index measuring the composite of triglycerides and high-density lipoprotein cholesterol, was also lower in the venison compared to beef. The fatty acid profiles were found to be similar between North American and African ruminants and pasture-fed cattle, but different from grain-fed cattle (Cordain *et al.*, 2002).

Several studies were found for this review that examined the nutritional composition of meat from wild animals specific to certain regions: wild fallow deer (*Dama dama*) from South Africa (Cawthorn *et al.*, 2020); wild axis deer (*Axis axis*) from Croatia (Kelava Ugarković *et al.*, 2020); wild boar in Italy (Russo *et al.*, 2017); hunted birds and game by Eastern James Bay Cree people of Quebec, Canada (Proust *et al.*, 2016); European game meat (Valencak *et al.*, 2015); wild boar in Latvia (Strazdiņa *et al.*, 2014); wild ungulates from Italy (Ramanzin *et al.*, 2010); and meats from wild animals in Nigeria (Abulude, 2007).

4.5 Insects and insect products

Insects are increasingly recognized for their value and potential for human health and nutrition, but as well for environmental sustainability and livelihoods (Nowakowski *et al.*, 2021). FAO estimates that over two billion people include insects in their diets from over 1900 species (Huis *et al.*, 2013). The most commonly consumed insects are: beetles (*Coleoptera* 31 percent); caterpillars (*Lepidoptera* 18 percent); bees, wasps and ants (*Hymenoptera* 14 percent); grasshoppers, locusts and crickets *Orthoptera* 13 percent); and cicadas, leafhoppers, planthoppers, scale insects and true bugs (*Hemiptera* 10 percent) (see Figure B2). Entomophagy, or consumption of insects, has been integral to hominin evolution and remains today a practice in many cultures (de Carvalho, Madureira and Pintado, 2020). However, barriers to consumption and consumer acceptance of insects and insect products have been described, such as neophobia and disgust (Jantzen da Silva Lucas *et al.*, 2020; Onwezen *et al.*, 2021). Some studies have focused on practices in certain countries such as Ghana (Parker *et al.*, 2020), Indonesia (Adámková *et al.*, 2017) and Kenya (Kinyuru *et al.*, 2015). These issues surrounding culture, consumer demand and acceptance of insect will be covered in Component Document 2 of this Assessment. The environmental sustainability features (e.g. low feed conversion rates) will be covered in Component Document 3.

Figure B2 Insects consumed by humans by biological classification



Source: Based on Jongema (2017).

The nutritional composition of insects depends on the stage of metamorphosis for some, sex, habit and feed. For example, larvae and pupae stages tend to show higher energy and fat levels than adult insects; female insects also have significantly higher concentrations of fat and energy compared to males. Relative to other TASF, insects show comparable levels of critical nutrients (Orkusz, 2021). In a review comparing commonly consumed insects and TASF, authors showed some insect species indicating higher protein, polyunsaturated fatty acids and cholesterol concentrations, while there were lower levels of saturated and monounsaturated fatty acids, thiamine, niacin, cobalamin and iron compared to other TASF. Insect content of vitamin C and dietary fibre was also highlighted for possible health advantages conferred by insects in the diet.

In terms of macronutrients, many insect species are recognized for their high concentration of protein and healthy fats (Churchward-Venne *et al.*, 2017). One review of 236 species showed edible insects could supply protein, monounsaturated and/or polyunsaturated fatty acids, in quantities to meet human requirements (Rumpold and Schlüter, 2013). Another more recent review explored the potential for insect farming both in terms of human nutrition and animal feed (Hawkey *et al.*, 2021). Investigators compared the macronutrient content of ten commonly used insects, demonstrating high percentages of protein in the Orthoptera order and Diptera (flies) orders, reaching 51–76 percent. By contrast, fat content was proportionally lower than protein across all orders, with some species exceptions: super worm (*Zophobas morio*), 44 percent; and greater wax moth (*Galleria mellonella*), 51.4–58.6 percent. They also contain several bioactive compounds (Jantzen da Silva Lucas *et al.*, 2020). In a study examining insect 212 species from Africa, investigators found that Lepidoptera had the highest protein (20–80 percent) and fat content (10–50 percent), while Coleoptera had the highest carbohydrate content (7–54 percent) (Hlongwane, Slotow and Munyai, 2020).

Insects and insect products have been reviewed for their micronutrient content as well. A systematic review of edible insects globally highlighted the wide-ranging content of nutrients found in insects (Weru, Chege and Kinyuru, 2021). Drawing data from 91 species, this study found that among the minerals, potassium was especially high across multiple species and copper levels were relatively low. For vitamins, insects showed higher concentrations of vitamin E and lower vitamin C. Some studies have highlighted the potential for insects in mitigating iron and zinc deficiencies globally. In one analysis, they showed that levels of these minerals across commonly reared and wild harvested insects were similar or higher than other TASF (Mwangi *et al.*, 2018). Authors noted, however, that the iron and zinc in insects are derived from non-heme compounds and thus the bioavailability is unknown.

Insect products, natural or fabricated, have also been the subject of study for human health and nutrition outcomes. Honey has been a valuable source of energy and nutrients for millennium to Homo species (Marlowe *et al.*, 2014). In recent years, honey produced by the honeybee and stingless bees, has been recognized for its anti-inflammatory and antioxidative factors as well as nutritional advantages (Alvarez-Suarez, Giampieri and Battino, 2013; Ranneh *et al.*, 2021) (see Table B8). Specifically, the flavonoids and phenolic acids in honey likely function in antioxidant and anti-inflammatory processes (Cianciosi *et al.*, 2018; Khalil, Sulaiman and Boukraa, 2010; Machado De-Melo *et al.*, 2017). Other studies have found honey may confer antidiabetic effects and protect cardiovascular health (Cianciosi *et al.*, 2018). Insect powders and processed products produced from drying, fermentation, among other technologies are being considered for meeting nutritional needs and mitigating malnutrition globally (Kewuyemi *et al.*, 2020; Melgar-Lalanne, Hernández-Álvarez and Salinas-Castro, 2019).

Table B8 Description of bee products and their functional properties

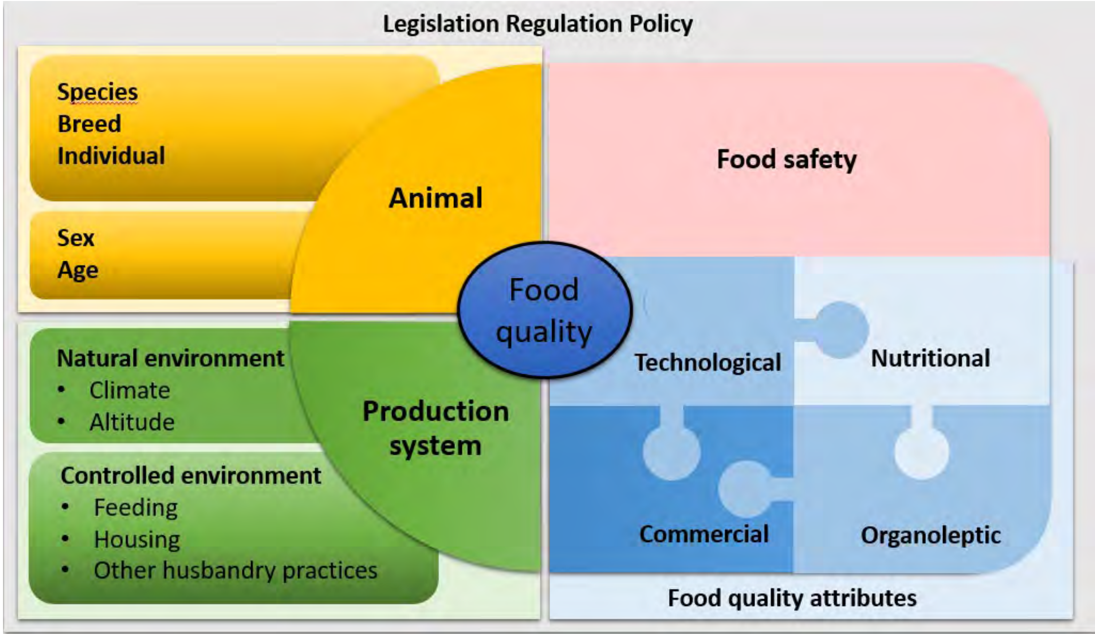
Bee product	Description	Functional properties
Honey	Natural sweet substance produced by honeybees from the nectar of plants or from secretions of living parts of plants or excretions of plant sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in the honey comb to ripen and mature	Antimicrobial activity and antioxidant capacity
Pollen	Bee's main source of protein to feed the larvae in the brood; the protein content varies between 7-35 percent	Used in order to desensitize allergic patients and for the treatment of various prostate problems
Propolis	Mixture of resins from trees and secretions from bees, a combination that yields a natural antibiotic is made by bees from tree resin and mixed with wax, honey and enzymes	Antioxidant, antimicrobial and antifungal activities
Royal Jelly	Secretion produced and used to feed queen bees and the larvae bees with high nutrient content	Used as dietary supplement due to its assumed stimulant and therapeutic value

Source:(Alvarez-Suarez et al., 2010; FAO and WHO, 2019b; Krell, 1996).

5 Differences in nutrient content and quality due to animal characteristics and husbandry

This subsection explores how intrinsic characteristics of animals such as genetic traits, sex and age, livestock husbandry practices and other aspects of production systems determine the nutrient composition and quality of TASF. Livestock husbandry practices encompass methods and measures applied by the producer. They include among others feeding, reproductive management, housing, health and welfare care from birth until slaughter. The definition of food quality refers to the attributes of a food that influence its value and that make it acceptable or desirable for the consumer (FAO and WHO, 2003). According to Prache *et al.* (2021) classification and definitions, different attributes of food quality are often intertwined and can be considered with associated synergies and antagonism. Nutritional attributes are based on the nutrient composition and bioavailability which impact on human health. In addition, organoleptic attributes relate to the sensorial experience of the consumer (e.g. taste, texture). Producers often get paid on the basis of commercial attributes including criteria like quantity and composition (e.g. protein and fat content, marbling of meat, production system). Food safety is linked to factors such as the absence or below threshold level of food-borne pathogens (e.g. poor hygiene practices during milking), harmful chemical or physical substances. The technological attribute refers to the suitability of raw TASF for preservation and processing. The types of factors that impact food quality of unprocessed TASF, i.e. the characteristics of the animal and the production system, are summarised in Figure B3. The degree of impact of each factor is further detailed in Table B9.

Figure B3 Factors impacting food quality and food quality attributes of unprocessed TASF



Genetic selection and livestock husbandry practices directly influence the nutritional content of TASF, and also play a substantial role in other aspects of food quality and safety or technological quality. Thus, the impacts of a given factor on different food quality attributes can be universally beneficial (synergetic), detrimental or a combination (antagonistic). These associations are developed further in Subsection 5.3.

Table B9 Impact of animal characteristics and producer practices on food quality attributes and food safety

Factors		Food safety	Food quality attributes			
			Nutritional	Organoleptic	Technological	Commercial
Animal characteristics	Genetic make-up		+	+	++	++
	Sex			+		++
	Lactation stage		+		+	+
	Age at slaughter	+	+	++	++	++
Production practices	Natural environment (climate, altitude)	+	+			+
	Feeding	+	++	++	++	++
	Housing	+	+	+		
	Husbandry practices*	++			+	+
	Transport	+	+	+	++	+

Adapted from Prache et al., 2021
*Note: *Husbandry practices refer among others to health care and good hygiene including biosecurity measures, feed safety, water management, milking management and hygiene and welfare practices.*

5.1 Intrinsic characteristics of animals impacting nutritional properties and quality of TASF

Protein and fat are the most important macronutrients provided by TASF. The impact of various factors on the variability in these nutrients has been studied extensively in livestock species. Micronutrients, such as vitamins, have been studied to a lesser degree. The breed of an animal and its individual genetic traits, as well as other intrinsic characteristics of animals such as age and sex, have been shown to impact the quality of TASF.

5.1.1 Impact of genetic traits

Genetic variation of the nutrient composition is described in meat, followed by eggs and milk. Table B10 further details the impact of breed on nutritional quality per species and type of TASF.

With the exception of chicken and to a lesser degree with milk, little genetic variation of the protein content of TASF has been reported for most livestock species. However, fat content and fatty acid profile can vary substantially among and within breeds and has been studied fairly extensively and has been considered in breeding decisions. For example, for pigs, in different periods throughout history genetic improvement schemes have frequently aimed to either increase or decrease the leanness of their meat, depending on market demand. In chickens, commercial broiler lines have been intensely selected for fast growth and leanness. Broiler meat breeds with slower growth rates are generally fatter and tend to have higher total PUFA content in the meat (Baéza, Guillier and Petracci, 2021; Mahiza, Lokman and Ibitoye, 2021).

Locally adapted breeds can have different nutrient contents than animals of international transboundary breeds subject intensive selection programmes. For example, higher fat content (by 26 percent) has been found in eggs of a local Spanish chicken breed compared to commercial laying hens (Franco *et al.*, 2020). Higher levels of PUFA in TASF, especially omega-3, and lower omega-6/omega-3 fatty acids ratios are preferred for human nutrition (see Subsection B.3). Meat from local breeds has been associated with this beneficial fatty acid profile compared to international sheep breeds (Van Harten *et al.*, 2016), duck (Onk, 2019) and pig (Kim and Kim, 2018). The higher fat content and specific fatty acid profile found in Iberico pigs, is desired for dry-cured ham processing and related to a better technological and organoleptic quality. Intramuscular fat content in Iberico pig meat was more than twice that in meat from Berkshire pigs (Ali *et al.*, 2021). The omega-6/omega-3 ratio, the PUFA content and linoleic acid content in Iberico were at least half of that of Berkshire. A high fat content and a low content of linoleic acid enable slow dehydration during the curing process (Ali *et al.*, 2021; Prache *et al.*, 2020b). The breed effect related to the variability of nutrient composition needs to be considered along with the feeding system and the geographical area where livestock is raised (Barnes *et al.*, 2012; Belhaj *et al.*, 2020) (see Subsection B.5.2).

Nutritional quality also depends on the cut of meat. Cuts from the loin or rear legs usually have much lower fat content than cuts from the belly, for example. Comparison of nutritional value of the same meat cut can be made between different breeds or species (Barnes *et al.*, 2012). Organ meats are particularly nutrient-dense compared to other meat (see Subsection B.4.3). However, information is poor on the variability of the nutritional content of organ meat related to breed and animal characteristics. A variation of the fatty acid profile in kidneys between sheep breeds was reported by Nguyen *et al.* (2017), with an omega-3 DHA proportion 19 percent higher in purebred Merinos than in White Suffolk Corriedale crossbred animals. However, the total lipid percentage and fatty acid profile of liver did not differ between breeds.

Variation of intramuscular fat content related to the palatability of the meat (marbling) has been reported within populations and between cattle breeds (Park *et al.*, 2018). It impacts both nutritional and organoleptic quality. Fat content varies between meat cuts in carcasses of different breeds, which has an effect on the organoleptic qualities (FAO, 2015a; Prache, Schreurs and Guillier, 2021). The fatty acid profile between subcutaneous and intramuscular fat in beef is documented with a minimum of threefold higher PUFA omega-6 and omega-3 content in intramuscular fat and a higher percentage of MUFA in subcutaneous fat (10-30 percent increase), independend from the diet (concentrate, forage) (Alam, Rana and Akhtaruzzaman, 2017; Indurain *et al.*, 2006; Orellana *et al.*, 2009).The higher the fat content of the carcass, the lower the PUFA omega-6 proportion in its intramuscular fat.

The fat content and fatty acid profile of the milk of animals is determined by their genetic make-up, thus species and breed. In most instances, this is a concentration effect. For instance, the Jersey dairy breed has a smaller milk productive potential than the Holstein Friesian but higher fat and protein contents in milk (Stocco *et al.*, 2017). Exceptions to this rule can be found, however. The Simmental breed produced higher milk yield with about 10 percent higher fat content than Italian local breeds (Rendena and Alpine Grey) (Stocco *et al.*, 2017). Although breed is an important source of variation in fat content, within breed variation in cow individuality and the stage of lactation tend to have a greater effect on milk fat composition than breed (Samková *et al.*, 2011). Beyond overall fat content, the composition of fat globule in milk varies between cattle breeds and impacts on the technological quality to make butter (Martini, Salari and Altomonte, 2016) (see Box B5) although nutritional quality is generally not affected.

Box B5 Fat globules in the milk impact on food quality

Fat globules in the milk impact on the technological, organoleptic and nutritional quality of milk products (Fleming *et al.*, 2017; Martini, Salari and Altomonte, 2016). The factors of variation of the composition are: species, breed, stage of lactation and season. The average fat globule size is generally lower in small ruminant species (goat and sheep), compared to cattle (Felice *et al.*, 2021). Milk fat globules are associated with a potential health benefit (immune system) and are used as supplement in infant nutrition (Fontecha *et al.*, 2020). Differences of diameter and number of globules result in variation of fat globule membrane surface, which may have a role in lipid and milk digestion and absorption, as well as anti-inflammatory action. Milk fat globules are also of particular interest in the manufacturing of cheeses, as the interaction between the surface of milk fat globule and the casein matrix influences both the structure and texture of the product. A higher diameter is better for butter production and certain types of cheese and is found in Jersey and Norman cattle for example. The smaller diameter of fat globules in goat milk contributes to the softer texture of goat's cheese compared to cow's milk (Martini, Salari and Altomonte, 2016). There is an association between the fat secreted and the average diameter of the milk fat globules.

Certain genes are known to be directly linked to quality traits and are targeted in genetic selection programmes to improve the commercial quality of TASF. In particular, a mutation of the myostatin gene can be associated with "doubled-muscle" animals with muscle hypertrophy (on average 20 percent heavier), lean carcass and more tender meat (Allais *et al.*, 2010; De Smet, Raes and Demeyer, 2004; Węglarz *et al.*, 2020). Double-muscled animals are well-represented in Belgian Blue and Charolais breeds. Reduced development of intramuscular fat is known for animals with a high muscularity (Hocquette *et al.*, 2010). Double-muscled animals display lower total fat, ca 50 percent lower proportion of saturated fatty acids, and a higher proportion of PUFA. Genes affecting milk composition have also been subject of research. A meta-analysis of Bangar *et al.* (2021) showed that B allele of kappa casein gene (milk protein) is associated with higher fat percentage in cow milk than allele A. Improving the traits that underlie meat and milk quality is a major challenge in the meat and milk industry and will be further discussed in Subsection 5.3.1.

Table B10 Impact of genetic traits on nutrient composition of food product by nutrient group, food product and species

Nutrient group	Food product	Species	Impact on nutrient composition of food product	Reference
Fat and fatty acids	Egg	Chicken	Higher percentages of SFA (14 percent more) and MUFA (50 percent more) in eggs from local Italian breeds;	Ianni *et al.*, 2021
			Higher content of fat (26 percent more) in eggs of local Galician (Spanish breed);	Franco *et al.*, 2020
			Constant fatty acid profile between 4 Portuguese and a hybrid population;	Lordelo *et al.*, 2020
	Meat	Cattle (*Bos taurus* and *Bos indicus*)	Variation of degree of muscling, intramuscular fat content (link to marbling score), fatty acid profile, meat aroma, juiciness and tenderness between breeds selected for dairy and beef production (e.g. Nordic Red Cattle/ Aberdeen Angus);	De Smet, Raes and Demeyer, 2004; Iso-Touru *et al.*, 2018; Sevane *et al.*, 2014
			Variability between *Bos taurus* and crossbred *Bos taurus indicus/ Bos taurus* in intramuscular fat content and fatty acid profile (saturated fatty acids);	Elzo *et al.*, 2012; Rubio Lozano *et al.*, 2021
		Chicken	Commercial hybrids with slower growth rates are generally fatter than crossbred genotypes because they have not been selected for leanness and they tend to have higher total PUFA content in the meat;	Baéza, Guillier and Petracci, 2021; Mahiza, Lokman and Ibitoye, 2021
			Lower lipid content (one third) in indigenous purebred chicken in comparison to hybrid chicken; genotype effect	Dalle Zotte *et al.*, 2020

			observed for higher level of lipid and protein oxidation which curtails protein bioavailability;	
		Duck	Breast meat of native Turkish ducks 6 percent higher PUFA, omega-6 proportion than Peking ducks;	Onk, 2019
		Pig	Higher fat content (twofold), better fatty acid profile with 20 percent higher level of oleic acid (MUFA), 7 percent higher palmitic acid (SFA) and alomost 50 percent lower omega-6/ omega-3 fatty acids ratio in meat from Iberico compared to Landrace, Yorkshire and Duroc with higher saturated stearic acid;	Ali *et al.*, 2021
			Native Korean pigs associated with 57 percent higher PUFA content;	Kim and Kim, 2018
		Sheep	Fat-tail sheep high proportions of PUFA in fat tail adipose tissue, gastrocnemius muscle and 50 percent higher level of omega-3 fatty acids in *longissimus dorsi* muscle;	Alves *et al.*, 2013; Van Harten *et al.*, 2016
			Tibetan sheep (high altitude dryland with scarce and low-protein content pasture) associated with superior fatty acid profile compared to Small-tailed Han (from northern China), with higher omega-3 PUFA and at least three times lower omega-6/ omega-3 PUFA ratio in meat of indigenous breed and higher concentrations of essential omega-3 fatty acids (alpha-linolenic acid, EPA and DHA);	Jiao *et al.*, 2020
Protein and amino acid	Egg	Chicken	Higher protein and higher yolk cysteine content in eggs from indigenous breed compared to hybrid population in same environment and with same feeding;	Franco *et al.*, 2020; Mori *et al.*, 2020
			Genetic variability impacts on yolk/albumen ratio;	Prache *et al.*, 2020
	Meat	Cattle Sheep Pig	Little genetic variation observed;	Prache *et al.*, 2020; Suliman *et al.*, 2021
		Chicken	Significantly lower (3-14 percent) protein content in high breast yield strain compared to standard breast yield hybrid and higher in indigenous chicken;	Dalle Zotte *et al.*, 2020; Petracci *et al.*, 2013
			Quality defects such as “white striping” or “wooden breast” associated with 7-18 percent decrease in muscle protein content and up to 11 percent increase in collagen content with genetic selection of growth rate in broilers;	Baéza, Guillier and Petracci, 2021
Fat and protein content	Milk	Cattle Goat Sheep	Fat and protein content higher in milk of Alpine goats compared to Saanen, and Norman and Jersey cattle compared to Prim’Holstein; Individual variability in milk composition (fat and protein) between animals of same breed, physiological status and feeding; Individual variability greater than variation between breeds;	Prache *et al.*, 2020; Samková *et al.*, 2011
		Cattle	Variation of milk fat globule size varies between breeds e.g. higher for Jersey cattle (see Box B5);	Martini, Salari and Altomonte, 2016
		Dromedary	Milk fat and protein composition varies between populations from Sudan, Saudi Arabia, Jordan;	Burger, Ciani and Faye, 2019
Vitamin	Milk	Cattle	Vitamin A content in milk varies between breeds, with 10-16 percent lower level in Holstein Friesian, compared to local breeds;	Weir *et al.*, 2017
			Beta-caroten (vitamin A precursor) milk content is up tp twofold higher in Jersey breed than Prim’Holstein	Prache *et al.*, 2020
		Sheep	Fat carotenoid content varies between breeds (differences in absorption, transfer into plasma and storage in body fat);	Macari *et al.*, 2017
	Meat	Cattle	No variation in vitamin E;	Juárez *et al.*, 2021

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5.1.2 Impact of non-genetic differences

Non-genetic differences among individual animals can also affect the nutritional quality of TASF. The sex of the animal and the time at which the TASF product is harvested are two factors that have been identified. Table B11 summarizes some examples of the impact on nutritional quality by type of TASF and species.

The sex of the animal influences the lipid content of resulting meat products and thus both the nutritional and the organoleptic quality. Females and castrated males have higher intramuscular lipid content. Sex hormones play a role, which is particularly noticeable between castrated and uncastrated animals. Meat from uncastrated boars may express an unpleasant odour (so called "boar taint") when heated due to the presence of skatole and androstenone in the adipose tissue (Lebret and Čandek-Potokar, 2021). Androstenone is a steroidal pheromone produced in the testicles and triggers urine odour whereas skatole, produced in the digestive tract of boars, is associated with faecal odour. Castration of piglets is a growing animal welfare concern. Research is ongoing on genetic selection of boars with low hormone levels.

The age of an animal at slaughter influences the fat content, fatty acid profile and protein content of its carcass. The variability of impact of age on protein content depends on the selected age groups in the studies and the species specific age at maturity. The fat content of meat generally increases with age. Also the haemoprotein content in red meat is higher in carcasses of older animals (Baéza, Guillier and Petracci, 2021; Polidori *et al.*, 2017; Schönfeldt, Naudé and Boshoff, 2010). Genetic selection on growth rate and carcass yield in chicken has led to a decrease of the slaughter age and thus an increase of the moisture/protein content ratio in the standard retail product (Baéza, Guillier and Petracci, 2021).

In addition to food nutritional quality attributes, food safety can also be affected by age. Chemical residues and environmental pollutants tend to be higher in carcasses at higher age at slaughter, as the exposure time and thus the risk of accumulation increases with age (Prache *et al.*, 2020b). The potential accumulation of undesirable heavy metals such as arsenic or cadmium along the animal life curtails the quality of milk, eggs, meat and offals (Hejna *et al.*, 2018).

Table B11 Impact of sex and age on nutrient composition of food by food product and species

Factor	Food product	Species	Impact on food quality	Reference
Sex	Meat	Pig	At the same backfat thickness, lower lipid content and higher proportion of omega-6 (linoleic acid) in subcutaneous adipose tissue from uncastrated males compared to females;	Wood *et al.*, 2008
		Geese	Higher PUFA (up to 8 percent) and omega-6 (up to 9 percent), essential alpha-linoleic acid omega-3 (up to 19 percent) contents in females than males; lower (up to 9 percent) PUFA omega-6/PUFA omega-3 ratio values in males;	Uhlířová *et al.*, 2019
		Cattle	Lower fat in males than females; Higher intramuscular fat in females than castrated and uncastrated males; Meat more tender with higher MUFA content in females;	Venkata Reddy *et al.*, 2015
		Goat Sheep	Higher fat deposition, lower total PUFA content (by 27 percent) and lower omega-6/omega-3 ratio (by 37 percent) in meat from castrated males than intact males;	Madruga, Arruda and Nascimento, 1999; de Mello Tavares Lima *et al.*, 2019
		Cattle (*Bos taurus* and *Bos indicus*) Buffalo	Higher PUFA, PUFA omega-6 and omega-3 content (about 40 percent) in males than castrated males; higher (nearly fivefold) essential omega-3 DHA and lower (31 percent) alpha-linolenic acid omega-3 in castrated males than intact males;	Giuffrida-Mendoza *et al.*, 2015
		Pig	Unpleasant odour due to skatole and androstenone in adipose tissue in uncastrated males;	Lebret and Čandek-Potokar, 2021
Stage of lactation	Milk	Buffalo	Decrease in protein and casein percentage reported in the mid stage (4–5 months) of Murrah compared to earlier or later lactation stage;	Arora, Sindhu and Khetra, 2020

Factor	Food product	Species	Impact on food quality	Reference
		Cattle	Fat and protein content inversely related to milk quantity;	Prache *et al.*, 2020
			Variation of fat composition higher in early lactation (<100 days in milk);	Samková *et al.*, 2011
		Donkey	Protein and casein content higher in first month of lactation (compared to the 6^{th}; 12 percent and 10^{th} month; 25 percent); No significant variation of fat content during lactation;	Salari *et al.*, 2019
Laying age	Egg	Chicken Duck	With age yolk weight increases and albumen weight decreases;	Onbaşılar *et al.*, 2014; Prache *et al.*, 2020
Age at slaughter	Broiler meat	Chicken	Decrease of slaughter age due to genetic selection on growth rate leads to increase of moisture/protein ratio;	Baéza, Guillier and Petracci, 2021
	Red meat	Cattle Duck Sheep	Haemoprotein content, especially myoglobin increases with age; Higher concentration of myoglobin makes meat darker;	Baéza, Guillier and Petracci, 2021; Prache *et al.*, 2020
		Cattle	Iron and palmitic acid (SFA) increases with age (by 41 and 8 percent respectively) while linoleic acid (omega-6 PUFA) decreases (by 50 percent) with age;	Schönfeldt, Naudé and Boshoff, 2010
	Meat	Cattle Sheep	Fat tissue carotenoid concentration increases with age; Age effect on tenderness depends on the muscle (muscles with less collagen show less impact of age); Stronger flavour with age;	Prache *et al.*, 2020; Prache, Schreurs and Guillier, 2021
		Alpaca Cattle Donkey Dromedary Duck Goat	Higher tenderness in young animals;	Baéza, Guillier and Petracci, 2021; Guerrero *et al.*, 2017; Kadim *et al.*, 2006; Polidori *et al.*, 2015; Popova *et al.*, 2021; Prache *et al.*, 2020
		Alpaca Chicken Dromedary Duck Llama Sheep	Fat content generally increases with age;	Baéza, Guillier and Petracci, 2021; Kadim *et al.*, 2006; Popova *et al.*, 2021; Prache, Schreurs and Guillier, 2021
		Chicken Duck	Fat and MUFA increase and PUFA decreases with age;	Baéza, Guillier & Petracci, 2021
		Sheep	Higher carotenoid in the fat tissue, PUFA and iron with age in lamb;	Prache, Schreurs and Guillier, 2021
		Alpaca	Highest levels of omega-3 PUFA (EPA, DHA), DPA and total PUFA content in alpacas at age of 18 months (about 10 percent more) compared to older animals;	Popova *et al.*, 2021
		Pig	Intramuscular fat increases with age (30 percent increase between 160 and 220 days), PUFA omega-6 (linoleic acid) content decreases (by 30 percent)in intramuscular fat with age;	Bosch *et al.*, 2012

5.2 Livestock husbandry practices and production systems

The way in which an animal is raised can have a substantial impact on the quality of the resulting TASF. Livestock production systems differ substantially in terms of the climate and other geographical aspects of the system's location, management practices, feed and feeding systems, housing and animal welfare. The nutritional quality of the resulting TASF is mostly influenced by the diet of the animal. Livestock husbandry practices and other aspects of production systems impact safety, organoleptic and technological food quality attributes more than nutritional content, but some impacts on nutritional content have been reported.

5.2.1 Feed and feeding systems

Whether livestock are being fed with grass, forage, cereals or concentrate feed impacts the nutrient content and especially the fatty acid and vitamin profile of their milk and meat. Table B12. summarizes examples of studies demonstrating the impact of differences in animal feeding and feeding systems on the nutritional quality of TASF. The impact of feed on organoleptic and technological quality is also presented below.

In general terms, grazing is associated with lower milk yield and (8 percent) higher protein content in milk in comparison to a diet consisting of grass silage, maize silage and concentrates (O'Callaghan *et al.*, 2018). Higher contents of vitamin A and E are documented in milk and meat from grass-fed ruminants (Juárez *et al.*, 2021; Martin *et al.*, 2004), as well as vitamin E in meat from free-range chicken (Baéza, Guillier and Petracci, 2021). Precursors of vitamin E and vitamin A in beef were reported up to fourfold higher in pasture-fed system and up to sevenfold higher in concentrate-fed system (Duckett *et al.*, 2009; Cabrera and Saadoun, 2014). The level of increase depends on the feeding system and proportion of forage in the diet. In cow milk, an increase of more than 50 percent of the precursor of vitamin A was reported in system with pasture-based diet compared to concentrate-based-diet (Martin *et al.*, 2004). No variation of protein content in eggs and meat is reported in the literature.

A high polyunsaturated fatty acid diet improves the nutritional content of beneficiary fatty acids in milk and meat. Enhancing essential fatty acids in TASF (conjugated linoleic acid for ruminants and omega-3 fatty acids), while decreasing omega-6/omega-3 ratio, provides benefits to human health. It is of particular interest for research and processing industry. The omega-6/omega-3 ratio is more affected by the diet of the animals than their genetic make-up. Human dietary recommended PUFA/SFA ratio in the intramuscular fat of most pig breeds can be reached through adequate diet of the animals (De Smet, Raes and Demeyer, 2004). A major difference in terms of impact of diet exists between monogastrics and ruminants.

The difference in the digestive system between ruminants and monogastrics is associated with different digestion and absorption of fats (Ponnampalam, Sinclair and Holman, 2021). In monogastric animals, dietary fatty acids are directly absorbed without biochemical reactions in the stomach and their composition reflects that of the meat. This is not the case in ruminants as ruminal biohydrogenations[4] of fatty acids decrease their absorption. However, conjugated linoleic acid, a nutritionally beneficial fatty acid, is synthetized in the rumen of ruminants. This is associated with the ingestion of forages - a major part of the diet of ruminants. Monogastrics (including rabbits and horses) can convert alpha-linolenic acid into PUFA. However, the conversion rate is low. Certain bacterial reactions in monogastrics can further contibute to this synthesis: caecotrophia in rabbits (reingestion of soft faeces, issued from bacterial fermentation in caecum) has been shown to increase PUFA content in the meat (Lebas, 2007).

Grazing and high omega-3-dense feed supplement (e.g. linseed) increases PUFA content in milk and meat and thus results in a more nutritionally beneficial fatty acid profile for human consumption. These effects of grazing are particularly observed with leguminous pasture or forages from diverse grasslands (Hampel *et al.*, 2021; Lourenço *et al.*, 2007; Albenzio *et al.*, 2016). For example, Hampel *et al.*, 2021 reported more than 20 percent increase of PUFA in lamb meat from animals fed with tropical legumes compared to grass-fed animals. Grasses are rich in alpha-linolenic acid, essential fatty acid and precursor of omega-3 fatty acids, whereas cereal grains have higher level of linoleic acid, precursor of omega-6 fatty acids (Prache *et al.*, 2021; Warren *et al.*, 2008). Dietary linseed increases the level of alpha-linolenic acid in meat of cattle, sheep, pig, rabbit and chicken (Lebas, 2007; Wood and Enser, 2017), especially in the form of oil compared to whole seeds (Albenzio *et al.*, 2016). Supplementing the diet of sheep with flaxseed was reported to increase omega-3 fatty acid (18 percent), EPA (47 percent) and DPA (22 percent) in kidneys (Nguyen *et al.*, 2017) and alpha-linolenic acid (twofold higher) in livers with alpha-linolenic acid in liver being almost three times higher than in muscles (Sterk *et al.*, 2011; Van Le *et al.*, 2019). Complementary feed and use of different local forages such as hay from Khortane grass, dried olive leaves or hay from *Stipa tenacissima*

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[4] Biohydrogenation is a process that occurs in the rumen where bacteria convert unsaturated fatty acids to saturated fatty acids. This results in highly saturated fatty acids leaving the rumen and a limitation of PUFA content in tissues.

grass, supplementing scarce pasture of goats in Tunisia, showed a positive impact on the fatty acid profile (lower omega-6/ omega-3 ratio; 30 percent variation) and vitamin E content of the meat (3.71mg/kg with olive leaves supplementation, i.e. almost three times higher than oat hay-based diet) (Ayeb *et al.*, 2019). In Brazil, a dairy goat system on semi-arid native pasture resulted in a better fatty acid profile of the milk compared to a confinement system. The native pasture comprised 71 different plant species, whereas the confinement-feeding system was based on hay from Napier grass (*Pennisetum purpureum)* (FAO, 2021c; Neto *et al.*, 2020; Sant'Ana *et al.*, 2019).

The biological significance of an increase in omega-3 content and conjugated linoleic acid in TASF on human health may be discussed as PUFA in TASF are rather low compared to vegetables. However, some clinical studies suggest a potential contribution the blood of consumers and the regulation of the metabolism. A higher concentration of PUFA omega-3 (20 percent increase of PUFA omega-3 out of the total fatty acids) was found in the blood of consumers whose diet included red meat (beef and lamb) derived from grass-fed animals compared to concentrate-fed animals (McAfee *et al.*, 2011). The EPA and DHA proportions in the fatty acids in the red blood cells decreased significantly in the group fed with standard products, whereas they were maintained in the group whose diet included a high level of omega-3 originating from linseed-fed animals (Legrand *et al.*, 2010). Conjugated linoleic acid and alpha-linolenic acid content in sheep milk is 3 to 4-fold higher that in cow's milk (Albenzio *et al.*, 2016). Sofi *et al.* (2010) reported significant reductions of inflammatory cytokines and platelet aggregation associated with the consumption of CLA-rich cheese (derived from pasture-fed sheep) compared to a commercially available cow cheese. An intake of 90g per day of sheep cheese rich in conjugated linoleic acid and alpha-linolenic acid (three times higher than control cheese, e.g. derived from grass-fed animals) resulted in significant increases in the consumer plasma concentrations of conjugated linoleic acid and alpha-linolenic acid and led to a regulation of lipid and energy metabolism (Albenzio *et al.*, 2016; Pintus *et al.*, 2013).

In populations, who do not consume significant quantities of fish, meat can contribute meaningfully to their omega-3 status, particularly when the meat is from pasture-fed animals (Coates *et al.*, 2008; Howe *et al.*, 2006). Australian adults consume six times as much meat as fish and seafood. Howe *et al.* (2006) found in the Australian population that 43 percent of the average intake of omega-3 in their diet came from meat (equivalent to the contribution of fish products). These results can be linked to the livestock husbandry and feeding system. In Australia, most cattle are raised on pasture and grain-fed beef, including a stage of the production in feedlot, represents 30 to 40 percent of total beef production (ALFA, 2022).Lenighan *et al.* (2020) found at the Irish population scale, a potential improvement of the quality of dietary fatty acid intake by the consumption of grass-fed beef with a higer PUFA content (compared to grain-fed beef). Coates *et al.* (2008) showed that the consumption of omega-3-enriched pork can significantly increase omega-3 content in human blood cells. The consumption of animal products derived from animals fed linseed diet (associated with an omega-6/omega-3 ratio reduced by 60 percent in meat and 86 percent in eggs) led to more than a two fold increase of omega-3 (alpha-linolenic acid) content in fatty acids in human plasma (Weill *et al.*, 2002). While TASF with higher content of PUFA have a more beneficial fatty acid profile, this can lead to higher risks of organoleptic and technological defects through a higher level of lipid and protein oxidation. Lipid oxidation of meat induces unpleasant taste and odour and is associated with change in colour and with the potential formation of toxic compounds (Prache *et al.*, 2020b). Spontaneous oxidized flavours develop when fats are oxidized in milk and meat. Protein and lipid oxidation lead to a reduction in digestibility and negatively impact bioavailability (Estévez, 2011; Prache *et al.*, 2020b). Feeding broilers with a diet high in omega-3 increases their incorporation into the meat but may compromise meat quality due to oxidation of lipids. A higher anti-oxidant activity and higher amounts of phytochemicals in milk and meat of grass-fed animals is reported compared to grain-fed animals (Van Vliet, Provenza and Kronberg, 2021). Antioxidants in feed, such as selenium supplementation in poultry feed, can decrease lipid and protein oxidation in meat (Baéza, Guillier and Petracci, 2021). Vitamin E limits lipid and protein oxidation of meat products and is used during processing.

Because feed is the main variable cost in raising livestock, new feed sources are frequently proposed and tested for safety and quality. For example, insect products are being increasingly used. Results of insect larvae use for laying hens and broiler production of chicken, quail and partridge related to nutrient composition and organoleptic quality of the resulting meat are controversial (Gasco *et al.*, 2019). Laying hens fed black soldier fly larvae produced eggs with higher fat content in the egg yolk while organoleptic quality did not change (Bejaei and Cheng, 2020; Tahamtani *et al.*, 2021). Overall, a minimal impact of insect larvae feed on TASF quality has been reported. The use of algae and fish oil as feed ingredient increased omega-3, EPA and DHA content in meat from cattle, chicken and sheep, although high levels caused unpleasant flavour (rancidity) and colour changes of the meat due to lipid oxidation (Baéza, Guillier and Petracci, 2021; Prache, Schreurs and Guillier, 2021; Wood *et al.*, 2004).

Furthermore, replacing edible feed crops by plant by-products that are human-inedible feed resources contributes to mitigate the environmental impacts of livestock production. A review by Salami *et al.* (2019) documents both the impacts on the environment and the nutritional quality of resulting meat from a variety of plant by-products. Up to 30 percent of distiller's grain with soluble (maize, wheat) or glycerine in animal diet has been associated with an increase in PUFA content in beef and lamb. Citrus pulp in the diet of the lambs does not affect performance nor carcass or meat quality and limits rumen biohydrogenation of PUFA as well as lipid and protein oxidation. More extracts from fruits are of interest to supply natural antioxidants in animal diet. By-products of potato can increase the PUFA content in subcutsaneous fat by 19 percent (Pen *et al.*, 2005). Dietary distillates from rosemary leaves increase PUFA content (by 12 percent) and thyme leaves decrease SFA content (by 8 percent) in mutton (Nieto, 2013). However, flavour and acceptability should be further assessed. Apart from mitigating greenhouse gas emissions, a higher content of beneficial fatty acids (omega-3: 14 percent increase) in meat derived from sheep additionally fed with tannins was reported in a recent meta-analysis (Torres *et al.*, 2022).

Genetically modified crops used as feed and feed ingredients have so far not been shown to impact safety and quality attributes of TASF. Apart from the nutritional composition of feed that influences the quality of TASF, the use of biotechnology in plants had led to a public health concern on the safety of food produced from animals fed with genetically modified crops. Nevertheless, this concern is not supported by current scientific evidence. Box B6 presents the current knowledge on the impact of genetically modified feed on TASF quality.

Box B6 Impact of genetically modified feed on public health

About 70 to 90 percent of the globally produced genetically modified (GM) crops are used as feed for food-producing animals (Lucht, 2015). According to the European Food Safety Agency GMO Panel Working Group on Animal Feeding Trials, scientific literature on feeding trials with GM crops showed no evidence of adverse impacts on the animals nor on the nutritional quality of their products and not on human health (EFSA GMO Panel Working Group on Animal Feeding Trials, 2008). No recent scientific publications report adverse impact on public health (de Vos and Swanenburg, 2018). No indication was found that intact GMO-related proteins and DNA would be transferred to food products of animal origin (fluids and tissues) (FAO, 2015a). Foods produced from GM food-fed animals are not regulated as such, nor is it mandatory to label these food products as GM foods. However, national regulations, such as in France, Germany and the United States of America, cover the use of voluntary claims, stating on the package of food products that the animals have not been fed with GM feed.

Table B12 Impact of feed and feeding systems on nutrient composition by food product and species

Nutrient group	Food product	Species	Feed and feeding system	Reference
Protein content	Milk	Cattle	Sown pasture (grass, clover) significantly higher concentration of protein (8 percent) and casein (10 percent) compared to grass silage, maize silage and concentrates indoor ration; No variation in amino acid profile;	Magan *et al.*, 2021; O'Callaghan *et al.*, 2018, 2016
	Egg	Chicken Duck Turkey	No variation;	Duckett *et al.*, 2009; Prache *et al.*, 2020; Schönfeldt, Naudé and Boshoff, 2010; Van Vliet, Provenza and Kronberg, 2021
	Meat	Cattle Goat Sheep		
Fatty acid profile and fat content	Milk	Buffalo Cattle Sheep	Richer-PUFA diet results in higher PUFA and omega-3 content (twofold); Pasture grazing results in significantly higher concentrations of fat and PUFA (omega-3), conjugated linoleic acid compared with silage-concentrate feeding;	Gómez-Miranda *et al.*, 2021; O'Callaghan *et al.*, 2018; Rodríguez, Alomar and Morales, 2020; Salzano *et al.*, 2021
			High-fat concentrate diet results in larger and more fat globules;	Martini, Salari and Altomonte, 2016
	Egg	Quail	Seeds like hemp seeds increase omega-3 content in egg yolk (sevenfold increase in alpha-linolenic acid);	Yalcin, Konca and Durmuscelebi, 2018
		Chicken	Higher PUFA (3-5-fold increase) and lower omega-6/omega-3 ratio (50 percent, reaching around 5) when hens have access to pasture;	Hammershøj and Johansen, 2016
	Meat	Monogastric (chicken turkey, pig)	Dietary fatty acids directly absorbed without biochemical reactions (reflected in meat); In ruminants this is not the case;	Prache *et al.*, 2020
		Chicken	Increasing dietary feed lipid content and decreasing energy/protein ratio lead to increase in intramuscular lipid content in poultry; Rich SFA diet (e.g. palm, copra oil) increases SFA proportion; PUFA dense oil from marine animals increases the proportions of long-chain omega-3 PUFAs;	Baéza, Guillier and Petracci, 2021
		Pig	Higher intra-muscular fat content (28 percent) and PUFA (10 percent) in free-range Iberian pigs feeding on acorns and grass compared to indoor feeding with concentrates;	Tejeda *et al.*, 2020
			Feed ingredients derived from chicory reduce skatole in backfat of uncastrated males, thus reducing associated unpleasant odour (boar taint);	Aluwé *et al.*, 2017
		Rabbit	PUFA omega-3 content doubled in rabbits fed with linseed in the diet (3 percent of linseed);	Petracci, Bianchi and Cavani, 2009
		Ruminants	Higher content of beneficial fatty acids in meat mainly results from plants and other components in the diet rich in linolenic acid;	Scollan *et al.*, 2014
		Cattle Goat Lama Sheep	Feeding grass or forages including omega-3 PUFA rich plants (e.g. linseed, plantain, chicory, legumes e.g. pigeon peas) increases content of omega-3 (alpha-linolenic acid and EPA) (around threefold increase in cattle and sheep), lowers omega-6/omega-3 PUFA ratio by factor 3-4; Grass-fed cattle and sheep have darker meat; Gras-fed sheep increases risk of 'off-flavours';	Hampel *et al.*, 2021; Leheska *et al.*, 2008; MacKintosh *et al.*, 2017; Mamani-Linares and Gallo, 2014; Rodríguez, Alomar and Morales, 2020; Scollan *et al.*, 2006; Wood and Enser, 2017

Nutrient group	Food product	Species	Feed and feeding system	Reference
		Cattle	Lower intramuscular fat content in meat from grass-fed animals compared to concentrate-fed and thus higher PUFA;	Juárez *et al.*, 2021
			Diet consisting more on concentrates than forage associated with higher level of MUFA (20 percent), lower level of SFA (13 percent) and omega-3 (73 percent), higher omega-6/omega-3 ratio (fourfold);	Leheska *et al.*, 2008
			Grain-based diets produce intramuscular fat with (30 percent) less total and saturated fat than grass-finished cattle; Lower omega-6/omega-3 ratio (at least 70 percent decrease) in intramuscular fat of grass-fed animals compared to grain-finished animals	Hall, Schönfeldt and Pretorius, 2016
			Pasture-fed animals with less proportions of myristic and palmitic acids deposit in the intramuscular fat than feedlot animals;	Rubio Lozano *et al.*, 2021
			Conjugated linoleic acid 2-times higher in pasture-fed animals compared to concentrate-fed animals	Cabrera and Saadoun, 2014
		Sheep	Ewe's milk fatty acid profile reflected on the suckling lamb meat fatty acid profile; Pasture-fed weaned sheep are associated with higher content of omega-3, lower content of palmitic acid, and lower omega-6/omega-3 ratio in meat than lambs fed a concentrate-based diet;	Chikwanha *et al.*, 2018; Prache, Schreurs and Guillier, 2021
	Offals	Sheep	Flax seed supplementation: increase omega-3 fatty acids (18 percent), EPA (47 percent) and DPA (22 percent) in kidney and acid alpha-linolenic omega-3 twofold higher) in liver and thus in liver almost 3 times higher than in muscle;	Nguyen *et al.*, 2017; Van Le *et al.*, 2019
			Linseed supplementation: better profile of fatty acids in liver, higher proportion of alpha-linolenic acid (threefold), EPA (threefold), DPA (twofold);	Kim *et al.*, 2007
		Pig	Linseed supplementation: decrease of omega-6/omega-3 ratio, 70 percent increase of alpha-linolenic acid, 3-fold higher content of EPA in liver;	Enser *et al.*, 2000
Vitamins	Milk	Cattle	Concentrate or maize silage based diets result in lower vitamin A precursor (carotenoids; 60 percent) and vitamin E (40 percent) content than grass-feeding;	Martin *et al.*, 2004
			Switching from grass silage to hay results in decrease of vitamin E (at least 30 percent) and beta-carotene (50 percent);	Nozière *et al.*, 2006
	Meat	Cattle Goat Sheep	Grass-feeding increases levels of vitamins or their precursors (vitamin A, C, E by up to sevenfold, 60 percent and twofold respectively);	Cabrera and Saadoun, 2014
			High levels of dietary starch reduce vitamin B12 levels in the rumen, leading to reduced vitamin B12 in meat;	Juárez *et al.*, 2021
			Higher (three times) concentration of vitamin B1, vitamin B2 (two times) and vitamin E (moer than three times) in grass-finished versus grain-finished beef;	Duckett *et al.*, 2009
		Chicken	Free-range access increases vitamin E content;	Baéza, Guillier and Petracci, 2021
Bioactive compounds	Milk	Goat	Supplementation with rich-bioactive compound forages increased total polyphenol, hydroxycinnamic acids, and flavonoid concentrations (anti-oxidant activity);	Delgadillo-Puga and Cuchillo-Hilario, 2021
Pigment	Eggs	Chicken	Yolk colour (consumer preference) impacted by carotenoids (e.g. yellow: maize, alfalfa, flower extracts; red: paprika) in diet;	Nys and Guyot, 2011; Prache *et al.*, 2020

5.2.2 Environmental conditions and climatic zone

Except for certain vitamin and mineral supplements, the diets of livestock are essentially plant-based. Climatic conditions, soil type, altitude and season all have impacts on the chemical composition of plants and thus of animal feed and the nutritional quality attributes of resulting TASF. All these factors are determined by environmental conditions. Table B13. summarizes key examples of the influence of environmental conditions on the nutritional quality of TASF.

Temperature and day length determine the growing season and thus feed intake and access to pasture. Summer season triggers higher levels of vitamin D, lower fat and higher PUFA content in milk. However, Liu *et al.* (2013) found no impact of latitude on the vitamin D3 content of lean beef in Australia, but fat from cattle in low latitude contained higher concentrations of vitamin D3 than fat of cattle from high latitude. Mountain ecosystems with high altitude pastures are associated with beneficial fatty acid profiles in milk and meat of sheep, cattle and yak (Cividini *et al.*, 2019; Han *et al.*, 2020). The diversity of rangelands and their specificities in soils, biodiversity and terrain allow pastoralists to take advantage of concentrations of nutritious plants (FAO, 2021c). Grazing on certain combinations of plants specific to geographical areas may improve the extraction of nutrients and impact the nutritional content of TASF. Dromedary camels in the Raika community of pastoralists, feed on 36 different plants in north western India (FAO, 2021c).

Environmental variables can also be important for production systems where feed is harvested, rather than consumed directly by grazing animals. Forages should be harvested at the optimal time to ensure maximum quantity and quality and consequently optimal nutritional content in resulting TASF. The proportion of digestible nutrients for ruminants decreases with the age of the plants (Duarte *et al.*, 2019). The concentration of the beneficial conjugated linoleic acid in cow milk fat is enhanced by dietary intake of fresh pasture (Kelly *et al.*, 1998). Climatic variations in tropical regions can greatly affect the quality of the grass and hence its nutritional contributions, including minerals (Huerta-Leidenz, 2021; Rubio Lozano *et al.*, 2021). The fatty acid profile is linked to the climatic zone and feeding system, particularly the combination of pasture management and grass maturity, diversity of grass, season and altitude which influence the concentration in alpha-linolenic acid (precursor of long-chain omega-3) in the diet. Differences in selenium content in meat have been reported in relation to the feeding sytem, the selenium content in feed (grains and grass) and environmental conditions (soil) (Cabrera and Saadoun, 2014; Gupta and Gupta, 2000).

Table B13 Impact of environmental conditions on nutrient composition of TASF by food product and species

Factor	Food product	Species	Impact	Reference
Plant composition of pasture	Meat	Sheep	10 grazing areas in North Macedonia associated with specific fatty acid profile and fat content of the meat (explained by the plant composition of pastures);	Vasilev *et al.*, 2020
	Milk	Cattle Sheep	Grazing on higher altitude leads to beneficial fatty acid profile with increased concentrations of PUFA (up to 87 percent), omega-3 fatty acids (e.g. alpha-linolenic) (up to 68 percent) and higher milk fat content;	Bartl *et al.*, 2008; Cividini *et al.*, 2019; Falchero *et al.*, 2010
	Meat	Yak	High altitude associated with higher percentages of PUFA (up to 25 percent);	Han *et al.*, 2020
	Milk	Yak	Higher altitudes (from 3,215 to 5410m) associated with higher content in vitamin A (by 60 percent) and E (by 28 percent)	Yang *et al.*, 2021
Season	Milk	Cattle Sheep	Spring and summer milk contains more vitamin D, calcium, larger fat globules, less saturated fatty acids and more PUFA, omega-3 than winter milk;	Altomonte *et al.*, 2019; Martini, Salari and Altomonte, 2016; Rutkowska, Adamska and Bialek, 2012; Weir *et al.*, 2017
		Cattle (*Bos taurus*)	Decrease in milk protein contents related to decrease in casein fraction in summer;	Bernabucci *et al.*, 2015
		Dromedary	Lower fat content during warmest month;	Musaad, Faye and Al-Mutairi, 2013
	Meat	Yak	Increased fat content in season when pasture is abundant;	Xiong *et al.*, 2021
		Pig	Pigs born in spring or autumn have a slightly lower carcass fatness compared to pigs born in winter; lowest muscle lipid content in Spring, myoglobin content unaffected; lower PUFA percentage in pigs born in autumn than pigs born in winter or spring;	Lebret *et al.*, 2021

5.2.3 Housing conditions and other husbandry practices

Husbandry practices encompasses all methods and measures taken by the producer until slaughter. They include feeding, housing, reproductive management, health and welfare care. Production systems that include grazing or free-range are generally associated with positive nutritional impact on TASF (Prache *et al.*, 2020a).

Housing conditions have been shown to impact the fatty acid profile, the contents in proteins and vitamins in meat. Pigs raised outdoors had a lower ratio of omega-6/ omega-3 PUFA compared with indoor pigs fed with the same diet (Dostálová *et al.*, 2020). The decreased ambient temperature associated with outdoor access was assumed to explain the higher content of MUFA in their meat. Ducks raised in irrigated rice fields in China had higher carcass weight with higher intramuscular fat, lower protein content and higher concentration of some essential amino acid (valine, methionine, phenylalanine, histidine, and arginine) and PUFA (omega-6 and omega-3) than ducks raised in floor pens (Huo *et al.*, 2021). Outdoor access had a beneficial effect on the vitamin A content, and on the proportion of PUFA, omega-3 fatty acids and omega-6/ omega-3 ratio in egg yolk (Sokołowicz, Krawczyk and Dykiel, 2018). A systematic review highlights overall controversial results related to the impact of housing system (cage versus free-range) on egg quality, especially the egg weight, the most studied quality indicator (Pires *et al.*, 2021). As vitamin D is synthetized when exposed to sunlight, housing and indoor rearing decrease the vitamin D content of cow’s milk (Weir *et al.*, 2017).

Organic production is increasing in the livestock sector. There are no international common standards of organic production, resulting in obstacles to compare such production systems and assess their outcomes on the nutritional quality of TASF. Results differ among studies due to different husbandry practices and combinations of factors such as diet, housing, breed and age of the animals. Nevertheless, attempts have been made to gather some observations about the impact of organic production systems on the nutritional quality of TASF. Two meta-analysis reported that certain organic meat (beef, lamb and pork) and cow milk have healthier fatty acid profile (higher concentration of PUFA in meat and milk, higher conjugated linoleic acid and vitamin E in milk) (Średnicka-Tober *et al.*, 2016a, 2016b). These results may be closely linked to the access to pasture, grazing and forage-based diets prescribed under organic production standards (Średnicka-Tober *et al.*, 2016a). As an illustration, Benbrook *et al.* (2013) reported 2.5-fold higher omega-6/omega-3 ratio in conventional compared to organic milk.

Box B7 Physiological and metabolic reactions resulting in stress and negative impacts of TASF

Physiological and metabolic reactions to stress have been described in the literature and (Terlouw *et al.*, 2021) have summarized the main effects of stress on the quality of TASF. Gonzalès-Rivas reviewed the effect of heat stress on meat quality (Gonzalez-Rivas *et al.*, 2020). Heat stress induces physiological reactions including faster heart rates, higher catecholamine (neurotransmitters) levels and metabolic stress with accelerating muscle glygogenolysis (production of glucose from glycogen stored in muscle) and ultimately high pH in muscles. The extent of the (physiological) pH decline in meat after animal slaughter depends on the amount of glycogen stored in the muscle before slaughter. The lower the glycogen stored in the muscle, the higher the ultimate pH and the poorer the meat quality. Muscle metabolism continues after death and can be higher under acute stress conditions right before slaughter, leading to depletion of glycogen store and a fast post-mortem pH decline. In this case, high ultimate pH, low level of stored glycogen and slower decrease of muscle temperature associated with a fast post-mortem pH decline, can lead to PSE (pale soft exudative) meat and increased toughness or 'high rigor temperature' beef carcasses (Gonzalez-Rivas *et al.*, 2020; Terlouw *et al.*, 2021; Warner *et al.*, 2014). PSE is more frequently observed in pig and poultry.

Chronic heat stress is more likely to trigger (dark firm dry) meat in ruminants and pigs due to lower glycogen reserves in muscles, lower production of lactic acid and a higher ultimate pH (Gonzalez-Rivas *et al.*, 2020; Zhang *et al.*, 2020). In poultry, chronic heat stress reduces feed intake and changes the chemical composition of breast meat (increase of fat, especially intramuscular fat deposit) and reduction of protein content (Gonzalez-Rivas *et al.*, 2020). Chronic stress factors also jeopardize the capacity of animals to deal with acute stress during pre-slaughter handling and transport.

Heat shock proteins (HSP) in ruminants and pigs play a role in muscle tenderness, juiciness and flavour. HSP expression during acute stress leads to toughness of meat (Gonzalez-Rivas *et al.*, 2020). For example, higher HSP70 expression in heat stressed animals may result in improving cell survival and prevent protein degradation (Archana *et al.*, 2018). A low expression of HSP70 gene in the Indian indigenous Salem Black goat indicates a better adaption of the breed to high ambient temperatures. However, no impact of heat stress on protein and fat content in two Indian indigenous breeds was reported (Archana *et al.*, 2018).

The egg weight decreases as the ambient temperature increases above 25 degrees Celsius, which is associated with a decline in egg albumin weight and a delayed decrease in egg yolk weight. This lower average egg weight is partly explained by the shortage of protein and energy intake during thermal stress (Renaudeau *et al.*, 2012). The glycogen store in muscles is impacted by physical activity and psychological stress such as food deprivation (Gonzalez-Rivas *et al.*, 2020; Terlouw *et al.*, 2021). It also induces oxidative stress which leads to protein and lipid oxidation, as well as shorter shelf-life. Lipid oxidation leads to off-flavour and decreases nutritional value. Protein oxidation can modify the digestibility of proteins and decrease the bioavailability of amino acids (Zhang, Xiao and Ahn, 2013). Heat stress also leads to a decrease of milk yield in cattle and affects milk composition with lower protein and fat content (Gorniak *et al.*, 2014; Liu *et al.*, 2019).

The production system and in particular housing have an impact on animal welfare, which has an impact on the quality of the resulting TASF. Free-range rearing and pasture-based systems have been shown to improve poultry and cattle welfare (Arnott, Ferris and O'Connell, 2017; Yilmaz Dikmen *et al.*, 2016). Stress factors before slaughtering such as thermal stress, fasting and water shortage, long transportation, impair animal welfare and TASF quality, especially the technological aspect are further described in Table B14. Heat stress is already major challenge to livestock production, impacting animal welfare, and this challenge may become even more important in the future, given global warming and forecasts of greater future demand for TASF in Asia and Africa. Elevated body temperature before slaughter is more frequent in cattle finished on grain than in grass-fed cattle and is associated with high rigour temperature, producing tougher meat. Stressors associated with poor animal welfare can lead to pale, soft, exudative (PSE) and dark, firm, dry meat (Alcalde *et al.*, 2017; Carrasco-García *et al.*, 2020). Meat is associated with dark colour, tough meat and reduced shelf life, exudative meat (PSE) with light colour, poor quality with low water retention and hard after cooking. Both types of meat are generally rejected by consumers. Box B7 further develops the physiological and metabolic reactions resulting in stress and negative impact on TASF quality.

Table B14 Factors impacting animal welfare and quality and safety of TASF

Factor	Impact
Heat stress	Acute heat stress before slaughtering leads to PSE (pale soft exudative) meat in poultry and pigs; Chronic heat stress more likely to trigger (dark firm dry) meat in ruminants and pigs; Chronic heat stress reduces feed intake and changes the chemical composition of breast meat in chicken (increased fat, especially intramuscular fat deposition, reduced protein content) (Gonzalez-Rivas *et al.*, 2020); Chronic stress factors jeopardize capacity of animals to deal with acute stress during pre-slaughter handling and transport; Decreased egg weight when ambient temperature increases above 25 degrees Celsius, associated with a decline in egg albumin weight and in egg yolk weight;
Fasting / food deprivation	Fasting and food deprivation increases risk of DFD in pigs (Gonzalez-Rivas *et al.*, 2020); Higher incidence of DFD reported during summer for ruminants related to limited pasture quality and reduced feed intake under high temperature (Gonzalez-Rivas *et al.*, 2020; Kadim *et al.*, 2004); Sheep breeds in temperate climate more likely to withstand reduced feed and subsequent nutrient intake than sheep in tropical arid and semi-arid areas with water scarcity. Impact of water scarcity on meat quality, especially fatty acid profile, need further research (Chikwanha *et al.*, 2021);
Mixing animals	Mixing pigs with unfamiliar individuals during pre-slaughter period impacts animal behaviour (Terlouw *et al.*, 2015); Mixing outdoor pigs with other animals well before slaughter resulted in less fighting and thus less stress in the slaughterhouse, leading to fewer body injuries and a lower risk of DFD and PSE meat compared to indoor pigs that were used to each other;
Density	High stocking density can lead to behavioural stress (e.g. pecking in poultry or cannibalism in pigs) altering the productivity but also quality of their meat; High stocking density increases sensibility to salmonellosis (Koutsoumanis *et al.*, 2019); Higher stocking density is considered as stress factor to laying hens (Kang *et al.*, 2018); No impact has been reported from stocking density on egg nutrient content; Higher stocking density leads to lower feed intake and egg production rate, and higher mortality rate (Geng *et al.*, 2020);
Transport	Poor quality roads are associated with higher incidence of DFD in lamb and cattle meat when transported for several hours (Terlouw *et al.*, 2015, 2021); Transportation under high ambient temperature can generate major physiological and muscle metabolic stress in goats (Kadim *et al.*, 2010);
Restraining method	Use of electric prods is documented as a factor of higher incidence of PSE and blood-splashed pork (Faucitano, 2018) and lower meat tenderness in cattle (Warner *et al.*, 2007);
Individual reaction	Individual reaction to stress also varies according to the species, experience and genetics, even if animals are slaughtered under the same conditions; The complexity of the biological response and individual adaptation may be understood as a non-linear system to predict the quality of meat (Terlouw *et al.*, 2021);

In Brazil, around 5 percent of bovine carcasses were considered DFD (Rosa *et al.*, 2016) and 19 percent of pig carcasses (Trevisan and Brum, 2020). Higher temperatures are more likely to produce PSE poultry meat, whereas chicken and turkey exposed to colder temperatures are more likely to produce DFD meat (Leishman *et al.*, 2021). A meta-analysis documented the effect of heat stress on poultry meat quality and the significance of this effect in production may be reached in extreme conditions: during transportation, heat waves or high apparent temperature (e.g. combination of high air temperature, low air velocity, high humidity and high stocking density) (Leishman *et al.*, 2021).

5.2.4 Husbandry practices and food safety

In addition to nutrient composition, husbandry practices can also impact the safety of TASF. Although public health and food safety are addressed in Section D, some specific aspects of husbandry and food safety are described below.

Ensuring safe animal husbandry practices until slaughtering, including in the case of home slaughtering (FAO, 2021a), is critical for addressing the risk of food-borne contaminants in TASF. Actions to be taken include biosecurity measures, traceability, feed safety, disease prevention and control and enhanced animal welfare. The type of hazard and associated level of risk depend on the TASF and the animal production system and animal management practices and strategies. Free-range systems, small and large-scale systems will not trigger the same levels of risk and require adapted practices to address food safety along the food chain.

Risk assessment based on Codex Alimentarius guidance enables the identification of the predominant risk factors according to the type of TASF (see Section D). Interventions to reduce contaminants exposure via feed or water are critical, in as much as feed and water are potentially significant contributors to contamination in the production system (FAO and IFIF, 2020). The OIE/FAO Guide to Good Farming Practices for Animal Production Food Safety (FAO and OIE, 2010) recommend a set of practices to reduce the risk of TASF contamination and food-borne diseases. Guidelines are available for small scale producers to minimize risks associated with food safety (FAO, 2021a).

Salmonella spp. in food, a bacteriological hazard, illustrates the key impact of livestock production on safety of TASF and human health. Non-typhoidal Salmonella are one of the top food-borne pathogens globally (see Section D). Guidelines are provided by (FAO and WHO, 2016) but risk factors and occurrence in livestock production systems of low to middle income countries are not sufficiently documented. Nevertheless, the risk factors are documented, especially in high income countries, and include farm management, biosecurity, staff hygiene and carcass handling along poultry production chains (Wilke, Windhorst and Grabkowsky, 2011). For instance, the risk factors of Salmonella contamination along the smallholder pig value chain in northern Vietnam include having a pen next to the household, unrestricted access of visitors to the farm, location of slaughter area next to the lairage without biosecurity measures and lack of practices to avoid cross-contamination at the slaughterhouse (Dang-Xuan *et al.*, 2019). An increased stocking density, larger farm size and stress also result in increased occurrence, persistence and spread of Salmonella in laying hen flocks (Koutsoumanis *et al.*, 2019).

Environmental contamination of TASF with heavy metals is closely linked with the feeding system and feed resources used. Industrial effluents, agrochemicals affect feed and feed ingredients, and water sources used for livestock production. Further data is needed to assess the level of contamination in carcasses in countries where official monitoring of heavy metal residues in carcasses is not conducted systematically such as in Nigeria (Njoga *et al.*, 2021), and improve monitoring to reduce risk such as in the Islamic Republic of Iran (Sarlak *et al.*, 2021). The level of soil contamination can also have an impact on TASF, for example eggs produced by free-range hens had a higher concentrations of heavy metals compared to eggs from cage-raised hens (Radu-Rusu *et al.*, 2013).

Public health risks are also linked to misusage of veterinary products and their residues in TASF. The misuse and overuse of antimicrobials, especially antibiotics, and the resulting antimicrobial resistance is a growing concern. Antimicrobials are used in animal production for therapeutic, metaphylactic, prophylactic purposes and as growth promotors (see Section D). They can be also administered through feed as a practical method of administering drugs to a large numbers of animals on a daily basis (FAO and WHO, 2019a).

However, their use depends on the country legislation. For instance, the European Union has banned the use of many antimicrobials as growth promotors since 2006. Several countries, are increasingly engaged in antimicrobial use reduction strategies, reporting veterinary antimicrobial sales, initiating specific regulation, (Tiseo *et al.*, 2020). Importing countries are more likely to require maximum residue limits. International standards on veterinary products used in medicated feed are set up by the Codex Alimentarius Guidelines for the design and implementation of national regulatory food safety assurance programme associated with the use of veterinary products in food producing animals (FAO and WHO, 2014).

Antibiotic utilization has increased with the expansion of high external input dependent livestock production leading high selection pressure of bacteria (Van Boeckel *et al.*, 2014). Compared to chicken and cattle production, pig production has been associated with the highest increase of antimicrobial use between 2017 and 2030 with 45 percent of the total projected increase of antimicrobial use (Tiseo *et al.*, 2020). Inappropriate use of antimicrobials as growth promotors or to prevent diseases in healthy animals as well as over-prescription and over-use in animal production, is accelerating the process (WHO, 2017) leading to increasing related human health risks through the development of antibiotic-resistant bacterial strains.

A transfer of the resistance gene to either pathogenic bacteria or commensal bacteria can occur, causing food-borne diseases without cure, or impacting the human microbiome in such a way that it harbours the resistance genes for an extended period of time. Antimicrobial resistant microorganisms can be spread to humans through direct exposure from infected or contaminated animals, through food or the environment. However, there is limited data that quantifies the occurrence of antimicrobial resistance due to the food supply and livestock production.

5.3 Drivers of production practices that influence nutritional quality of the resulting TASF

Over the last decades, breeding and husbandry practices have been driven by commercial purposes that generally do not specifically consider the nutritional value of TASF. Priority is essentially given to commercial quality attributes, the primary basis upon which producers are paid, especially for standard-commodity TASF (Prache *et al.*, 2020a). Technological requirements to meet processing protocols (e.g. production of cheese) and the need to standardize production to reduce costs may influence genetic selection programmes and contribute to shaping livestock production systems. Synergies and antagonisms between the different quality aspects (nutritional, technological, organoleptic, commercial) and food safety, play in favour or at the expense of nutritional quality.

5.3.1 Drivers of genetic selection

In a recent review, Prache *et al.* (2021) underlined the historical priority given to commercial qualities to orientate genetic selection (milk and carcass yield, egg production rate). Genetic selection, gene-editing and genomic biomarkers usually target increased productivity, health and longevity, other quality attributes, heat tolerance, technological quality defects and elimination of allergens (Van Eenennaam, 2019) (Prache *et al.*, 2021). Markets have generally emphasized payment for quantity of production, rather than nutritional composition so this latter aspect has not historically been considered in genetic selection programmes. When a trait is not considered in selection programmes, the expectation is for the trait to remain constant over time, unless the trait is genetically correlated with the traits for which selection is practiced. This practice will however result in decreased quality attributes if these attributes have an unfavourable genetic relationship with the traits for which selection is practiced. In broiler chicken, for example, genetic selection for high growth rate and breast meat yield has been associated with the observation of lower meat quality and the occurrence of constraints for processing. "White striping" or "wooden breast" defects are associated with a lower protein content in the muscles and a higher content of collagen in broiler meat and have become more prevalent in populations selected for increased growth rate. In various livestock species, commercial drivers leading to genetic selection in favour of higher lean meat yield and lower fat deposition led to lower tenderness.

The halothane gene in pigs is associated with the Porcine Stress Syndrome (PSS), i.e. a sudden death of pigs placed under stressing conditions before slaughter, including transport. Animals affected by a mutation of this gene also tend to more frequently develop PSE meat, a major technological defect of meat described above. The variance of the halothane gene with respect to PSS incidence is also favourably associated genetically with growth rate and production of lean meat. Therefore, genetic selection programmes for different breeds and populations have alternatively included removal or inclusion of the allele, depending on the intended purpose, including the commercial value (carcass lean meat content), the meat technological quality, and the genetic background of the population undergoing selection. Based on data from South African slaughterhouses, 96 percent of the pigs did not carry the mutation. This meant that the halothane gene was an insignificant factor to PSE meat in the country. Therefore, the focus was placed on other husbandry practices such as decreasing stress to curtail PSE occurrence (Soma, Marle-Köster and Frylinck, 2014).

Examples can be found where quality attributes are a strong driver to influence research studies and genetic selection programmes. For example, proteomic studies have been conducted to identify proteins associated with the occurrence of DFD meat following pre-slaughter stress in ruminants (Chikwanha *et al.*, 2021). Recent interest in nutritional value of TASF has led to the inclusion of heritable traits affecting nutrient composition in genetic selection programmes. Beta-casein milk protein has two variants: A1 and A2. The A2 variant has been associated with a higher digestibility of milk than the A1 variant, but current outcomes related to cardiovascular diseases and diabetes are inconclusive (Kuellenberg de Gaudry *et al.*, 2021). This has led to a genetic selection programme in Australia, New Zealand and the United Stated of America, producing milk with higher proportion of variant A2. Furthermore, to reduce allergic reaction triggered by beta-lactoglobulin protein in milk, gene-editing has been used to annihilate the protein expression (knockout) and produce hypoallergenic milk (Sun *et al.*, 2019). A debate is still ongoing whether this novel technique to produce transgenic animals falls under GMO regulations and is subject to pre-market safety assessment (see Box B8).

The previously mentioned boar taint that causes unpleasant odour and taste of meat from male pigs is genetically controlled. Therefore selective breeding to reduce boar taint through genetic markers is ongoing in several countries. With respect to animal welfare, this approach is considered favourable to castration.

Box B8 Effects of genetically modified animals on human nutrition and health

Based on the Cartagena Protocol on Biosafety, WHO defined Genetically Modified Organisms (GMO) as organisms in which the genetic material has been altered in a way that does not occurred naturally, in order to induce or remove a trait.

Regulatory framework and risk assessment policy

The Codex Alimentarius Commission provides internationally harmonized guidance for undertaking risk analysis on the safety and nutritional aspects of foods derived from modern biotechnology (FAO and WHO, 2011). A pre-market safety assessment should be undertaken on a case-by-case basis and include a comparison between the food derived from modern biotechnology and its conventional counterpart including extensive comparative studies of the chemical composition, nutritional quality, toxicity, allergenicity of proteins. Safety assessment should include data and information to reduce the possibility that a food derived from a recombinant-DNA animal would have an unexpected, adverse effect on human health. Careful monitoring of the post-release effects of these products and processes is also essential to ensure their continued safety to human beings, animals and the environment.

The responsibility for formulating policies and making decisions regarding GM food belongs to national competent authorities. FAO provides on request, advice and technical assistance to strengthen the national and regional capacities of Members on agricultural biotechnologies. The GM products that are currently on the international market have all passed safety assessments conducted by national authorities. The Organisation for Economic Co-operation and Development (OECD) has established safety assessment processes based on the principle of “substantial equivalence” to assure that foods derived from GM crops are as safe and nutritious as those from plants derived through conventional breeding.

Genetically modified animals for human consumption

AquAdvantage® salmon is the first GM animal authorized for human consumption in the world, by the United States of America authorities (Food Drug Administration) in 2015. It grows to market-size in 18 months instead of 36 months. The company announced in June 2021 the first commercial scale harvest in its farm in Indiana. The product is approved for sale by Health Canada since 2016, and the company announced the approval of its application to Brazil’s National Biosafety Technical Commission for the sale of GMO Atlantic salmon in Brazil.

Labelling requirements for GMO differ from one country to another. There is no mandatory labelling requirement specific to GMOs in Canada. GMO labelling regulatory requirements came into force in the United States of America in January 2021 and do not neither apply to restaurants nor catering industry.

One GM terrestrial animal has been authorized in 2020 for human consumption, called the Galsafe® pig. The animals lack alpha-gal sugar protein which can trigger allergic reactions for people suffering from alpha-gal syndrome, an allergy to red meat. GalSafe® pigs can also be used to produce medicaments, such as heparin, to solve the problem of rejection of organ transplants. The Food Drug Administration concluded that the safety of food products originating from GalSafe® pigs is no different than the safety of food products originating from non GM pigs. These conclusions were based on toxicology and microbial food safety evaluations. No nutritional content variation was reported. No testing was conducted on people suffering from alpha-gal syndrome. Potential for the development of antimicrobial resistant bacteria was included and ongoing surveillance for antimicrobial resistance is required to monitor for the development of resistance to aminoglycoside, in line with Codex Alimentarius Commission (FAO and WHO, 2008). Research interest, supported by the private sector, particularly focuses on disease resistant animals, animals that grow faster and for therapeutic use.

The debate is ongoing whether genome-edited organisms obtained by precise gene-editing bio techniques should be considered as GMOs, covered by GMO regulations, and thus are subject to a pre-market safety assessment for their release for human consumption. The European Union and New Zealand argue that products originating from genome edited organisms should underlay the same regulations as GMOs (Callaway, 2018; Fritsche *et al.*, 2018), whereas Canada and the United States of America are not taking the same direction (Canada, 2020; FDA, 2020).

5.3.2 Drivers of livestock practices

The standardization of milk (fat content) and meat production (through weight and age of slaughtering) contributes to standardize the TASF nutrient content in the supply and in successive in trade and marketing (Huerta-Leidenz, 2021). This standardization is key to lower production costs, compliance with slaughterhouse equipment (e.g. size and pace of slaughter lines), processing industry requirements (e.g. thermal treatment, preservation) and ultimately lower consumer prices.

The commercial attributes of meat are mainly defined by the carcass grade classification, which determines the payment to the producer. The South African classification targets lean carcasses which has contributed to drive the beef breeding and management systems towards emphasizing that goal(Hall and Schönfeldt, 2015). The same trend, in line with national dietary guidance since the 1980s, of a decrease in fat and saturated fatty acid content in beef, has been documented in the United States of America (McNeill *et al.*, 2012), but also in the European Union, and for other species (pig, sheep) as well (Prache *et al.*, 2020b).

Enhancing commercial attributes towards a heavier and leaner carcass has also triggered technological and organoleptic side-effects in poultry and pig production. Due to genetic selection and optimization of feeding, the reduction in fat content and intramuscular fat (for example in Pietrain pigs), reduces the flavour and juiciness of cooked meats as well as the suitability for processing (De Smet, 2012). A higher level of PUFA in TASF can reduce the organoleptic and technological quality through a higher level of lipid and protein oxidation (see Subsection 5.2.1.). Feeding pigs with high levels of PUFA can lead to off-flavours linked to oxidation, and a softness of the fat which limits the technological process. The higher the PUFA content, the softer the meat at a given temperature, when firm fat enables the process of curing. Antioxidants in a PUFA rich diet can contribute to enhance the technological quality while maintaining the benefits of high level of PUFA for human health.

Due to the genetic selection and production practices towards greater weight gain and higher productivity of broilers in the United Kingdom, the content of fat has increased and that of omega-3 DHA has decreased from 1870 to 2004 (Wang, undated). The confinement of animals indoors with ad-libitum high-energy feed access as well as the use of growth promoters are reported as contributing factors. In the early twenty-first century, a chicken carcass of an international strain contained up to three times the energy of fat compared to protein (less than one time before 1950) (Wang, undated). Chicken meat has been considered as a lean alternative to red meat and a nutritional source of omega-3 DHA. Similarly in France, genetic selection has led to 12 percent increase of leanness of the pig carcass since the 1970s (Bidanel *et al.*, 2020).

Nutritional quality as well as other aspects related to perceived sustainability are increasingly demanded by consumers. Consumer demand for quality and safety associated with rising income needs to be considered as a driver of shifts in livestock production in all countries (Jabbar, Baker and Fadiga, 2010). For instance, in order to target a niche market by producing milk and meat from cattle with a specific quantity of omega-3, specifications exist requiring a certain quantity of PUFA (omega-3) in the diet. This supply chain ("Bleu-Blanc-Coeur") has been developed in France and extended to several countries (e.g. Brazil, Malaysia, Saudi Arabia, Taiwan, Province of China, Tunisia).

Quality is a vector of marketing through certification of specifications (Huerta-Leidenz, 2021). Certification and quality brands often cover organoleptic and/or nutritional quality linked to genetic make-up, animal management and geographical origin, such as the Certified Angus Beef brand in the United States of America, the "poulet bicyclette" in Burkina Faso, the Cabrito de Tete goat in Mozambique and Ternera de Navarra cattle and acorn-fed Iberico pig in Spain. In these cases, the growing interest and demand of the consumers on the production area and type of production system are translated into market value, which in turn influences production practices.

International trade opportunities can also orientate livestock production, including export specifications in the value chain, to consider aspects such as specific weight, age of slaughter, or specific genetics. Production systems are guided by meeting commercial standards and regulations. Commercial standards of importers may differ from the quality standards of the country of production. Marbling score in beef and pork is a key quality indicator for export. It is linked to meat palatability, a factor of consumer preference, and the level to be reached varies across the world (De Smet, 2012; Rubio Lozano *et al.*, 2021). The marbling score is associated with the intramuscular fat deposition which gives the meat its flavour and palatability, whereas the subcutaneous fat has less commercial value. There are on-farm nutritional strategies to improve marbling such as the supplementation of conjugated linoleic acid in fattening stage of pig and cattle to increase intramuscular fat and decrease subcutaneous fat deposition (Li *et al.*, 2020).

The rules for export are also based on compliance with international regulations (Codex Alimentarius and OIE) to ensure public health. The European Union has import requirements regarding the water-protein ratio in meat cuts. These requirements tackle the fraud associated with adding external water to the carcass to artificially increases the weight (Dias *et al.*, 2020). The ratio differs between countries according to national regulations. The maximum residue limits of veterinary products also vary between countries, which implies different levels of tolerance, and monitoring of livestock interventions on farms whose production is dedicated to export.

6 Limitations, gaps and needs in the evidence-base

The assessment of nutrient composition and value of TASF revealed several limitations in the evidence-base. Generally, there has been a narrow focus in public health nutrition on single nutrients without more holistic consideration of the food matrix and dietary patterns underlying TASF digestibility. As in other sections of the document, evidence from LMIC on nutrient composition of local TASF is limited. Despite potential for human health, the literature is limited for food from hunting and wildlife hunting and insects, grubs and their products. Below we summarize gaps and needs in the evidence base that follow:

- TASF nutrients and bioactive compounds interactions in the food matrix and dietary patterns:

Deeper understanding of the complex interplay of nutrients and foods within dietary patterns is necessary to further characterize the role of TASF in human nutrition and health. More investigation is needed for underexplored nutrients (e.g. vitamin K2) and bioactive compounds (e.g. carnitine, anserine) found in TASF.

- Nutrient density and bioavailability metrics and modelling:

In order to more optimally describe TASF in relation to environmental impacts and issues of cost and access, improved metrics for nutrient density and bioavailability are needed. Modelling can then provide more robust evidence for TASF role.

- Food composition data bases:

There is a need to develop more comprehensive and representative food composition databases to capture TASF from local breeds and species and dietary patterns from LMIC.

- Insects inlcuding grubs and their products:

Research is needed on nutrient bioavailability and composition of insects and insect products.

- Nutrient content and quality due to animal characteristics and husbandry:

Robust studies on TASF quality variation are limited in developing countries, where research and investment efforts are more targeted on increasing productivity. Reviews and publications particularly cover internationally traded breeds. Further research is required on the impact of the diversity of local breeds, husbandry practices, grazing practices and traditional husbandry systems on TASF quality, including for the following species: dromedary and Bactrian camel, cattle, yak, Llama. There is a lack of meta-analysis to cover the different production systems and husbandry practices. Factors including genetics, animal nutrition, season, housing conditions, etc. should be taken into account in combination with the production system in studies to identify cross-effects and the impact of each factor on TASF quality. Nutritional quality indicators should be systematically considered and measured along with the organoleptic and technological quality indicators. The impact of livestock interventions on the nutritional value of TASF in the literature is documented focusing on the nutrient composition of TASF but little is known about the variation of bioavailability of the nutrients. Further research is needed to assess the linkages between on-farm interventions, e.g. animal diet, the nutritional quality of TASF and the resulting impact on human health.

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Section C EFFECTS OF TERRESTRIAL ANIMAL SOURCE FOOD ON HEALTH AND NUTRITION OVER THE LIFE COURSE

Key findings

- Dietary intakes of TASF can have effects on nutrition (nutrient status, anthropometry), health (infectious disease, NCDs, immune system function broadly, bone health), and cognition (development, neuroprotection, and neurological disease prevention).
- Across all life course phases[1], there is a stronger evidence-base examining milk and dairy products in relation to human health compared to other TASF. Beef and eggs follow in terms of availability of evidence. Pig and poultry meat, meat from wild animals, insects and meat from other minor species have been studied to a lesser extent. In sum, the evidence suggests beneficial effects of TASF intakes at appropriate levels for several health outcomes.
- Milk and dairy consumption during pregnancy was found to benefit healthy weight of infants at birth and may also benefit birth length and foetal head circumference. Among infants and young children, eggs, milk and meat consumption has been studied with mixed findings depending on overall diet and environmental exposures. Evidence for school-age children and adolescents on milk and dairy products shows positive effects for increased height and reduced adiposity and overweight and obesity. Beef consumption in school age children may improve cognitive outcomes.
- In adults, there is strong evidence showing positive effects from milk and yoghurt for reducing risks for all-cause mortality, hypertension, stroke, type 2 diabetes, colorectal cancer, breast cancer, obesity, osteoporosis and fractures. Evidence shows egg consumption in adults does not increase risks for stroke or coronary heart disease. High quality evidence shows meat intake (85-300g/d) is positively associated with iron status in adults. Poultry meat has been studied to a limited extent relative to beef, but findings suggest non-significant effects on stroke risk with sub-group analyses suggesting protective effect in women.
- Unprocessed and processed red meat has been evaluated extensively for NCD outcomes among adults largely through prospective cohort studies with risk of bias. The Global Burden of Disease Study has set risk thresholds at 23g (18–27g) per day of red meat, and 2g (0–4g) per day of processed meats. Evidence on processed red meat consumption has been shown unequivocally to increase risk for mortality and chronic disease outcomes (cardiovascular disease and colorectal cancer). However, studies have found non-signifcant effects for unprocessed red meat and NCD with mixed findings only for HIC.
- Epidemiological evidence for the health effects of TASF in the older adults comes primarily from HIC. A fairly robust evidence-base shows positive effects for lean red meat consumption on muscle health. Other evidence suggests the potential for milk and dairy products and other TASF in mitigating impacts on sarcopenia (muscle loss), fractures, frailty, dementia and Alzheimer's disease.
- There were limitations for evaluating evidence across life course phases in terms of heterogenity in study design for: comparator groups (counterfactuals including substitution or replacement foods); dosing and exposure (quantity of TASF intake), and context (HIC versus LMIC). A preponderance of evidence for adults particularly came from observational studies with moderate-to-serious risk of biases.
- Cow's milk and poultry eggs are among the eight food groups that pose allergenic risks to the populations and it is therefore mandatory to state their presence in foods as part of precautionary allergen labelling. However, there is no evidence that avoiding such foods during infancy can delay or prevent reactions. Lactose malabsorption is widespread, but does not automatically lead to lactose intolerance, which also greatly varies in severity.
- Most recommendations are for TASF in general, followed by recommendations on meat (in general), milk and dairy products, eggs and red meat (especially beef). There is significantly less coverage on offal, poultry and rabbit (as part of white meat), meat from wild animals and insects.
- Most recommendations are linked to human micronutrient needs and NCD and targeted to the entire population. Micronutrient-related recommendations tend to be more detailed compared with NCD-

[1] Life course phases: women during pregnancy and lactation; infants and young children; school age children and adolescents; adults and older adults.

related recommendations, providing quantitative indications in terms of daily or weekly intake of TASF. Most recommendations do not consider the implications of under and over consumption of TASF, a pertinent gap given the co-existence of micronutrient deficiencies with both undernutrition and overweight, obesity and NCD.

- In total, there were 378 recommendations that follow a life course approach – with specific guidelines targeting the individual life phases, 282 in FBDGs, irrespective of the income class of the countries. While the recommendations in the FBDG of high-income countries were more detailed, overall, there was a balanced distribution of both qualitative and quantitative recommendations.
- Environmental sustainability considerations were only included in documents from eight upper middle income countries and mostly provided qualitative recommendations. Animal welfare was only mentioned in the FBDG of Denmark and Sweden with a specific reference to an animal welfare labels to inform consumers.

Summary

This section presents the synthesized epidemiological evidence for dietary intakes of TASF on nutrition and health outcomes. Human biology and nutrient requirements vary across different phases in the life course giving rise to differential needs and impacts from TASF consumption patterns. This review of the evidence base also shows varying quality and amounts of scholarly work for different TASF within each life course phase. In sum, the evidence suggests beneficial effects of TASF intakes at appropriate levels for several health outcomes and non-significant increases in chronic diseases, among apparently healthy individuals. However, this conclusion rests on the assumption of TASF intakes among populations without medical preconditions.

This section commences with an analysis of evidence of TASF intake during pregnancy and lactation, examining the nutrition and health outcomes for the mother, foetus and exclusively breastfed child. Despite being identified as a critical period in the first 1 000 days of life, pregnancy and lactation has been understudied across a full range of TASF. Literature focusing primarily on milk and dairy products provides consistent findings for healthier weight at birth and to a lesser extent, increased birth length. There is some indication that milk consumption earlier in the pregnancy during the first trimester conferred the greatest nutrition advantages, notably anthropometric outcomes, for the offspring. Some evidence suggests a possible effect of milk and dairy intakes on foetal head circumference.

Infants and young children have been studied to a greater extent than other phases of the life course in part due to the established literature for the high nutrient needs during this period and life-long consequences of malnutrition in early childhood. Eggs, milk and meat consumption in infants and young children have been examined with mixed findings for nutrition and health outcomes depending on context and the overall dietary pattern. Generally, results show positive or null effects on anthropometry and child development. School-age children and adolescents slow in growth velocity but still require TASF to support neurological development, bone health and reproductive health. Evidence again focusses on the effects of milk and dairy products showing positive effects of daily consumption on increases in height and protective effects of dairy consumption on adiposity and overweight and obesity. The Assessment identified evidence suggesting positive effects from beef consumption in school age children on cognitive outcomes.

Among adults, findings suggest positive effects from milk and dairy products specifically yoghurt for reducing risks for all-cause mortality and other chronic diseases. Egg consumption was not associated with increased risks for stroke or coronary heart disease according to the published literature. The quality of data and studies examining the effects of unprocessed and processed read meat intakes and human health outcomes remains in question, with high degrees of heterogenity and risk of bias. From the available evidence, risk analyses indicate that modest amounts of unprocessed red meat (ranging from 9-71g/d) consumption holds minimal risk. However, processed meat consumption does confer an elevated risk for mortality and NCDs including cardiovascular disease and colorectal cancer. Red meat intake was also found to be positively associated with iron status in adults. Poultry and other meat beyond beef have been studied to a lesser extent.

In the older adults, epidemiological evidence for the health effects of TASF comes primarily from HIC and is limited given the co-existence of medical conditions among older adults, which goes beyond the scope of this assessment. There was evidence indicating positive effects for lean red meat consumption on muscle health, but the evidence for red meat was equivocal. Other evidence suggests the potential for milk and dairy products in mitigating impacts on sarcopenia (muscle loss), fractures, frailty, dementia and Alzheimer's disease. Poultry and eggs have been studied to a lesser extent.

A total of 123 Food Based Dietary Guidelines were reviewed from 95 countries. They provided 695 recommendations related to TASF consumption mostly linked to micronutrient intake, followed by 145 recommendations for diet-related NCDs. Environmental sustainability was mentioned only in nine occasions and was included in FBDGs published from 2015 onwards. Most of the recommendations were for the general public although there were also many recommendations provided for specific phases of the life course. A total of 79 NCD related documents were reviewed from 51 countries. They provided 168 recommendations related to TASF mostly linked to the prevention of diet-related NCDs with only ten recommendations related with micronutrient intake and three linked to environmental sustainability. The great majority focused on the general public with only few recommendations provided for specific groups according to the life course. An additional 35 documents were reviewed including food and agriculture legislations and nutrition policies and programmes for a total of 50 recommendations related to TASF. The recommendations were mostly of qualitative nature and targeted at a generic public with reference to micronutrient intake.

Most recommendations on TASF consumption are for TASF in general, followed by recommendations on meat, milk and dairy products, eggs and red meat (especially beef). There is significantly less coverage on offal, poultry, rabbit, meat from wild animals and insects. Most recommendations are linked to human micronutrient needs and NCDs and targeted to the entire population. Micronutrient-related recommendations tend to be more detailed compared with NCD related recommendations, providing quantitative indications in terms of daily or weekly intake of TASF. Most recommendations do not consider the implications of under and over consumption of TASF, a pertinent gap given the co-existence of micronutrient deficiencies with both undernutrition, overweight, obesity and NCDs.

In total, there were 378 recommendations that follow a life course approach, 282 in FBDGs, irrespective of the income class of the countries. While the recommendations in the FBDG of high-income countries were more detailed, overall, there was a good distribution of both qualitative and quantitative recommendations.

Environmental sustainability considerations were only included in documents from nine upper middle income countries and mostly provided qualitative recommendations. Animal welfare was only mentioned in the FBDG of Denmark and Sweden with a specific reference to an animal welfare labels to inform consumers.

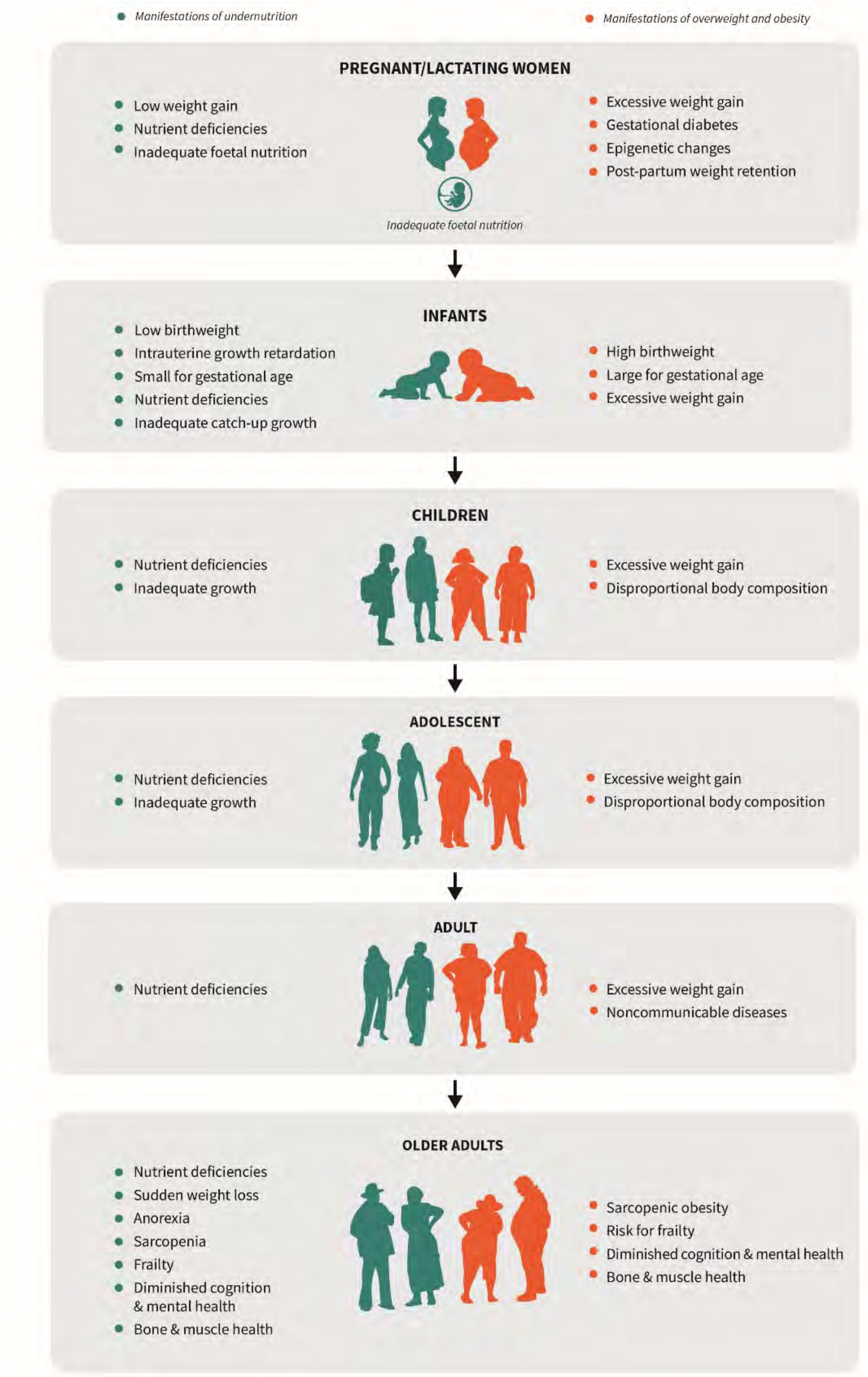
1 Introduction

This section provides an overview of evidence on the effects of TASF intake throughout the life course. In human biology, different physiological processes and environmental exposures drive nutrient demands throughout life. Social determinants may influence these pathways and ultimately impact the health of an individual (as will be covered in Component Document 2). Section B summarized evidence on the composition of nutrients and bioactive compounds contained in TASF and implications for human health, drawing from the literature spanning from food chemistry to public health nutrition. This section primarily highlights epidemiological evidence on the nutrition and health impacts of TASF intake by life course phase. Additionally, subsections on TASF-related allergies, as well as policy considerations to inform population-level TASF consumption, are discussed. This form of evidence takes into account factors across multiple levels from cells of the human body to society enabling further insights into how TASF affect human nutrition and health as what might be represented in socio-ecological framework (Mahmudiono, Segalita and Rosenkranz, 2019).

3 Concepts, definitions, and methods

One of the original frameworks for nutrition in the life cycle was published by ACC/SCN (2000) (see adapted as Figure C1). Despite multiple different iterations and adaptations, the framework has largely endured in its original form. Figure C1 visually represents manifestations of malnutrition in each life course phase, defined in Box C1. This portion of the assessment follows similar life course phases with some minor changes, but narrows the scope to examining the consequences of TASF consumption.

Figure C1 Nutrition throughout the life cycle



There are many causes of all forms of malnutrition that often share common pathways including genetics, inadequate infant and young child feeding, frequent infections during early childhood, unhealthy diets, food insecurity, poor health status, inadequate health or care behaviors and low physical activity. The double burden of malnutrition in an individual refers to the co-existence of under-nutrition (e.g. micronutrient deficiency or stunting) with overweight, obesity and/or NCDs.The most common combination is micronutrient deficiency with overweight and obesity with implications for NCDs. Figure C1 provides an overview of the health implications of both undernutrition and overweight or obesity for each life phase and resulting implications for child development, NCDs and educational, mental and physical capacity.

Box C1 Life course phases relevant for human health

The term life course is applied here to encapsulate both biology and social determinants of health, as compared to life cycle which generally refers to the biological developmental phases of an organism and life span, describing temporal aspects of an individual from conception to death (Brown, 2019; Herman *et al.*, 2014).

The following life course phases are being distinguished:

- Infants and young children (below 5 years)
- School age children and adolescents of five to 18 years of age
- Adults (men and women in adulthood)
    - Women of reproductive age 15-49 years
    - Women during pregnancy and lactation, including needs of the developing foetus and the exclusively breastfed child through six months of age
- Older adults (above 65 years)

Section C partitions the life course into five phases based on nutritional requirements and alignment in the published literature. For infants and young child, the review considers TASF consumption during complementary feeding for both breastfed and non-breastfed children (6–23 months). In the case of school age children and adolescents, in some cases youth older than 18 years may be included if part of the sample in a study was evaluated.

Methods for this part of the assessment followed PRISMA guidelines for conducting systematic reviews (Page *et al.*, 2021b, 2021a). PRISMA stands for: Preferred Reporting Items for Systematic Reviews and Meta-Analyses. It is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses. Findings have been compiled and presented below in narrative form.

Using the Population Intervention/Exposure Comparator Outcome (PICO/PECO) framework, the inclusion criteria follow:

- Population – apparently healthy populations falling into the respective life course phases defined above; apparently healthy refers to the absence of disease based on clinical signs and symptoms and function, normally assessed by routine laboratory methods and physical evaluation. Some studies reviewed included sample populations across multiple life course phases; these findings were considered in various subsections as appropriate.
- Intervention/Exposure – consumption of TASF and/or their products at varying levels (more versus less; some versus none; TASF type versus another TASF type).
- Comparator – usual diet (often used as control group); TASF intakes at lower levels; TASF intakes at higher levels; PBF or other foods/diets.
- Outcome – nutrition and health outcomes were evaluated with some variation depending on life course phase; anthropometry and growth; biomarkers of nutrient and/or health status (e.g. haemoglobin concentration, nutrient biomarkers, etc.); infectious and chronic disease morbidities and diagnoses; indicators of food hypersensitivities and allergies; all-cause and cause-specific mortality; cognition and other domains of neurological function and development.

No single question could be formulated using the PICO/PECO because of the multiple populations, TASF and outcome examined. Studies conducted in the last five years were prioritized, but studies dating back to 2000 were also included.

Exclusion criteria were the inverse of the inclusion criteria with some specifications noted here. In terms of sample populations, studies examining TASF effects in: immunocompromised individuals; people requiring therapeutic diets; and medical case reports, were excluded. Concerning the intervention/exposure, studies focused on aquatic food only were excluded, though in some studies aquatic food were part of the overall category of TASF and described as such. Further studies examining TASF isolated components; TASF as ingredients in processed foods; and fortified TASF products were also excluded. Some systematic reviews included findings from TASF supplements, but this section reports only on the findings in these reviews related to TASF. Of note, however, some of these products are included in Section D as part of the emerging evidence base.

For Section C, the literature search and screening included peer-reviewed articles and grey literature with a set of pre-defined search terms across multiple databases including PubMed, Medline, EMBASE, Google Scholar and various institutional websites (see Box C2). The articles, documents and reports were categorized by type: systematic reviews; other reviews; intervention trials; observational studies; and grey literature (see Box C3). Two rounds of screening were conducted: for eligibility and strength of evidence. In the first round the quality and salience of the evidence were assessed. Then studies of high quality evidence were identified applying the GRADE domains of risk of bias, imprecision, indirectness and publication bias. Following the smaller sub-set of studies was screened for inclusion in this assessment. In the second round of snow-ball sampling, suggestions received from the Scientif Advisory Committee and other collaborators were considered in addition applying the same criteria and included with the original set.

Box C2 Search terms by database used for Subsection C3

Search terms using Academic Search Complete via EBSCOHost
(“animal source food” OR “animal sourced food” OR “animal based food” OR “livestock derived foods” OR “animal derived foods” OR “TASF” OR “meat” OR “milk” OR eggs) AND (“child” OR “Infant” OR “adolescent” OR “adult” OR “elderly” OR “school-age child” OR “child under the age of 5” OR “schoolchildren” OR “older adults” OR “breastfeeding” OR “lactation” OR “teenager”) AND (“health” OR “nutrition)

Search terms using PubMed
(“animal source food” OR animal source food* OR “animal based food” OR “livestock derived foods” OR “TASF” OR “meat” OR “milk” OR “eggs” OR “dairy” OR “insects” OR “honey”) AND (“child” OR child* OR “infant” OR infant* OR “adolescent” OR “adult” OR “elderly” OR “school-age child”* OR “child under the age of 5” OR “older adults” OR “breastfeeding” OR “lactation” OR “teenager”) AND (“health” OR “nutrition”) AND (“meta-analysis” OR “systematic review” OR “experimental trial” OR “observational study”)

Search terms using ScienceDirect
(“animal source food” OR “animal sourced food” OR “animal based food” OR “livestock derived foods” OR “TASF” OR “meat” OR “milk” OR “eggs” OR “dairy” OR “insects” OR “honey”) AND (“child” OR “Infant” OR “adolescent” OR “adult” OR “elderly” OR “school-age child” OR “child under the age of 5” OR “older adults” OR “breastfeeding” OR “lactation” OR “teenager”) AND (“health”)

The flow diagramme presented in Figure C2 presents the results of this process. In total, 1 334 records were initially identified. Round#1 yielded 107 studies for extraction of evidence after excluding duplicates and ineligible studies. An additional 49 studies were identified from round#2 snow ball sampling and eligibility screening ultimately yielding a total of 146 studies for the assessment of effects of TASF on health and nutrition over the life course.

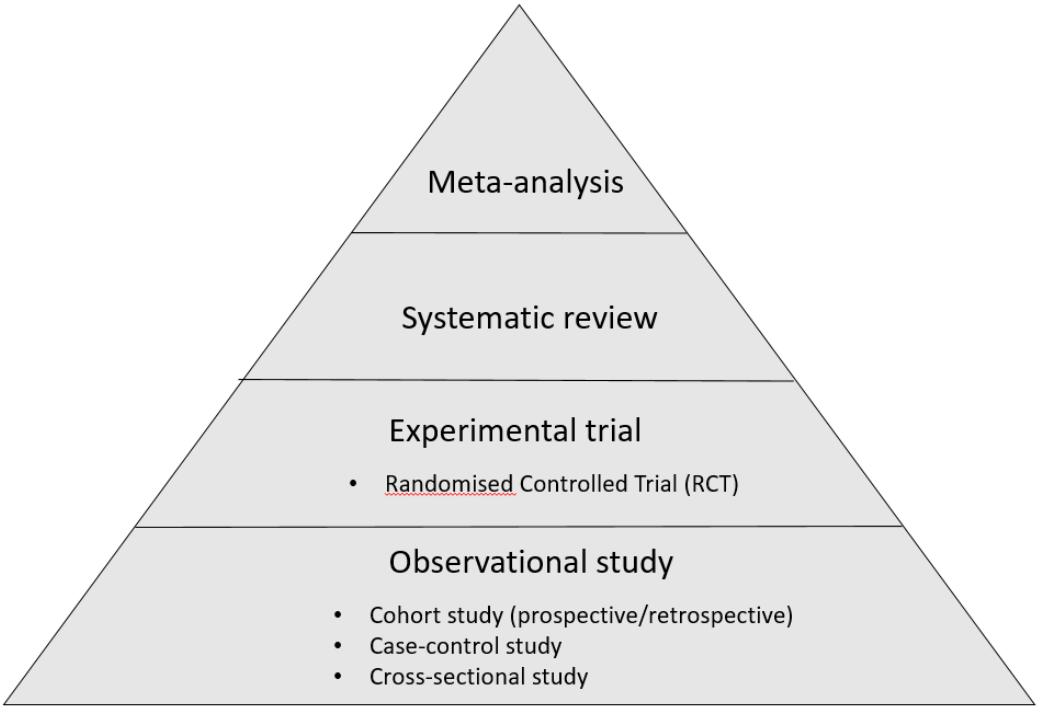
Box C3 Research methods in human nutrition

Meta-analysis: a statistical analysis of combined data and results from a number of independent studies of the same subject, in order to determine overall trends.

Systematic review: a review of a clearly formulated question that uses systematic and reproducible methods to identify, select and critically appraise all relevant research.

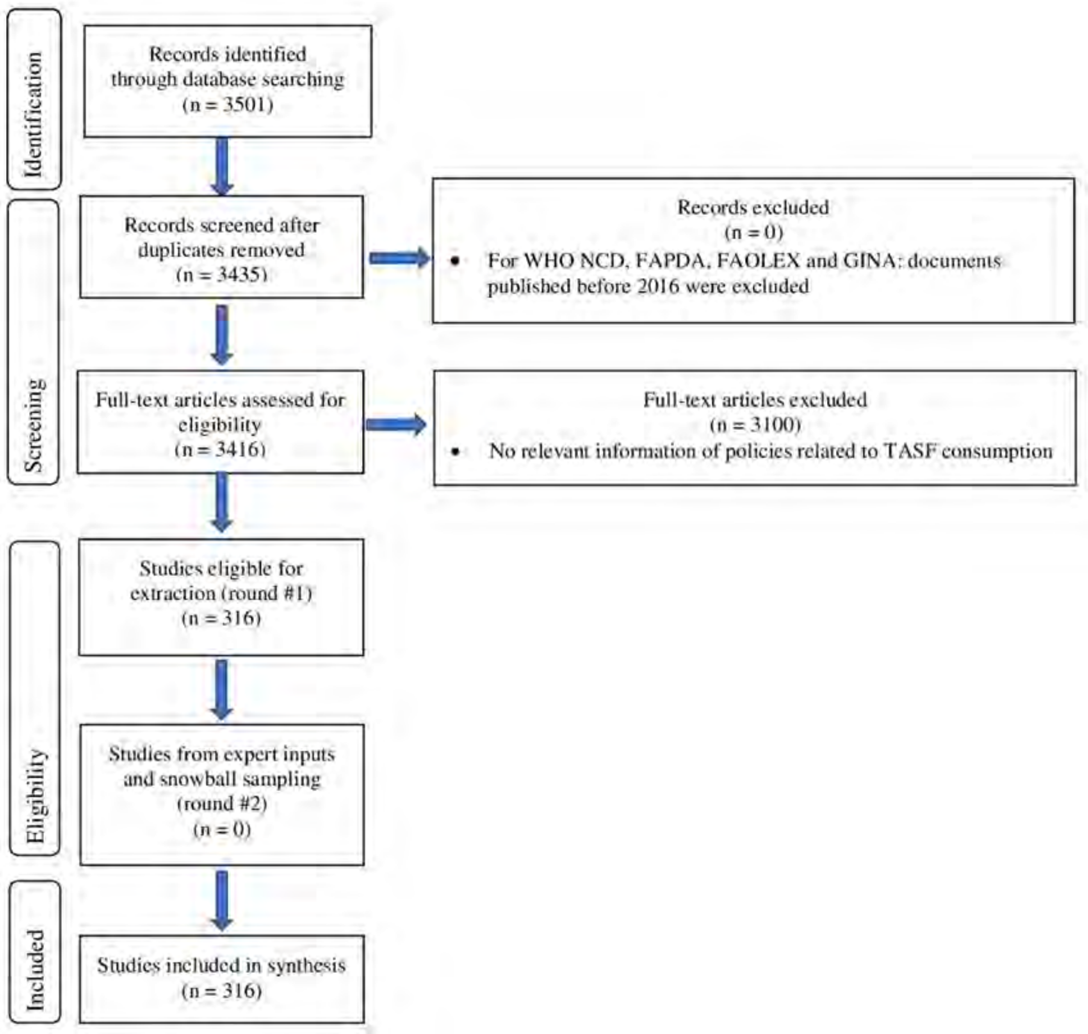
Experimental trial (or intervention trial): study of effects of an intervention (e.g. risk factor, medical treatment, specific diet) on people who are assigned to different groups. People are randomly assigned to a group in randomized controlled trials. The control group receives no specific intervention or a placebo.

Observational study: study of the effects of an intervention on people who were already exposed to this intervention before the study. A cohort study compares the effect of an intervention on a group of people with shared characteristics (a cohort), who have been exposed to the intervention with the effect on a group of people who have not been exposed. A case control study compares people with an existing health issue to people without that issue. A cross-sectional study analyses numerous characteristics and variables at once (at a single point in time).



Narrative review describe the evidence on a topic but are not systematic and do not follow a specific method.

Figure C2 PRISMA Flow diagramme[2] assessing effects of terrestrial animal source food on health and nutrition over the life course



4 Life course phases

Results of the assessment of TASF effects on nutrition and health outcomes through the life course are described below and summarized in Table C1 and Annex Table C6 with the following information: TASF; specific findings; sample size; country of study; study design (including number of embedded studies if systematic review); and reference. For each phase of the life course, sections briefly highlight key requirements and biological processes ongoing in the life course phase and the potential role of TASF, followed by an overview of the epidemiological evidence for impacts on nutrition and health. Each section presents the most robust, high-quality evidence first, including systematic reviews and meta-analyses and experimental trials, followed by well-designed observational studies. Within these categories, to the extent possible as evidence is available, the outcomes are presented in the same sequence: nutrition (nutrient status, anthropometry); health (infectious disease, NCDs, bone health); and cognition (development, neuroprotection, neurological disease prevention). Indicators commonly used to assess the nutritional status of children are defined in Box C4.

[2] Flow diagramme following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines; See for further information: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097 and www.prisma-statement.org.

Box C4 Definition of indicators related to the development of children – before, at and after birth

Indicators for the nutritional status of foetuses and infants before and at birth

- Intrauterine growth retardation: impaired growth and development of the foetus and/or its organs during gestation.
- Small-for-gestational age: child with a weight below the tenth percentile for the gestational age in comparison with average infant population of the same sex and gestational age.
- Large-for-gestational age: child with a weight above the ninetieth percentile for the gestational age in comparison with average infant population of the same sex and gestational age.
- Prematurity/preterm birth: neonates born alive before 37 weeks of pregnancy[1].
- Low birthweight: weight at birth of below 2 500 gram[1].

Indicators for the nutritional status of children

- Height-for-age z-score (HAZ): the height of a child in relation to the average height of children of the same age and sex. When a child has low height-for-its age (<-2 standard deviation from the median of the WHO Child Growth Standards), it is stunted.
- Weight-for-age z-score (WAZ): the weight of a child in relation to the average weight of children of the same age and sex. When a child has low weight-for-its age (<-2 standard deviation from the median of the WHO Child Growth Standards), it is underweight.
- Weight-for-length/height z-score (WHZ): the weight of a child in relation to the average length/height of children of the same age and sex. When a child has low weight-for-its length/height (<-2 standard deviation from the median of the WHO Child Growth Standards), it is wasted. Child overweight is weight-for-height greater than 2 standard deviations above WHO Child Growth Standards median; and. obesity is weight-for-height greater than 3 standard deviations above the WHO Child Growth Standards median.

Annex Tables C1-C5 provide the contribution of selected animal and plant food items to the recommended nutrient intake for vitamin A, vitamin B12, iron, zinc and calcium during specific life course phases.

Table C1 Important nutrients required for health functions during specific life course phases provided by TASF

Life course phase	Key health functions	Nutrients
Infants and young child (6 to 59 months including 6-23 months)	Adequate growth Adequate bone growth Cognitive development Immune system functioning Vision health	Vitamin A Vitamin B12 Choline Calcium Iron Zinc Proteins Fatty acids (DHA, Ratio Linoleic to Alpha-Linolenic Acids - LA:ALA)
School age children (5 to 18 years)	Adequate growth Immune system functioning Normal cognitive functioning and brain development	Vitamin A Vitamin B12 Calcium Iron Zinc Proteins Fatty acids (DHA, LA:ALA)
Adolescents (10 to 18 years)	Adequate growth Reproductive maturation Normal cognitive development and neuroplasticity	Vitamin B12 Calcium Iron Zinc Protein Fatty acids (DHA, LA:ALA)
Women in reproductive age including during pregnancy and lactation (15 to 49 years)	Anaemia prevention Bone preservation Lower risk of infection Breastmilk quality Supporting increasing blood volume Birth outcomes (prevention of LBW, IUGR) Full-term infant Necessary ratio of essential fatty acids (LA:ALA) and blood cholesterol (high-density to low high-density lipoprotein) required to maintain health functions.	Vitamin A Vitamin B12 Choline Folate Calcium Iron Zinc Protein Fatty acids (DHA, LA:ALA, cholesterol)
Adults (18 to 65 years)	Cognitive maintenance and adequate nutrient levels Immune system functioning Necessary ratio of essential fatty acids (LA:ALA) and blood cholesterol (high-density to low high-density lipoprotein) required to maintain health functions.	Vitamin B12 Calcium Iron Zinc Protein Fatty acids (DHA, LA :ALA, cholesterol)
Older adults (65 + years)	Bone health Immune system functioning Memory and cognitive preservation Muscle mass maintenance Necessary ratio of essential fatty acids (LA:ALA) and blood cholesterol (high-density to low high-density lipoprotein) required to maintain health functions.	Vitamin B12 Calcium Zinc Protein Fatty acids (DHA, LA:ALA, cholesterol)

3.1 Women during pregnancy and lactation, including foetus and breastfeeding child through 6 months

Conception initiates the first 1 000-day period, a critical phase in the life course that requires nutrient-dense, healthy diets to support a developing foetus and infant while sustaining the health and well-being of the mother. Offspring growth and development depend not only on diet, but also on a wide array of genetic and environmental factors (McDade *et al.*, 2019). Malnutrition in this life phase can induce critical consequences for both mother and offspring. For the mother, there may be compromised nutrient status, impaired bone health, metabolic perturbations, and increased overweight and obesity, among others (Black *et al.*, 2013). For the foetus and infant, malnutrition during pregnancy may result in intrauterine growth restriction or small-for-gestational age, large-for-gestational age, low birth weight and height, pre-term birth, long term health outcomes, among others (Barker, 1997; Chia *et al.*, 2019; Christian *et al.*, 2015). Iron deficiencies, in particular, are increasingly prevalent during pregnancies and can induce a range of complications for the mother and the foetus during gestation, with longer-term impacts on offspring mental health, brain development, and cognition (Georgieff, 2020).

In the lactation period, breastmilk composition, particularly levels of fatty acids and some vitamins, depends on maternal diet and body reserves (Bravi *et al.*, 2016; Dror and Allen, 2018; Kovacs, 2016). Maternal dietary required intakes may augment further from pregnancy with breastfeeding as the dependent neonate and infant grows. Calcium and iron requirements for example are very high in both pregnancy and lactation (Black *et al.*, 2013; Georgieff, 2020; Hacker, Fung and King, 2012; Kovacs, 2016). Evidence shows women increase the efficiency of absorption during these periods, though their own skeleton may be resorbed to compensate for the high mineral needs of the offspring (Kovacs, 2016). Several other nutrients, found to be bioavailable in TASF, are also required at higher levels during pregnancy and lactation, to sustain increases in blood plasma expansion, foetal growth and development, milk production, and multiple other biological processes (Allen, 2013).

Evidence from intervention studies on TASF consumption during pregnancy and lactation has largely focused on milk and dairy products. Two comprehensive systematic reviews were conducted for milk and dairy products. Quality observational prospective cohort studies that underline findings from the systematic reviews were also identified.

A recent systematic review and meta-analysis for the effects of milk and dairy products consumed during pregnancy on perinatal nutrition (anthropometry) outcomes pooled data on 111 184 pregnant women identified from 14 studies (Pérez-Roncero *et al.*, 2020). Investigators combined data from these studies to demonstrate that intake of higher quantities of milk and dairy products as compared to lesser quantities or none was associated with increased birth weight (mean difference=51.0g, 95% CI 24.7-77.3). Five of the studies showed a positive effect on infant length (mean difference=0.33cm, 95% CI: 0.03-0.64) in meta-analyses. Authors found reduced risks for small-for-gestational age (odds ratio=0.69, 95% CI: 0.56-0.84) and low birth weight (odds ratio=0.63, 95% CI: 0.4-0.84), and increased risk for large-for-gestational age (odds ratio=1.11, 95% CI: 1.02-1.21). No effect of milk and dairy products were observed for the standard ultrasound measures of the foetal size.

Another systematic review examined both nutrition (anthropometry, breastmilk composition) and health (birth outcomes). Drawing evidence from 17 studies (three intervention; six prospective cohort; three retrospective cohort; and two case-control), they showed consistent findings with the review described above for infant birth weight and length in positive association with milk intake during pregnancy (Achón *et al.*, 2019). Evidence was insufficient to draw conclusions for the effects of milk and dairy intakes during pregnancy on preterm birth and spontaneous abortion or on breastmilk composition during the lactation period.

Observational studies, when appropriately designed, can also provide evidence for TASF consumption impacts during pregnancy and lactation. The Generation R Study and its follow-on Generation R Next in the Netherlands are prospective cohort studies from foetal period through young adulthood (Generation R, accessed in 2021). One analysis emerging from this group assessed the association between first trimester milk consumption and foetal growth, and neonatal complications (n=3405 mothers) (Heppe *et al.*, 2011). Data from a semi-quantitative food frequency questionnaire showed three or more glasses of milk per day, compared to one or zero glass of milk per day, was associated with greater foetal weight gain in third trimester and an 88g higher birth weight (95% CI: 39-135g). Head circumference was also increased by 2.3 cm in the offspring of mothers drinking three or more glasses of milk compared to one or zero. No association was found for length. They also found that maternal protein intakes from milk (but not other dairy products) was associated with birth weight.

Another prospective cohort study examined the effects of milk consumption during pregnancy in Danish women on offspring nutrition (anthropometry) at birth and health (IGF-1 levels, insulin levels) outcomes approximately 20 years follow-up (n=685) (Hrolfsdottir *et al.*, 2013). Investigators found that maternal milk consumption of greater than or equal to 150ml/d at 30 weeks gestational age compared to less than 150ml/d was associated with higher birth weight-for-age Z score (0.32, 95% CI: 0.06; 0.58) and birth length-for-age Z score (0.34, 95% CI 0.04; 0.64). The offspring of mothers with higher milk consumption followed 20 years later showed trends for higher height Z scores, higher level of IGF-1, and higher insulin levels.

Other observational studies were identified to allow for greater population representativeness of the assessment. Pregnant women living in an urban area of South India were studied in a prospective, cohort trial (Mukhopadhyay *et al.*, 2018). The effects of dietary intakes of milk and dairy products using a food frequency questionnaire on birth nutrition outcomes (anthropometry) were examined (n=2036). This study found a positive association of total milk and dairy product intakes and percent of protein from milk and dairy products in first trimester for birth weight in gram (beta=86.8, 95% CI:29.1-144.6; beta=63.1, 95% CI:10.8-115.5; P<H0.001). Authors also examined percent of total vitamin B12 intakes from milk products but found no association with birth weight.

An observational study among Portuguese pregnant women (n=98) found a relationship between total dairy intakes in first trimester and head circumference (beta=0.002, P=0.014) and placental weight (beta=0.333, P=0.012) (Abreu *et al.*, 2017). There was also some indication that increased dairy intakes between first and second trimester were associated with lower maternal weight gain during pregnancy (beta=-0.007, P=0.020).

In sum, evidence from randomized controlled trials has examined milk and dairy products to a greater extent than other livestock-derived TASF during pregnancy and lactation. Consistent findings here showed a positive effect for milk intake on healthy birth weight, with some evidence suggesting greater effects if the intervention starts in the first trimester. Prospective cohort studies adjusting for multiple confounding factors have similarly shown positive association between milk consumption during pregnancy and healthy foetal growth outcomes. However, there are limitations inherent to drawing conclusions from observational studies. Findings for ultrasound parameters were more equivocal, but gave some indication of TASF effects on head circumference.

3.2 Infants and young children

It is well established that the life course phase of infancy and young childhood is among the most vulnerable to malnutrition. In this subsection, we cover TASF in the diets of children ages 6-59 months. Complementary feeding is defined as the period when an infant or young children, age 6-23 months, continues to breastfeed but requires other foods to meet daily requirements (WHO, 2021c). TASF may be particularly critical in this period to supply bioavailable nutrients that may be more efficiently absorbed (Iannotti, 2018; Murphy and Allen, 2003). Infants have a limited gastric capacity, thus needing complementary foods fed more frequently throughout the day and supplying nutrients that may be efficiently absorbed to support rapid growth and neurological development (Bergman, 2013; Brown and Lutter, 2000). Immunity is also transitioning from the passive immunity conferred by the mother through pregnancy and lactation to an independent, maturing system in the child. Zinc found concentrated in TASF is one example of a critically important nutrient for the development of adaptive immunity particularly (Ackland and Michalczyk, 2016).

As described in Section B, certain nutrients and bioactive compounds provided only by TASF or more biologically active compared to PBF are critical during infancy and early childhood for growth and development. Vitamin B12 supports neurological development among many other processes and can only be delivered through TASF (Allen *et al.*, 2018). Zinc and iron deficiencies are highly prevalent in young children, leading to stunting, diarrhoeal morbidities and mortality and compromised cognition, language and socio-emotional development (Black *et al.*, 2017, 2013). During the complementary feeding period, the non-breastfed infant may be especially vulnerable to nutrient deficiencies and, therefore, require nutrient-dense foods such as TASF after six months of age (WHO, 2005). On the other end of the nutrition spectrum, excessive TASF consumption during early childhood may heighten the risk of child and adult overweight and obesity (Lind *et al.*, 2017). Overweight and obesity are risk factors for NCD outcomes including cancer acting through multiple mechanisms (De Pergola and Silvestris, 2013). This subsection reviews the epidemiological evidence across multiple contexts for effects of TASF on infant and young child nutrition and health outcomes.

A series of systematic reviews have examined TASF effects on nutrition outcomes (anthropometry) in young children. It should be noted that the reviews encompass a range of TASF and different kinds of comparator groups (usual diet, fortified foods, etc.). One review examined the literature for effectiveness of TASF on growth and development outcomes among children 6-59 months (Eaton *et al.*, 2019). They identified six trials (n=3036 children) from China, the Democratic Republic of Congo, Ecuador, Guatemala, Pakistan, the United States of America, and Zambia. Three studies showed a significant increase in the change in height-for-age Z score or length-for-age Z score in the intervention group compared to control. As well, three studies reported significant increases in a change in weight-for-age Z score associated with TASF consumption. All-cause morbidities were assessed, and one study testing yoghurt reported a significant reduction in duration and incidence of diarrhoea and upper respiratory infections. The randomized controlled trial conducted in Ecuador examining eggs during complementary feeding reported an increase in diarrhoea morbidity compared to control. The review also reported findings from a study examining meat- and dairy-based diets, indicating a significant increase in length-for-age Z score for meat but not dairy and non-significant findings for weight-for-age Z score.

Another systematic review examined TASF effects on stunted growth among children 6-60 months, identifying 21 studies for inclusion (Shapiro *et al.*, 2019). One randomized controlled trial and one cross sectional study in this review showed significant reductions in stunting. Secondary outcomes of anaemia, height/weight, and head circumference were non-significant. Another systematic review and meta-analysis focused only on milk and dairy products and physical growth of children ages 2 to 18 years of age (de Beer, 2012). Using data from 12 studies conducted in China, Europe, Kenya, Indonesia, India, the United States of America and northern Vietnam, authors found for each incremental increase in daily milk by 245 ml, there were increases in child height by 0.4 cm per year compared to children consuming less. Their results also showed that children with stunted growth had greater growth benefits from milk consumption and that the milk effect on child height was greater than other dairy products.

A systematic review focusing on complementary feeding practices within high-resource contexts and their impacts on infant micronutrient status suggested that meat reduced the risk of iron deficiency among breastfeeding infants who had low iron intake or were at risk of inadequate iron stores during the first year of life. This relationship was however less clear for infants with adequate iron stores. There was also limited evidence for meat’s impact on infant zinc status during the complementary feeding period (Obbagy *et al.*, 2019).

RCT and other types of experimental trials testing the effects of TASF on child nutrition and health outcomes have been included in the systematic reviews described above. A few trials are highlighted here to point to nuances in the findings and the importance of context and the overall dietary pattern. A series of trials has tested the effects of eggs introduced early in the complementary feeding period, from 6-9 months of age. One of the early studies, Lulun Project (Iannotti *et al.*, 2017a), was carried out in Ecuador and showed a relatively large effect on child growth (Length-for-age Z score increased by 0.63 (95% CI, 0.38-0.88); and stunting reduced by 47 percent (prevalence ratio 0.53; 95% CI, 0.37-0.77) (Iannotti *et al.*, 2017a). The trial also found significantly increased concentrations of biomarkers of brain development including choline and DHA (Iannotti *et al.*, 2017b). When the study was replicated in Malawi (Mazira Project), however, there were non-significant findings for eggs on child growth and development outcomes (Prado *et al.*, 2020; Stewart *et al.*, 2019). Important contextual differences were noted. The sample population for Mazira was located near Lake Malawi and was already consuming animal source food in the form of small fish. The staple food was maize, likely high in dietary phytates that can interfere with TASF nutrient absorption. The Lulun sample, by contrast, had limited TASF in the diets and the staples were potatoes and rice. The diverging findings for these two studies highlight the need to consider child diets more holistically.

There is a limited number of studies assessing insects and their products in young children. Caterpillar cereal as a complementary food was tested in the Democratic Republic of Congo showing a positive effect on haemoglobin concentrations and reductions in anaemia (Bauserman *et al.*, 2015). In a small study from Indonesia, young children 24–59 months (n=60) were randomized to receive 45g/d of honey for two months or a control group (Harmiyati *et al.*, 2017). There was some evidence for an effect on anthropometry with differences evident for height-for-age Z, weight-for-age Z, and weight-for-height Z, that may merit replication in a larger trial.

In sum, while systematic reviews point to some benefits of TASF intake among infants and young children in terms of increased hight/length and weight, the diversified findings highlight the importance of considering the environmental health and overall child diets when assessing the relationships across multiple contexts.

3.3 School age children and adolescents

As the young child ages into middle childhood and adolescence, nutrition remains an important factor underlying health. The rate of linear growth slows as energy and nutrients are redirected into other developmental processes (Norris *et al.*, 2022). Among primates, *Homo sapiens* have one of the longest juvenile periods in the life span (Bogin, 2009). Evolutionary biologists posit that the long duration of this period arose for multiple reasons including to enable learning and brain development (Bogin, 2009). This period is characterized by rapid neurogenesis and synapsis formation followed by a period of intense pruning during adolescence (Black *et al.*, 2017). Brain development requires energy- and nutrient-dense diets to meet high glucose and micronutrient requirements, reaching 50 percent of the body's total basal requirements during childhood (Goyal, Iannotti and Raichle, 2018). Similar to infancy and early childhood, the nutrients driving brain development including DHA, iron, zinc, choline, B vitamins, among others are those found bioavailable in TASF. In some contexts, infection may interfere, through inflammation, in nutrition-driven neurodevelopment (Suchdev *et al.*, 2017).

Other important biological processes during the school age and adolescent periods necessitate healthy diets. Growth trajectories follow similar patterns in prepubescent boys and girls (Ruxton & Derbyshire, 2013). Around nine years of age, girls begin their pubescent growth spurt and boys approximately two years later. Differences emerge by biological sex of the individual in this phase for adiposity tissue and fat deposits (Ruxton & Derbyshire, 2013). Peak bone mass is reached during adolescence requiring sufficient supplies of protein, calcium, vitamin D, zinc, phosphorous, magnesium, among others (Wallace *et al.*, 2020). Evidence clearly supports the need for healthy diets to support bone health during these life course phase (Golden, Abrams & Committee on Nutrition, 2014). The immune system also continues to develop and interact with dietary intakes and microbial exposures (Norris *et al.*, 2022). Importantly, adolescents also enter a phase of rapid reproductive development and endocrine system changes, which further require healthy diets and other health-promoting behaviours. With menarche, girls' iron requirements increase (Brabin and Brabin, 1992). In totality, the nutrient requirements of the school-age child and adolescent points to the ongoing importance of healthy diets, which may be inclusive of TASF.

TASF consumption has been evaluated in school-aged children and adolescents for nutrition (anthropometry), health (bone health) and cognition outcomes. In the systematic review and meta-analysis described above examining milk and dairy products, they found an increase in height growth of 0.4cm per year associated with daily consumption of 245ml of milk/dairy (de Beer, 2012). Data was drawn from samples in China, Europe, Kenya, Indonesia, India, northern Vietnam and the United States of America. Adolescents showed increased height effects from dairy consumption compared to school-aged children and among all children and adolescents, those with low height-for-age showed greater effects on height in association with milk intakes.

Some concerns have been raised about longer-term risks of overweight and obesity in association with child consumption of milk and dairy products. One systematic review examined this question directly (Lu *et al.*, 2016). They identified 10 studies (n=46 011 children and adolescents) with an average of three-year follow-up period. Children in the highest dairy intake groups showed a reduced risk for overweight/obesity compared to the lowest intake group (pooled odds ratio=0.62; 95% CI: 0.49-0.80). The adjusted regression modelling showed that for each additional one serving per day of dairy, the risk of overweight/obesity was 13 percent lower than children consuming lower quantities (odds ratio=0.87; 95% CI: 0.74-0.98).

A previous systematic review and meta-analysis showed consistent findings for milk or dairy consumption in relation to adiposity (Dror, 2014).This analysis included children across multiple age categories – pre-school, school-age and adolescents living in high-income countries from 36 studies. The investigator found no significant effect for milk or dairy intake and increased adiposity, and among adolescents, they showed dairy intake reduced adiposity with an effect size of -0.26 (95% CI-0.38, -0.14, P<0.0001).

As well as anthropometry, bone health has been studied in relation to dairy and egg consumption in school age children and teenagers. A review of randomized controlled trials found eight studies indicating positive effects of dairy consumption on both bone mineral content and bone mineral density (Kouvelioti, Josse & Klentrou, 2017).

Another observational study in a population in the United States of America examined egg consumption and bone health among 13 year olds (n=294) (Coheley *et al.*, 2018). They found that egg consumption was positively associated with bone mineral content (radium cortical bone mineral) and biomarkers of bone metabolism (osteocalcin).

Although there is compelling evidence for highly active brain development during childhood and adolescence that could be responsive to TASF in the diet, few studies have examined this linkage. One systematic review aimed to examine the effects of beef and beef products on cognitive outcomes in children and young adults (An *et al.*, 2019). They assessed findings from five unique interventions, some of which have been covered previously in the section on young children (Krebs *et al.*, 2012). Interventions evaluated in the trials compared beef to other TASF (e.g. a glass of milk) or PBF. There was only one intervention that compared beef to a usual diet control group, and this was also the only study showing positive effects on cognitive outcomes (Neumann *et al.*, 2007).

The series of papers published from a cluster randomized controlled trial carried out among Kenyan school children (n=911) have been widely cited in the literature for TASF nutrition (Gewa *et al.*, 2009; Hulett *et al.*, 2014; Neumann *et al.*, 2007; Whaley *et al.*, 2003). This group compared the health and development outcomes of four groups: meat with githeri stew (maize, beans and greens), milk with githeri stew, githeri stew alone and a control group. They found that children in the meat group performed better in terms of cognitive function than the milk or control groups and children in both the milk and the meat groups had better growth outcomes than the control group (Neumann *et al.*, 2007). Multiple other health and nutrition outcomes have been reported from this study. Vitamin B12 plasma concentrations were increased in the meat and milk groups (McLean *et al.*, 2007; Siekmann *et al.*, 2003). Arm muscle area and mid-upper arm circumference were significantly higher over time in the meat and milk groups compared to the githeri and control groups (Neumann *et al.*, 2013b). Differences were also observed for morbidities among other outcomes (Neumann *et al.*, 2013a).

In sum, the school age child and adolescent undergoes critical growth, reproductive, endocrinal, and neurodevelopmental changes that require energy and nutrient dense foods. Similar to pregnancy and lactation life course, more synthesized evidence is available for the effects of milk and dairy products, though meat has been evaluated for cognition, growth, and other health impacts. Findings from systematic reviews on milk and dairy are associated with increased height, bone health and lower risks for overweight and obesity. Similarly intake of eggs is associated with bone mineral content and bone mineral density. Meat and milk intakes were associated with positive health, nutrition and cognitive outcomes in a cluster randomized controlled trial in Kenya.

3.4 Adults

Healthy diets are important during adulthood for maintaining biological systems, responding to changes that may occur such as infection or other environmental exposures, and supporting ongoing neurogenesis. Overall anthropometry and body composition differ in men and women, influencing the levels of macro- and micronutrients required in the diet to maintain health (Brown, 2019). On average, muscle mass is higher in men than women, while women have higher fat mass with differing dietary needs (Gallagher, Chung and

Akram, 2013). Women of reproductive age 15–49 years are also set apart requiring additional nutrients found in TASF such as iron due to menstruation and other reproductive health processes.

During adulthood, TASF within the context of a healthy diet can protect and promote health. This section will overview the benefits and risks of dietary intakes of TASF at a range of different levels. Table C2 summarizes the levels presented as healthy reference intake as well as risk thresholds depending on the nature of the analysis. For example, the healthy reference diet of the EAT-Lancet Commission incorporates daily intake levels for several different TASF based on nutrient intake adequacies and analyses of the literature (Willett *et al.*, 2019b). Similarly, the Global Diet Quality Score (GDQS) is a food-based metric consisting of 25 food groups of which 16 are classified as healthy, 7 as unhealthy and 2 (red meat and high-fat dairy products) as unhealthy when consumed in excess. Investigators based the score on the analysis of datasets containing 24-hour dietary recalls across different regions and an analysis of the association with each candidate metric with a range of diet quality outcomes related to nutrient adequacy and NCD risk. By contrast, the GBD estimates provide thresholds for risk analyses across different dietary factors including processed and unprocessed meats (Afshin *et al.*, 2019b; Murray *et al.*, 2020b). In the GBD 2019, they reduce theoretic minimum risk exposure level (TMREL) to zero as presented in Table C2.

Overconsumption of TASF, however, can be associated with overweight and obesity and NCD. The World Health Organization has established a Global Action Plan the Prevention and Control Of Non-Communicable Diseases 2013-2020 (WHO, 2021b) – cardiovascular disease, cancer, chronic respiratory diseases and diabetes. Unhealthy dietary behaviours are among the risk factors targeted for chronic disease prevention (WHO, 2014). Processed meats specifically have been classified as carcinogenic by the International Agency for Research on Cancer in 2015, though biological mechanisms are not well established and need to be considered following risk assessment within the context of healthy dietary patterns (Boobis *et al.*, 2016; IARC, 2015; Thøgersen and Bertram, 2021). A large body of epidemiological evidence was available in the development of the report examining the association between meat consumption and colorectal cancer with a dose-response relationship evident in both processed and unprocessed meats – leading the report to conclude a clear association for processed meats and probable link for unprocessed meat (Bouvard *et al.*, 2015). Subsequent analyses have questioned the validity of findings due to a weak effect size, heterogeneity and a lack of dose-response patterns (Alexander *et al.*, 2015).

The biological mechanisms for NCD vary and depend on a range of factors extending beyond unhealthy dietary practices, such as genetics, physical inactivity, underlying health conditions and comorbidities and environmental exposures. TASF consumption has been associated with increased levels of low-density lipoprotein-cholesterol in the blood, which can in turn, increase risk for atherosclerosis (disease of large arteries) and cardiovascular disease. Dietary intakes of saturated fatty acids can increase low-density lipoprotein in the blood, though dietary cholesterol has been shown to have minimal effects on plasma concentrations of low-density lipoprotein cholesterol (Astrup *et al.*, 2020; Fernandez, 2012; Guasch-Ferré *et al.*, 2019). As described in Section B, cholesterol plays important roles in the human body including cell membrane activity and integrity and serving as a precursor for steroids such as sex hormones, adrenocortical hormones, and vitamin D (Gropper, Smith and Carr, 2021b). In excess as previously described, cholesterol may not be catabolized readily leading to increased risk of atherosclerosis (Schade, Shey and Eaton, 2020).

Potential mechanisms underlying red meat association with chronic disease include pro-inflammatory factors, serum ferritin, heme iron, heterocyclic amines, trimethylamine N-oxide, and saturated fats, among others. Evidence largely derives from observational studies in humans, animal models and cell cultures (Kim, Keogh and Clifton, 2015; Kruger and Zhou, 2018). With regards to processed red meat, reviews examining the mechanisms highlight particular compounds that can harm DNA: carcinogenic N-nitroso compounds from curing meats with nitrite; polycyclic aromatic hydrocarbons from smoking; and heterocyclic aromatic amines from high-temperature cooking (Domingo and Nadal, 2017; Turesky, 2018). Another review of the biological mechanisms underlying the effect of meat on colorectal cancer suggested that in vitro studies do not represent normal dietary intakes for heme exposure in particular (Kruger and Zhou, 2018). This review also found that the type of NOC in the human body after ingestion with red meat are nitrosyl iron and nitrosothiols, with different chemistries than those implicated in the formation of DNA adducts.

Table C2 Healthy reference intake and risk thresholds of specific TASF for adults, method and data source

Healthy reference intake					
Food	Study	Mean (range in g/d)	Method for calculating range	Analysis or data source	Reference
Red meat	World Cancer Research Fund (WCRF)	350-500g/week[a]	The recommendation on consumption of red meat identifies the level of consumption that the independent panel of experts judges to provide a balance between the advantages of consuming red meat (e.g. as a source of essential macro- and micronutrients) and the disadvantages (e.g. increased risk of colorectal cancer).	Based on an integrated approach to the evidence for defining a "modest amount of red meat and little or no processed meat" to reduce the risk of NCDs. More specific guidance is not possible, because the exact conversion depends on the cut of meat, the proportions of lean meat and fat and the method and degree of cooking.	WCRF, 2018
Red meat, unprocessed	Global Dietary Quality Score[b] (GDQS)	9-46g/day	Categories of consumed amounts: Low: <9g/day Middle: 9–46g/day High: >46g/day Unhealthy in excessive amounts	Based on ability to produce a reasonably even distribution of categories of consumed amounts of each food group using analyses of Food frequency questionnaire and 24-h dietary recall data from cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021
Red meat, processed	Global Dietary Quality Score	9-30g/day	Categories of consumed amounts: Low: <9g/day Middle: 9–30g/day High: >30g/day Unhealthy	Based on ability to produce a reasonably even distribution of categories of consumed amounts of each food group using analyses of Food frequency questionnaire and 24-h dietary recall data from cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021
Beef and lamb	EAT-Lancet Commission	7g/day (0-14g/day)	Because intake of red meat is not essential and appears to be linearly related to total mortality and risks of other health outcomes in populations that have consumed red meat for many years, optimal intake might be 0g/day, especially if replaced by plant sources of protein. Because data on risk of low intakes of red meat are imprecise, it was concluded that an intake of 0g/day to about 28g/day of red meat is desirable and a midpoint of 14g/day for the reference diet.	Derived using calculations of nutrient intake adequacy relative to WHO recommendations. Systematic review of evidence-base.	Willett *et al.*, 2019
Pork	EAT-Lancet Commission	7g/day (0-14g/day)	Because intake of red meat is not essential and appears to be linearly related to total mortality and risks of other health outcomes in populations that have consumed it for many years, optimal intake might be 0g/day, especially	Derived using calculations of nutrient intake adequacy relative to WHO recommendations. Systematic review of evidence-based.	Willett *et al.*, 2019

			if replaced by plant sources of protein. Because data on risk of low intakes of red meat are imprecise, it was concluded that an intake of 0g/day to about 28g/day of red meat is desirable and have used a midpoint of 14g/day for the reference diet.		
Chicken and other poultry	EAT-Lancet Commission	29g/day (0-58g/day)	Since consumption of poultry has been associated with better health outcomes than has red meat, it was concluded that the optimum consumption of poultry is 0g/day to about 58g/day and a midpoint of 29g/day.	Derived using calculations of nutrient intake adequacy relative to WHO recommendations. Systematic review of evidence-based.	Willett *et al.*, 2019
Poultry and game meat	Global Dietary Quality Score	16-44g/day	Categories of consumed amounts: Low: <16g/day Middle: 16-44g/day High: > 44g/day Healthy	Based on ability to produce a reasonably even distribution of categories of consumed amounts of each food group using analyses of Food frequency questionnaire and 24-h dietary recall data from cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings	Bromage *et al.*, 2021
Low fat dairy	Global Dietary Quality Score	33-132g/day	Categories of consumed amounts: Low: <33g/day Middle: 33-132g/day High: > 132g/day Healthy	Based on ability to produce a reasonably even distribution of categories of consumed amounts of each food group using analyses of Food frequency questionnaire and 24-h dietary recall data from cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021
High fat dairy[c] (in milk equivalents)	Global Dietary Quality Score	35-734g/day	Categories of consumed amounts: Low: <35g/day Middle: 35-142g/day High: 142-734g/day Very High: >734g/day Unhealthy in excessive amounts	Based on ability to produce a reasonably even distribution of categories of consumed amounts of each food group using analyses of Food frequency questionnaire and 24-h dietary recall data from cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021
Whole milk or derivative equivalents (e.g. cheese)	EAT-Lancet Commission	250g/day (0-500g/day)	Because a clear association does not exist between intake of milk or its derivatives greater than 0–500g/day and major health outcomes and competing risks for some types of cancer, a wide range of intakes are compatible with good health. Because consumption of unsaturated plant oils conveys lower risks of cardiovascular disease than dairy fat, optimal intake will usually be at the lower end of this range and 250g/day were used for the reference diet.	Derived using calculations of nutrient intake adequacy relative to WHO recommendations. Systematic review of evidence-based.	Willett *et al.*, 2019

Egg	EAT-Lancet Commission	13g/day (0-25g/day)	An intake of eggs of about 13g/day or about 1.5 eggs per week were used for the reference diet, but a higher intake might be beneficial for low-income populations with poor dietary quality.	Derived using calculations of nutrient intake adequacy relative to WHO recommendations. Systematic review of evidence-based.	Willett *et al.*, 2019
Egg	Global Dietary Quality Score	6-32g/day	Categories of consumed amounts (g/day): Low: <6g/day Middle: 6-32g/day High: > 32g/day Healthy	Based on ability to produce a reasonably even distribution of categories of consumed amounts of each food group using analyses of Food frequency questionnaire and 24-h dietary recall data from cross-sectional and cohort studies of non-pregnant and non-lactating women in diverse settings.	Bromage *et al.*, 2021
Risk thresholds					
Food	Study	Mean (range)	Method for calculating range	Analysis or data source	Reference
Red meat unprocessed	Global Burden of Disease2017	23g/day (18–27g/day)	20% above/below mean	Comparative risk assessment[d]	Afshin *et al.*, 2019
Red meat processed	Global Burden of Disease2017	2g/day (0–4g/day)	20% above/below mean	Comparative risk assessment[d]	Afshin *et al.*, 2019
Read meat	Global Burden of Disease2019[e]	0g/day	No data	Comparative risk assessment[d]	Murray *et al.*, 2020
Meat, processed	Global Burden of Disease2019[c]	0g/day	No data	Comparative risk assessment[d]	Murray *et al.*, 2020

Notes: Foods are named as in reference.

[a] WCRF recommendation: Consumption of red meat should be limited to no more than about three portions per week. Three portions are equivalent to about 350–500g cooked weight. Consumption of processed meat should be restricted to very little, if any.

[b] *GDQS is based only on cross-sectional and cohort data from non-pregnant, non-lactating women of reproductive age in 10 African countries and China, India, Mexico, and the United States of America. The classification in healthy, unhealthy in excessive amounts and unhealthy is based on review of the literature on dietary contributors to nutrient intakes and NCD risk globally (Intake, Harvard School of Public Health and Instituto Nacional de Salud Pública, 2021; Micha* et al.*, 2017; Willett* et al.*, 2019a).*

[c] Hard cheese should be converted to milk equivalents using a conversion factor of 6.1 when calculating total consumption of high-fat dairy for the purpose of assigning a GDQS consumption category.

[d] Based on World Cancer Research Fund evidence grading criteria to separately assess the strength of the epidemiologic evidence on the causal relationship between each dietary risk factor and disease endpoint, and included only dietary risk factors for which convincing or probable evidence on their relationship with chronic diseases was found.

[e] The study states that sufficient evidence was found supporting the causal relationship of red meat intake with ischaemic heart disease, breast cancer, haemorrhagic stroke and ischaemic stroke and these outcomes were added and the dose–response curve of relative risk for red meat and outcomes based on the most recent epidemiological evidence and a newly developed method for characterising the risk curve updated. Controversy about the non-transparent methodology has been discussed (WFO Scientific Council, 2021).

As was found for other life course phases, milk and dairy products have been studied extensively for nutrition and health outcomes in adults. One meta-review compiled this evidence to assess the effect on all-cause mortality (Cavero-Redondo *et al.*, 2019). They included eight meta-analyses, assessing the quality of the evidence finding that 50 percent met the criteria for "very good," while 25 percent were "good" and 25 percent "acceptable". Relative risks were reported for dairy products, milk, cheese and yoghurt finding no excess risk for all-cause mortality associated with these products. Other reviews have parsed the effects of milk and dairy on different chronic disease outcomes. A systematic review and meta-analysis showed one cup of milk (200 ml) per day reduced risk of cardiovascular disease, stroke, hypertension, colorectal cancer, metabolic syndrome, obesity and osteoporosis in a dose response manner (Zhang *et al.*, 2021). Authors also found an increased risk associated with milk for prostate cancer and Parkinson's disease.

Another systematic review and meta-analysis drew data from 13 cohort studies for coronary heart disease, seven for ischaemic stroke, finding that an increase of 200g/d intake of high-fat milk intake was positively associated with coronary heart disease, RR 1.08 (95% CI:1.00-1.16) while an increase of 90g/d of cheese reduced the risk of coronary heart disease, RR 0.96 (95% CI:0.93-0.98) (Jakobsen *et al.*, 2021). In another updated systematic review and meta-analysis, investigators focused on risk assessment for dairy products and hypertension only (Heidari *et al.*, 2021). The combined 16 studies showed reduced risks for hypertension, for: all dairy products, RR 0.90 (95% CI:0.87, 0.94); low-fat dairy products, RR 0.86 (95% CI:0.77-0.96); milk, RR 0.94 (95% CI:0.90-0.99); and fermented dairy, RR 0.95 (95% CI:0.91-0.99). In subgroup analyses, however, authors reported differential findings based on sex, region, and stage of hypertension.

Milk and dairy products also seem to protect against type 2 diabetes. A systematic review and meta-analysis combined 22 cohort studies to show that dairy intakes for each 200g/d increase reduced risk of type 2 diabetes, RR 0.97 (95% CI:0.95–1.00) (Gijsbers *et al.*, 2016). Yoghurt intakes at 80g/d versus no intake also reduced risk, RR 0.86 (95% CI:0.83, 0.90). Heterogeneity across the included studies, however, was high. A meta-analysis of cohort study in adults in the United States of America found only yoghurt to be protective of T2D, HR 0.83 (95% CI:0.75–0.92) (Chen *et al.*, 2014). Breast cancer was also studied in relation to milk and dairy intakes in a systematic review and meta-analysis (Zang *et al.*, 2015). There were again a total of 22 prospective cohort studies included in this analysis and authors showed high and modest intakes of dairy products reduced the risk of breast cancer compared to low intakes and subanalyses for particular dairy products protective effects from yoghurt and low-fat dairy as well.

Other systematic reviews and meta-analyses confirm the positive effects of milk and dairy products for reducing risks of metabolic syndrome (Chen *et al.*, 2015), colorectal cancer in men (Ralston *et al.*, 2014), vertebral fracture (Matía-Martín *et al.*, 2019) and hip fracture (for yoghurt only) (Hidayat *et al.*, 2020). One systematic review and meta-analysis showed dairy intakes reduced the risk of endometriosis (Qi *et al.*, 2021). Those consuming greater than 18 servings per week of full fat dairy products showed a relative risk of 0.68 (95% CI:0.76-0.96). In stratified analyses by dairy product, the relationship held for cheese, but not whole or reduced fat/skim milk or yoghurt.

Few studies have examined systematically the effects of substitution or replacement foods for TASF. One prospective cohort study over 32 years in the United States of America found consumption of nuts, legumes or wole grains instead of dairy foods was associated with lower mortality, and consumption of red and processed meat instead of dairy was associated with higher mortality (Ding *et al.*, 2019).

Concerns over dietary egg intakes in adults have largely focused on the risk of blood cholesterol in association with coronary heart disease, stroke, and hypertension. Strong evidence does not support these linkages in healthy adults. A systematic review of meta-analysis of randomized controlled trials examined the impacts of egg consumption on blood pressure in adults (Kolahdouz-Mohammadi *et al.*, 2020). They identified fifteen randomized controlled trials (n=748 participants), finding overall egg consumption showed no significant effect on systolic blood pressure (weighted mean difference 0.046mmHg; 95% CI 0.792, 0.884) and diastolic blood pressure (0.603mmHg; 95% CI 1.521, 0.315). Investigators reported no heterogeneity among included studies.

An earlier review evaluated for association of egg consumption with stroke and coronary heart disease in a systematic review and meta-analysis (Rong *et al.*, 2013). Authors drew data from 17 reports (3 081 269 person years and 5 847 incident cases for coronary heart disease, and 4 148 095 person years and

7 579 incident cases for stroke). Findings indicated no association for either condition. The relative risks of one egg per day were: 0.99 (95% CI:0.85–1.15) for coronary heart disease; and 0.91 (95% CI:0.81–1.02) for stroke. Heterogeneity assessed using I^2 (the percent variance from the point estimate attributable to heterogeneity in study design) was zero percent. In a subgroup analysis among diabetic individuals, there was an increased risk of coronary heart disease comparing the highest with lowest intake levels RR 1.54 (95% CI:1.14–2.09).

Another systematic review and meta-analysis carried out in China using the Guangzhou Biobank Cohort Study including 28 024 participants without cardiovascular disease at baseline (Xu *et al.*, 2019). This study confirmed findings above showing that when comparing high (more than seven eggs per week) to low (less than one egg per week) egg consumption, there were no significant increases in risk for all-cause mortality, mortality from cardiovascular disease, ischaemic heart disease, or stroke. Authors found a small reduction in risk for stroke (HR 0.91. 95% CI 0.85–0.98), but recommended further study.

Meat consumption has also been studied in adult samples with a view towards understanding effects on chronic diseases primarily, though some studies have examined muscle tissue ("flesh") meat intakes on nutrient status. As a bioavailable source of heme-iron described in Section B, meat may affect iron status and anaemia in adults. One systematic review of studies in adults from HICs identified seven high quality studies examining this question (Jackson *et al.*, 2016). They examined intakes of animal flesh foods, defined as muscle tissue of an animal carcass, and included both red and white meats from chicken/poultry, sheep, pig, cattle, goat, fish, seafood, buffalo, kangaroo, camel, deer or rabbit. They included processed meats such as ham, bacon and sausage, but excluded offal such as liver and kidney. Five of these studies indicated that meat intake (85-300g/day) was positively associated with iron status. Although not assessing direct consumption, one systematic review examined the impact of livestock husbandry on anaemia among women and children in LMIC (Lambrecht, Wilson and Jones, 2019). Authors found that interventions trials to targeting poultry production showed a positive effect on anaemia among women and children, while observation studies demonstrated the chicken ownership increased risk for anaemia in young children, potentially arising from increased risk of enteric pathogen exposures.

Red meat consumption (processed and unprocessed) in adults has been studied in association with NCD. Processed meats were consistently defined to include those undergoing changes (e.g. salting, curing, smoking or adding chemical preservatives). While a relatively large evidence base was found, there were serious limitations noted in the assessment of findings derived largely from observational studies with moderate-to-high risk of biases. Analyses have been carried out to explicitly examine the quality of evidence from epidemiological evidence evaluating red and processed meat consumption. In one study looking at processed meat only, authors found risk of misclassification of exposure, serious risk of confounding and moderate-to-serious risk of biases including selection, reporting and missing data biases (Händel *et al.*, 2021). Another overview of the quality of evidence for both unprocessed and processed red meat applied GRADE criteria in a process for developing guidelines (Johnston *et al.*, 2019). The panel of experts from HIC concluded recommendations were weak and come from low certainty evidence. Nonetheless, an overview of the findings is presented below.

The Global Burden of Disease Study (GBD) at the Institute of Health Metrics has carried two recent analyses of dietary risk factors using statitical analyses. In the GBD 2017 study, investigators established thresholds for dietary intake levels based on compilations of epidemiological data (see Table C2) (Afshin *et al.*, 2019b). Analyses showed red and processed meat contributed to global burden of disease calculated as life years lost due to disability or death, though they ranked low relative to other dietary risk factors such as high sodium, low fruits and low whole grains. Authors noted that this could be a function of limited evidence. In the GBD 2019, the theoretical minimum risk level was reduced to zero increasing the contribution of meat consumption to mortality and burden of disease (Murray *et al.*, 2020b). There may be uncertainty and lack of representation from low- and middle-income countries for the data used for both the GBD (Beal *et al.*, 2021).

Red meat was examined in relation to specific NCDs largely through application of prospective cohort studies. The prospective cohort study, the Prospective Urban Rural Epidemiology (PURE), included 21 countries with representation from low-, middle- and high-income populations. They showed that higher intakes of processed red meats (≥150g/wk versus 0g/wk) increased risk of total mortality (Hazard ratio:1.51;

95% CI:1.08-2.10) and cardiovascular disease (Hazard ratio:1.46; 95% CI:1.08-1.98) (Iqbal et al., 2021). The analysis showed non-significant findings for unprocessed red meat and poultry on the negative health outcomes. Another prospective cohort study in a population of men in the United States of America only found an increased risk of cardiovascular disease for one additional serving of meat per day: total red meat HR 1.12 (95% CI:1.06-1.18); unprocessed red meat HR 1.11 (95% CI:1.02-1.21); and processed meat HR 1.15 (95% CI:1.06-1.25) (Al-Shaar et al., 2020).

As described above, the IARC analyses found substantial epidemiological evidence linking meat to colorectal cancer, in particular processed meat as analyzed in an older meta-analyses (IARC, 2015). A more recent umbrella review of meta-analyses also found suggestive evidence for positive associations between red and processed meat consumption on risk of colorectal cancer; for 50g/d of processed meats RR 1.16 (95% CI, 1.08–1.26) and for 100g/d red/processed meat RR 1.19 (95% CI, 1.10–1.29) (Papadimitriou *et al.*, 2021). This review ranked the quality of this evidence, however, as lower than the strong and highly suggestive findings for beverages and other foods. Cohort studies also found associations between red meat consumption and pancreatic and advanced stage prostate cancers (Bouvard *et al.*, 2015). Another older prospective cohort study carried out in the United States of America showed a positive association between increased daily servings of unprocessed red meats (430.9g/d) and processed meats (421.8g/d) with four-year weight gain (Mozaffarian *et al.*, 2011).

Red meat consumption has been associated with different forms of diabetes in cohort studies. Among Spanish women, total meat consumption, highest versus lowest quartile, was associated with increased risk of gestational diabetes mellitis [OR 1.67 (95% CI 1.06-2.63)], with greater odds observed for red meat [OR 2.37 (95% CI 1.49-3.78)] and processed meat [OR 2.01 (95% CI 1.26-3.21)] (Marí-Sanchis *et al.*, 2018). An older study examined red meat consumption and risk of type 2 diabetes in adults in the United States of America (Pan *et al.*, 2011). They found that for 100g/d of unprocessed meat and 50g/d of processed meat, there was an increased relative risk of diabetes by 1.19 (95% CI: 1.04–1.37) and 1.51 (95% CI: 1.25–1.83), respectively.

Biomarkers of chronic disease have also been examined in relation to meat. A systematic review and meta-analysis examined the effects of total red meat consumption comparing pre- and post-values in biomarkers from greater than or equal compared to less than 0.5 servings (35g)/day of total red meat intakes in a series of randomized controlled trials. They found no significant difference in change values in glucose, insulin, Homeostatic Model Assessment of Insulin Resistance or c-reactive protein (O'Connor *et al.*, 2021).

Few studies have examined meat within the context of the overall diet. One recent prospective cohort study, however, showed that the level of consumption of fruits and vegetables together with processed meats mattered for cancer risk (Maximova *et al.*, 2020). Investigators found low levels of co-consumption of fruit and vegetables with high levels of processed meat increased risk of all-cause and 15 cancers (men: HR 1.85, 1.91; women: HR 1.44, 1.49) compared to high vegetables and fruit with low processed meat intakes.

Replacement or substitution foods in relation to meat have also been minimally studied. A meta-analysis compared red meat with alternative "protein sources": high-quality plant protein sources (legumes, soy, nuts); chicken/poultry/fish; fish only; poultry only; mixed animal protein sources (including dairy); carbohydrates (low-quality refined grains and simple sugars, such as white bread, pasta, rice, cookies/biscuits); or usual diet (Guasch-Ferré *et al.*, 2019). No differences were observed between red meat and the combined category for all alternative diets for changes in blood concentrations of total, low-density lipoprotein or high-density lipoprotein cholesterol, apolipoproteins A1 and B or blood pressure, though there were lesser decreases in triglycerides (weighted mean difference, 0.065mmol/L; 95% CI, 0.000–0.129). Compared to high-quality plant protein sources, red meat resulted in lesser decreases in total cholesterol and low-density lipoprotein, while compared to fish, red meat yielded greater decreases in low-density lipoprotein.

Poultry meat consumption, while sometimes included in analyses of unprocessed meats, has been evaluated to a lesser extent than red meat and other TASF. A systematic review and meta-analysis of cohort studies assessing poultry consumption and stroke risk found seven studies (n=354 718) (Mohammadi *et al.*, 2018). Non-significant pooled relative risks of total stroke risk were demonstrated: highest versus lowest poultry intake categories RR 0.92 (95% CI, 0.82–1.03); and the dose-response risk of stroke, RR: 1.00 (95% CI: 0.96–1.03). Sub-group analyses gave evidence for inverse relationships in a population in the United States of America and women. A nonlinear association was also revealed for lower risk of stroke at consumption of one serving per week.

Evidence is minimal for the effects of insect, grubs and insect products in the diets of adults on health outcomes. One systematic review looked at bee products and cardiovascular risk, but was unable to draw conclusions based on the evidence base (Hadi, Rafie and Arab, 2021). Some experimental trials have studied insect products in relation to biomarkers. Honey compared to sucrose improved lipid profiles (Rasad *et al.*, 2018) and in another study honey was shown to not adversely affect blood lipids in adults (Al-Tamimi *et al.*, 2020). A double-blind randomized controlled trial found evidence suggesting cricket powder improved gut health and reduced inflammation but authors called for more studies (Stull *et al.*, 2018).

In sum, considerable evidence has mounted around dietary intakes of milk and dairy products. These findings suggest protective effects for several health outcomes: all-cause mortality; hypertension; stroke; breast and colorectal cancers; type 2 diabetes, metabolic syndrome and fractures. Evidence for milk and dairy intakes on coronary heart disease is equivocal, and there may be some increased risks for prostate cancer, Parkinson's disease and iron deficiency anaemia but heterogeneity and confounding across these studies may comprise the strength of findings. The evidence for eggs largely point to null effects on a range of chronic disease outcomes in adults. Meat has been studied fairly extensively in adult populations though limitations in design heterogeneity, a context focus in HIC and risk of biases preclude definitive conclusions. Consumption of muscle tissue from a range of animals improves iron status and reduces anaemia. While evidence on processed red meat consumption has been shown unequivocally to increase risk for mortality and chronic disease outcomes (cardiovascular disease and colorectal cancer), recent systematic reviews and meta-analysis found non significant effects of unprocessed red meat intake on health outcomes and biomarkers of chronic diseases compared with older meta-analyses. Poultry has been studied to a lesser extent with evidence showing non-significant findings for chronic disease. More research is needed for meats from hunting and wildlife farming and insects.

3.5 Older adults

Several physiological processes occur during aging that may alter dietary needs (Solomons, 2013). At the cellular level, senescence or growth arrest of replicating cells commences leading to altered protein expression and increased oxidative stress due to accumulation of iron and other inflammatory factors. Tissues (e.g. depigmentation of hair or loss of connective tissue in skin) and organ systems (e.g. respiratory, cardiovascular, immune systems) also change during aging (Brown, 2019). Alterations in blood flow and neurotransmitter metabolism and inflammatory processes can influence cognition and memory. There has been increasing interest in TASF to address some of these deficits in the older adults, though the evidence base remains minimal compared to other life course phases. One example of a nutrient, found concentrated in TASF and of interest in healthy aging, is choline which has been shown to improve memory among other neuroprotective effects (Blusztajn, Slack and Mellott, 2017).

TASF contain nutrients and bioactive compounds that may be critical for preserving muscle mass, bone health and reducing brain disorders and impaired cognition among older adults (Cardoso, Afonso and Bandarra, 2016). Sarcopenia is the loss of muscle or lean body mass in the aging process (Santilli *et al.*, 2014). Protein metabolism changes with age such that the protein synthesis cannot compensate for the protein catabolism (Baum, Kim and Wolfe, 2016). Investigators have suggested increasing high quality protein intakes in older adults to 25–30g per meal (Paddon-Jones and Rasmussen, 2009). Meat containing bioactive compounds such as creatine and carnitine has been hypothesized to counteract this effect (Phillips, 2012). One narrative review identified in this assessment showed that the consumption of 113g of meat five times a week would be the optimal dietary intake levels in older adults for addressing sarcopenia (Rondanelli *et al.*, 2015). Relatedly, TASF may protect bone health and prevent osteoporosis, which again results from the body's inability to replace old bone with new bone tissue. For both men and women, dietary nutrient requirements for some minerals increase after age 65 years, notably calcium and magnesium. These minerals as well as vitamin D are needed to prevent bone loss and related frailty fractures in aging (Bonjour *et al.*, 2013). Finally, TASF providing DHA such as eggs may be important for preventing macular degeneration and brain disorders, enhancing memory and neuroprotection more broadly (Cardoso, Afonso and Bandarra, 2016).

There is increasing epidemiological evidence, particularly from high-income countries, examining the health effects of dietary intakes of TASF and nutrition and health outcomes among older adults. Still, there were limitations present including grouping older adults with adults in the literature and the reality that older adults experience more medical conditions than other life course phases. This document included studies in apparently healthy populations, limiting the breadth of evidence for older adults.

Milk and dairy consumption in older adults or earlier in the life course with impacts measured in older adults has been evaluated for nutrition (sarcopenia), health (frailty) and cognitive outcomes (cognitive decline, Alzheimer's). A narrative review examined the effectiveness of dairy intakes on sarcopenia, frailty and cognitive decline among older adults, finding only six studies: five observational prospective cohort studies and one randomized controlled trial (Cuesta-Triana *et al.*, 2019). High consumption of dairy showed an association with reduced frailty and sarcopenia through improved skeletal muscle mass. Authors highlighted two prospective cohort studies conducted in Japan that demonstrated positive effects on cognition, though across all studies, the effects on cognition were equivocal. The Cuesta-Triana review also found that milk consumption in midlife may diminish verbal memory performance later in life. Another review of the literature was carried out to examine milk and dairy effects on preventing dementia and Alzheimer's (Bermejo-Pareja *et al.*, 2021). Again, the two prospective cohort studies from Japan gave evidence in support of this effect – one showing that almost daily intake of milk compared to less than four cups per week reduced the odds of Alzheimer's (Yamada *et al.*, 2003) and the other finding increased consumption of milk and dairy reduced risks for dementia and Alzheimer's disease (Ozawa *et al.*, 2014).

Another systematic review covered intervention and observational trials examining whole foods including TASF for effects on muscle health and sarcopenia (Granic *et al.*, 2020). There were consistent and robust findings for beneficial effects of lean red meat consumption and dairy foods on muscle mass or lean tissue mass. Evidence for eggs and fish was inconclusive.

There were other recent experimental trials not included in the systematic reviews identified in this assessment. A cluster randomized controlled trial also carried out in Australia across 60 residential aged care facilities (n=7 195 participants, mean age 86±8.2 years) (Iuliano *et al.*, 2021). Thirty residential facilities received additional milk, yoghurt and cheese as the intervention. Results showed that there were reduced risks for all fractures by 33 percent (hazard ratio 0.67, 95% CI: 0.48-0.93; P=0.02), by 46 percent for hip fractures (HR 0.54, 95% CI: 0.35–0.83; P=0.005), and 11 percent for falls (HR 0.89, 95% CI: 0.78–0.98; P=0.04). Significance was reached for falls by three months of dairy intakes and by five months for hip fractures. No difference in mortality risk was observed. Another cluster randomized controlled trial, also in Australia, tested the effects of lean red meat (160g/d) consumed 6 days/week with progressive resistance training on muscle health (Daly *et al.*, 2014). Compared to the control group, the intervention group showed greater gains in total body and leg lean tissue mass and muscle strength. A similar randomized controlled trial in a different Australian setting presented some contrasting findings. In a 6–month bundled intervention with a 3–day/week resistance training combined with either two 80g servings of cooked lean red meat or approximately 225g of cooked pasta or rice (control) on training days (n=154; age ≥ 65 years), no significant differences were found in changes for total body and leg lean mass. Additionally, the intervention did not significantly affect changes in thigh muscle cross-sectional area, leg and back muscle strength, executive and cognitive functioning, systolic blood pressure and physical function. Relative to the control group, individuals assigned to the lean red meat group had greater improvements in arm lean mass, gait speed, muscle density and appendicular lean mass. The control group for this study was reported to have significantly greater improvements for indicators of memory and learning at 12– and 24–week follow-up points in the study (Formica *et al.*, 2020).

Other small-scale dietary intervention studies have been conducted in older adults – one assessing the effect of replacing meat with a soy-based diet in post-menopausal women (Roughead *et al.*, 2005) and the other comparing lactovegetarian diet with meat in older men (Haub *et al.*, 2002). Neither showed significant findings for effects on health outcomes. Another study in the Netherlands showed that fermented milk drink improved bowel habits in older adults (van den Nieuwboer *et al.*, 2015).

A large prospective cohort study (n=16 948) assessing the relationship between consumption of different meat types (red meat, poultry, fresh fish/shellfish, preserved fish/shellfish) during midlife (mean age at baseline: 53.50±6.23 years) and cognitive outcomes during later life (mean age at endline: 73.18±6.41 years) was identified. Based on a cohort from the Singapore Chinese Health Study, findings indicated that individuals in the highest quartile of red meat consumption (median intake: 48.61g/day) had significantly higher odds of cognitive impairment (OR 1.16, 95% CI: 1.01–1.32, *P* for trend = 0.009), compared to those in the lowest quartile (11.81g/day). On the other hand, poultry intake in the highest quartile (median intake: 37.18g/day) was protective against cognitive impairment, though this relationship was not statistically significant (OR 0.89, 95% CI: 0.78–1.02, *P* for trend = 0.10). Further assessments of different types of red meat found organ meat consumption in the highest quartile to be protective against cognitive impairment (OR 0.91, 95% CI: 0.7–1.05, *P* for trend = 0.02), whereas consumption of fresh red meat and preserved/processed meat in the highest quartile were respectively associated with a 15 percent increased likelihood of cognitive impairment (fresh red meat: OR 1.15, 95% CI: 1.00–1.32, *P* for trend = 0.05; preserved/processed red meat: OR 1.15, 95% CI: 1.00–1.32, *P* for trend = 0.02) (Jiang *et al.*, 2020).

In sum, in older adults, epidemiological evidence for the health effects of TASF comes primarily from HIC. There was consistent strong evidence indicating positive effects for lean red meat consumption on muscle health, while one prospective cohort study examining unprocessed and processed red meat suggests increased likelihood of cognitive impairment, except for organ meat. Other evidence suggests the potential for milk and dairy products and other TASF in mitigating impacts on sarcopenia (muscle loss), fractures, frailty, dementia and Alzheimer’s disease.

5 Allergies related to terrestrial animal source food

Food allergies are considered a food safety concern that affect a subset of the population (FAO and WHO, 2021a). These allergies vary in prevalence, severity and potency (FAO and WHO, 2021a). While previously considered a minority issue, food allergies have emerged as a key concern at both an individual and food business operator level (Sicherer and Sampson, 2018; Taylor, 2000). According to the Codex Alimentarius Expert Committee on Food Allergens (FAO and WHO, 2021b, 2021c), from the many different TASF analysed, egg and milk proteins were two of eight key food groups that pose allergenic risks to the population. It is therefore often mandatory to state the presence of either eggs or dairy in food (FAO and WHO, 2020) as part of precautionary allergen labelling. The rationale behind this decision and the potential risks posed from milk and egg allergies are discussed below.

4.1 Milk sensitivity

Milk sensitivity can be caused by either lactose or milk proteins (Muehlhoff *et al.*, 2013): the former is the result of non-digestion of lactose, the main sugar present in human and other mammals’ milk, due to lactase deficiency, whereas the latter is an adverse reaction to proteins. Depending on this, hypersensitivity will have different symptoms, diagnosis and management or treatment. For ease of understanding, Box C5 provides a glossary of terms used in this section and explains differences across them.

Lactase deficiency and lactose malabsorption are not diseases but normal variants of human metabolisms, differently from congenital lactase deficiency, which is a very rare genetic disorder. According to a recent systematic review (Storhaug, Fosse and Fadnes, 2017), the global prevalence of lactose malabsorption among individuals older than ten years is estimated to be 68 percent, with some variations depending on the assessment method as well as varying definitions and thresholds, which were also indicated as limitations of the study. There are significant differences across regions, as well as among nations and within ethnic groups in each country (see Figure C3). Lactose malabsorption is significant in the Middle East (70 percent of the population ranging from 56 percent in Israel to 96 percent in Oman), Northern Africa (66 percent ranging from 53 percent in Western Sahara to 84 percent in Tunisia), Asia (64 percent ranging from 58 percent in Pakistan to 100 percent in South Korea) and Sub-Saharan Africa (63 percent ranging from 13 percent in Niger to 100 percent in Malawi and Ghana).

Box C5 Glossary of terms related to allergies and intolerances caused by milk

Lactase deficiency: also called lactase non-persistence, is the inability to digest large amounts of lactose. Lactose is digested and absorbed by the body thanks to lactase, an enzyme, which is highest in concentration during infancy and decreases after weaning (Misselwitz *et al.*, 2019).

Congenital lactase deficiency: a very rare genetic disorder (for example, ranges in Western European population between 1:23 000 and 1:44 000 births) that appears right after birth and has severe symptoms such as delayed mental development and death, frequently caused by a fulminant *E. coli* sepsis (EFSA, 2010).

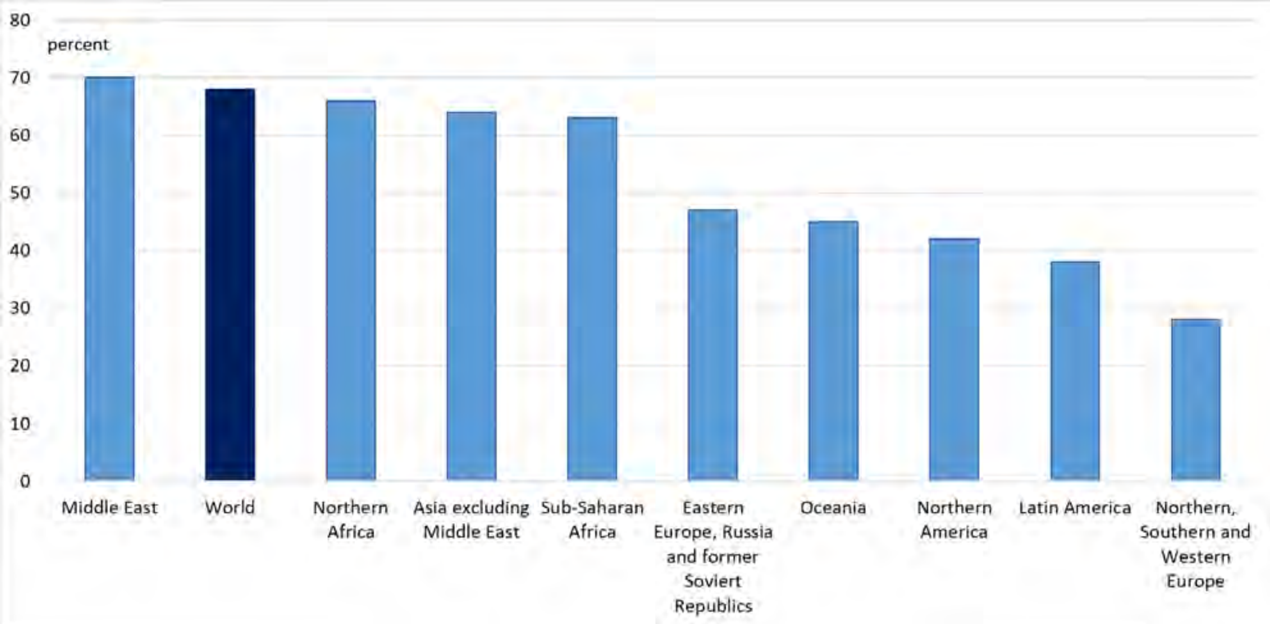
Lactose malabsorption: refers to failure to digest and/or absorb lactose in the small intestine. Lactose malabsorption can have different causes: primary lactose malabsorption (the most common form) is due to lactase deficiency, whereas secondary lactose malabsorption can be transitory and be, among others, caused by rapid small intestinal transit or small bowel bacterial overgrowth (Misselwitz *et al.*, 2019). Not all individuals with lactose malabsorption have lactose intolerance.

Lactose intolerance: indicates symptoms associated with the ingestion of food containing lactose, such as abdominal pain, bloating and diarrhoea. Individuals with lactose intolerance have different levels of tolerance towards dairy products. In some subjects with lactose malabsorption, less than 6g of lactose can lead to symptoms of lactose intolerance; however, according to the European Food Safety Authority (EFSA) Panel on Dietetic Products, Nutrition and Allergies (NDA) the vast majority can tolerate up to 12g with no or minor symptoms (EFSA, 2010). According to a systematic review on the management of lactose intolerance (Shaukat *et al.*, 2010) this figure is between 12–15g; whereas another review (Deng *et al.*, 2015) indicates 20g in lactase deficient individuals. Furthermore, in individuals with lactose intolerance, the severity of symptoms depends on the dosage, type of food consumed, as well as on their microbiome and the presence of visceral hypersensitivity (for example irritable bowel syndrome) (Misselwitz *et al.*, 2019).

Milk-protein allergy: also called cow's milk allergy, is an immune mediated adverse food reaction to milk proteins and can be due to immunoglobulin E (IgE), non–IgE mediated or mixed reactions (Di Costanzo and Berni Canani, 2018). Around 60 percent of those with cow's milk allergy have the IgE mediated form (Flom and Sicherer, 2019), although some differences exist based on the study population and age group. Although cow milk contains approximately 20 potentially sensitizing proteins (Fiocchi *et al.*, 2010) those involved in cow's milk allergy are mainly two: β–Lactoglobulin and casein (Muehlhoff *et al.*, 2013). Cow's milk allergy is one of the most common food allergies, especially in the first year of life, but tends to be outgrown by patients around the age of 2–5 years (Di Costanzo and Berni Canani, 2018). Symptoms of cow's milk allergy include gastrointestinal, skin and respiratory reactions (Fiocchi *et al.*, 2010). Clinical manifestations of IgE–mediated cow's milk allergy are usually immediate (from a few minutes to 2 hours) and include urticaria and/or angioedema with vomiting and/or wheezing (Lifschitz and Szajewska, 2015). Mixed and non–IgE mediated cow's milk allergy tend to have delayed onset and mainly involve the gastrointestinal tract and the skin. In general, cow's milk allergy causes mild to moderate reactions whereas anaphylaxis, a life threatening reaction, is rare (1–2 percent) (Lifschitz and Szajewska, 2015).

Lactose malabsorption and lactose intolerance

Figure C3 Prevalence of lactose malabsorption by region



In Northern and Western Europe, the prevalence of lactose malabsorption is low-to-moderate (4--36 percent); whereas in Eastern Europe it is moderate-to-high (28-81 percent). The review showed 38 percent in Latin America (from 48 percent in Mexico to 80 percent in Colombia); 45 percent in Oceania (from 10 percent in New Zealand to 99 percent Solomon Islands) and 42 percent in Northern America. Interestingly, in Canada and Australia, native populations show different prevalences. An hypothesis is that selection has played a role in maintaining lactase persistence in populations where cattle was important in order to allow digestion of dairy products. This is also the case in Northern Europe and nomadic tribes (Storhaug, Fosse and Fadnes, 2017), as well as in groups that practice pastoralism in Africa, the Arabian Peninsula and Central Asia (Ranciaro *et al.*, 2014).

Table C3 Lactose content in milk from livestock species

Species	Lactose (in g/100g milk)
Buffalo	4.4
Cattle	5.2
Mithan	4.4
Yak	4.8
Goat	4.4
Sheep	5.4
Alpaca	5.1
Bactrian camel	4.2
Dromedary	4.3
Llama	6.3
Reindeer	2.9
Donkey	6.4
Horse	6.6

Note: Nutrient values expressed per 100 gram edible portion on fresh weight basis.

Source: (Australian Food Composition Database, 2021; Balthazar et al., 2017; FoodData Central USDA, 2021; Frida, 2021; Medhammar et al., 2012; Tabla de Composición de Alimentos Colombianos, 2021).

Not all animal's milk and dairy products contain the same level of lactose (see Tables C3 and C4). Lactose content in 100g of milk ranges from 2.9g in reindeer to 6.6g in horse milk and from as low as zero in ghee and different types of cheese such as hard cheese and blue/white mould cheese to around 5g in buttermilk and yoghurt. Live cultures contained in yoghurt and other dairy products with added live cultures are able to support lactose digestion in the gut, therefore reducing the likelihood of symptoms associated with lactose intolerance (Muehlhoff *et al.*, 2013).

Table C4 Lactose content in dairy products

Dairy product	Lactose (in g/100g milk)
Buttermilk	4.9
Yoghurt	5.1
Milk powder	4.3
Cream	3.7
Sour cream	4.6
Ice cream	4.4
Fresh cheese	2.3
Soft cheese	0.9
Butter	0.03
Blue mould cheese	0
Hard cheese	0
White mould cheese	0

Note: Nutrient values expressed per 100 gram edible portion on fresh weight basis
Source: (Australian Food Composition Database, 2021; FoodData Central USDA, 2021).

Individuals with lactose intolerance that avoid milk and dairy products may have reduced intake of calcium, which in turn can cause rickets in young children as well as low bone mineral density and higher risk of fracture in adults (Hodges *et al.*, 2019). Indeed, the WHO (2019) indicates that calcium intakes lower than 300mg/day are associated with almost a 5-fold increased risk of developing rickets.

Cow's milk allergy

A number of factors influence tolerance or sensitization to cow's milk: genetic predisposition, infections, intestinal microflora alteration, as well as age at first exposure, maternal diet, antigen transmission through breastmilk, and the nature, quantity, and frequency of antigen load (Fiocchi *et al.*, 2010).

According to a recent review (Flom & Sicherer, 2019), the prevalence of cow's milk allergy (CMA) in high income countries at one year of age ranges between 0.5 -3 percent. The authors focus specifically on IgE-mediated CMA and observe that available studies are very heterogeneous, making comparison and estimates difficult. In a review of nine guidelines published between 2012 and 2019, Vincent *et al.* (2022) indicate that existing CMA guidance for infants may lead to caregivers mistaking normal infant reactions to cow milk for CMA, leading to overdiagnosis. It seems that 70 percent of children with CMA can tolerate baked foods containing milk if extensively heated (Sicherer and Sampson, 2018).

WHO's guiding principles on complementary feeding indicate that there is no evidence that avoiding potentially allergenic foods (such as eggs and milk) after the age of 6 months can delay or prevent reactions. However, concerning liquid milk, these guidelines advise on delaying its consumption after 12 months of age due to the risk of contamination in environments with poor hygiene (PAHO, 2003).

In adults, the prevalence of CMA is estimated to be 0.5 percent (Fiocchi *et al.*, 2010). With regards to low- and middle-income countries, there seems to be a lack of studies and therefore the prevalence of CMA is not known.

4.2 Egg hypersensitivity

Egg hypersensitivity is one of the most frequent food allergies with an estimated prevalence of 1.7 percent (Hasan, Wells and Davis, 2013) and is the most common food allergy in children with atopic dermatitis (Benhamou *et al.*, 2010). While the first studies date back to 1980s (Hasan, Wells and Davis, 2013), egg hypersensitivity is a complex phenomenon which has only partially been characterized (Benhamou *et al.*, 2010). Ovomucoid, one of the proteins found in egg white, is the dominant allergen, although it only makes up for 10 percent of egg white's protein (Benhamou *et al.*, 2010). Differently from other egg proteins, ovomucoid is also heat-resistant.

Clinical signs usually appear during the first year of life (Benhamou *et al.*, 2010) and can include hives, wheezing, vomiting, eczema, asthma and, very rarely, anaphylaxis (Hasan, Wells and Davis, 2013). Mild reaction in the past does not exclude severe reactions in the future and vice versa (Hasan, Wells and Davis, 2013).

With regards to its resolution, some initial studies indicated that the majority of children tends to outgrow egg allergy by pre-school age, while others show that it is rather during the late teens that egg allergic individuals tolerate eggs (Hasan, Wells and Davis, 2013). Consumption of baked or well-cooked eggs (350°C for 20 minutes) can accelerate the development of tolerance to eggs (Hasan, Wells and Davis, 2013).

Same as for milk, WHO recommendations on complementary feeding advise the introduction of food (including eggs) at six months, as no evidence is available on the benefit of delayed consumption for the purpose of allergy prevention (PAHO, 2003).

Diets which completely exclude eggs and foods that contain them, especially long term ones, need to be monitored to control nutritional adequacy as there is a risk of negative outcomes, and the passage to normalized diets should be done as soon as feasible (Fiocchi *et al.*, 2010).

5 Policies shaping consumption of terrestrial animal source food

Food and nutrition policies are pivotal elements in guiding food consumption at national, regional and global level (FAO, IFAD, UNICEF, WFP and WHO, 2021). This subsection will explore how policy can shape the food system, thereby influencing consumption of common TASF such as milk and dairy products, red meat, poultry and eggs.

Food, nutrition and health policies can have a significant impact on the quantity and diversity of TASF consumed by the public (Bechthold *et al.*, 2018). Unlike agricultural and supply chain policies, which affect the quantity and quality of food produced, food-based policies influence the food system of an entire commodity sector. For example, in a model developed by Springmann *et al.* (2020), moderation of red meat consumption, as suggested by contemporary food-based dietary guidelines (FBDGs), could potentially reduce average greenhouse gas emissions by 13 percent and premature mortality by 15 percent. Miller *et al.* (2021) note that 70 percent of FBDGs encourage increased dairy consumption, whilst less than 55 percent of FBDGs advocate for increased consumption of meat. The authors suggest that these guidelines may have influenced many school feeding policies, which now aim to reduce or moderate meat consumption whilst increasing dairy consumption in order to improve health and environmental sustainability.

National, regional and global policies must balance the various implications associated with TASF consumption (Herforth *et al.*, 2019a). This means adjusting consumption recommendations based on their health outcomes in the generic population and among vulnerable groups, concerns over the environment and socio-economic impacts, whilst accounting for emerging ethical concerns such as animal welfare (Dave *et al.*, 2021). As these policies evolve, it will be important to take stock of the changes being made and ensure that recommendations align with the contexts that they aim to influence.

Recognising the importance of policy, this assessment reviewed a set of five key food and nutrition databases to determine trends in global TASF consumption policy, including FBDGs from the FAO FBDG website (FAO, 2021a), NCD policy from the WHO NCD document repository (WHO, 2021a), nutrition policy from the WHO global database on the implementation of nutrition action (GINA) (WHO, 2021), food legislation from the FAOLEX database (FAO, 2021c) and food and agriculture policy decisions from the FAO Food and Agriculture Policy Decision Analysis (FAPDA) Database (FAO, 2021d):

1. FBDGs are government endorsed documents for practicing healthy diets (Wijesinha-Bettoni *et al.*, 2021). These documents typically aim to impact the food environment and consumer behaviour, guiding individuals towards choosing/ demanding healthier diets (Leroy and Cofnas, 2020). FAO takes a leading role in providing technical support for the development of these guidelines, with a full list of national FBDGs listed on the FAO website (FAO, 2021a).
2. NCD documents are targets, policies and guidelines that focus on preventing and treating NCDs such as obesity, diabetes, cardiovascular disease and cancer (Boudreaux *et al.*, 2020). These documents often make dietary recommendations, with the primary goal of either reducing the symptoms of an NCD or supporting healthy lifestyle choices that reduce NCD risk. TASF consumption is a common theme, with lean meat, eggs and low-fat dairy intake suggested as a good source of micronutrients that support growth and prevent undernutrition. In addition, moderation or reduction of fatty meat, processed meat and red meat consumption are suggested for obesity, cardiovascular disease and cancer risk reduction (Herforth *et al.*, 2019b). The WHO NCD repository contains a rich set of global NCD documents, making it an ideal source for accessing NCD-related national publications.
3. FAOLEX is a repository of national laws, regulations and policies on food, agriculture and natural resource management. Legal and regulatory documents and policy frameworks have strong implications for the food systems within their remit. For example, Mexico's use of fiscal policy to tax soft-drinks has led to a reduction in sugar sweetened beverages amongst young children and adolescents (Thow *et al.*, 2018). Likewise, the mandatory fortification of grain products with folic acid has significantly reduced the prevalence of spina bifida in newborn babies (Martinez *et al.*, 2021). Many countries have implemented food policies and legislation related to the consumption of TASF, with legislation often targeted towards school feeding programmes (Miller *et al.*, 2021).
4. Similar to FAOLEX, the FAO's database on national policy documents (FAPDA) contain national documentation related to food, agriculture and natural resource management. FAPDA, however, focuses mainly on policy framework decisions, which define the basis for broad based strategic, programmatic and financial planning on food systems, including those linked to the consumption of food produced by the livestock sector.
5. Nutrition policies and programmes are guidance documents or policy frameworks that contain diet related guidelines and commitments towards healthy diets and nutrition outcomes (WHO, 2018). These documents often aim to address local malnutrition related issues, such as stunting and wasting in children under five years of age. The WHO Global Database on the Implementation of Nutrition Action (GINA) is a repository of such documents.

All documents were reviewed manually to identify policies related to TASF consumption. Documents were considered in all languages as published. FBDGs available on the FAO food-based dietary guideline website and documents published from 2016-2021 and the following databases were considered: WHO NCD, FAOLEX, FAPDA and GINA databases. Both the search terms and keywords that were used in each database are detailed in Box C6. In addition to the search criteria and keywords, the review considered: country, region, quantitative/ qualitative status, target group within the life cycle (general (adults), infants, young children, adolescents, women of reproductive age, pregnant women, lactating women, older men, older women, older adults in general) and document type (FBDG, NCD, nutrition recommendation, policy framework) (see Annex Tables C10-C15). The flow diagramme presented in Figure C4 presents this process.

The review considered whether recommendations link to human micronutrient needs, overweight, obesity and diet-related NCDs such as diabetes, cardiovascular disease and cancer, if they include environmental sustainability considerations (for example, if recommended serving sizes are based on environmental considerations) and whether they follow a life course approach (with a focus on meeting the needs of nutritionally vulnerable individuals). In addition, the review made note of references to an emerging topic of concern - animal welfare. The drivers behind the different recommendations, consistency between different policies and public health bases for the guidance were also explored.

Box C6 Search terms by database used for Subsection C5

Common search terms
(“animal source foods”, “livestock products”, “egg”, “meat”, “poultry”, “milk”, “dairy”, “cheese”, “game”, “bushmeat”, “insect”, “NCD”, “non-communicable disease”, “obesity”, “diabetes”, “cancer”, “cardiovascular”, “sustainability”, “animal welfare”, “red meat”, “white meat”, “micronutrient”, “vitamin”, “mineral”)

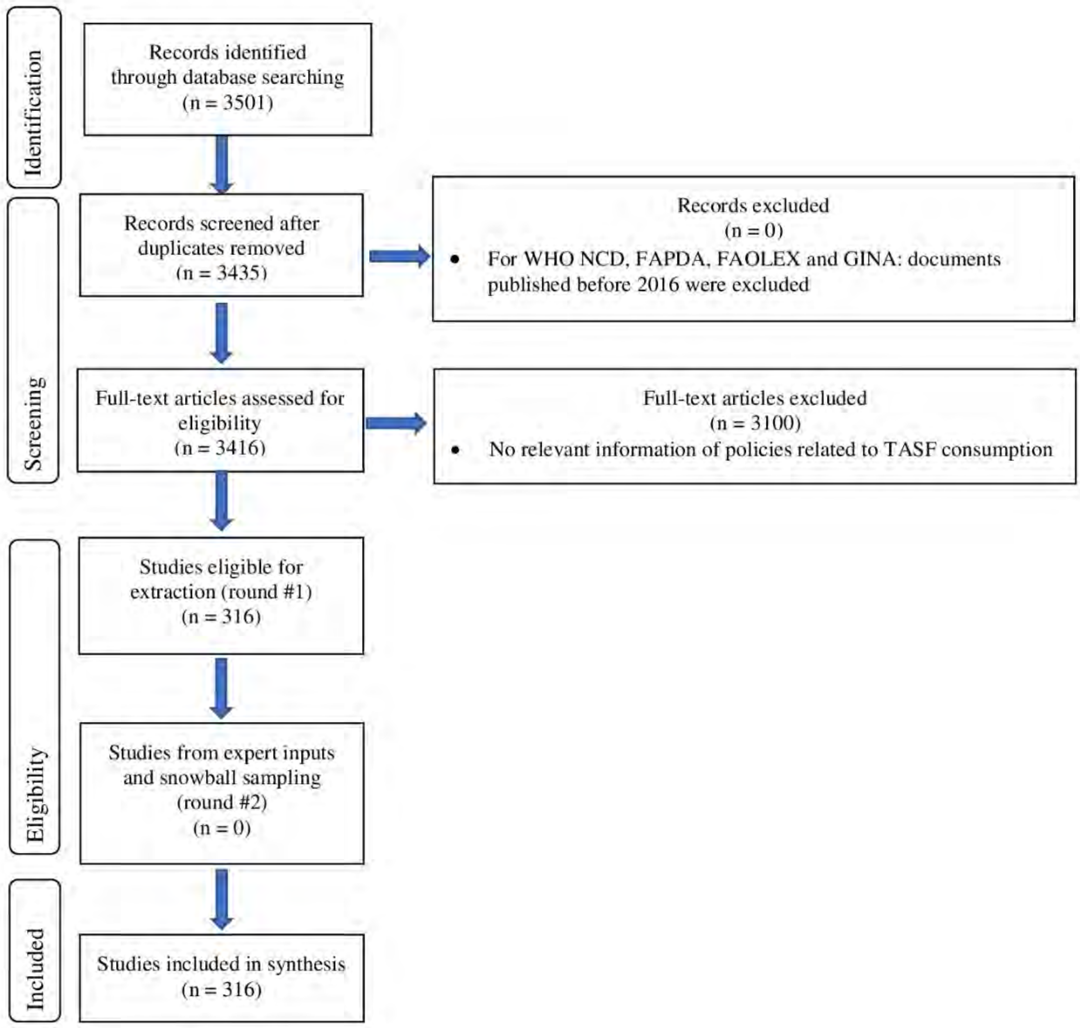
Search terms using WHO NCD database
(“integrated NCD policies”) AND (“cardiovascular disease policies”); (“cancer policies”) AND (“diabetes policies”) AND (“chronic respiratory disease policies”); (“obesity policies”) AND (“diet policies”); (“front-of-pack-labelling policies”) AND (“marketing policies”); (“saturated fat policies”) AND (“integrated guidelines”) AND (“cancer guidelines”); (“cardiovascular guidelines”) AND (“chronic respiratory disease guidelines”); (“diabetes guidelines”) AND (“obesity guidelines”)

Search terms using FAOLEX database
(“infant food”) AND (“animal production”); (“family farm”) AND (“food security”) AND (“production”); (“nutrition”) AND (“meat”); (“eco production”) AND (“meat”); (“nutrition”) AND (“meat”) AND (“public health”); (“animal welfare”) AND (“animal production”); (“animal welfare”) AND (“animal production”) AND (“eco production”); (“poverty”) AND (“meat”); (“use restrictions”) AND (“meat”); (“food security”) AND (“meat”); (“poultry”) AND (“food security”); (“food sovereignty”) AND (“animal production”); (“school feeding”) AND (“meat”); (“environmental protection”) AND (“animal production livestock”); (“fats”) AND (“labelling”) AND (“public health”); (“insects”) AND (“food security”)

Search terms using FAPDA database
Policy classification: “consumer oriented” AND “producer oriented” AND “trade oriented”
Food security dimension: “access” AND “access/availability/utilization of food” AND “access/availability of food” AND “access to food” AND “availability” AND “availability/access/utilization of food” AND “availability/access to food” AND “availability of food” AND “utilization”AND “utilization of food”
Commodity: “meat and other animal derived products”
Policy frameworks: “food security and nutrition” AND “agricultural and rural development”

Search terms using GINA database
(“animal source foods”, “livestock”, “egg”, “meat”, “poultry”, “milk”, “dairy”, “fish”, “bushmeat”, “insect”, “sustainability”, “animal welfare”)

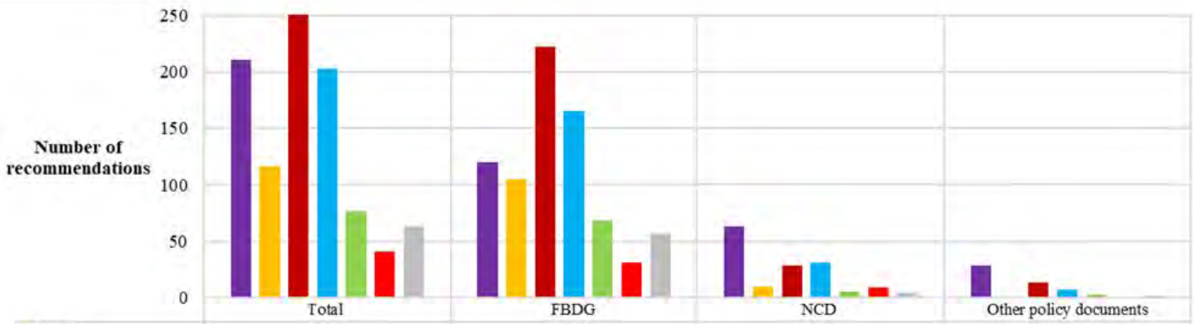
Figure C4 PRISMA Flow diagramme assessing policy trends related to TASF consumption



Recommendations on consumption of terrestrial animal source food

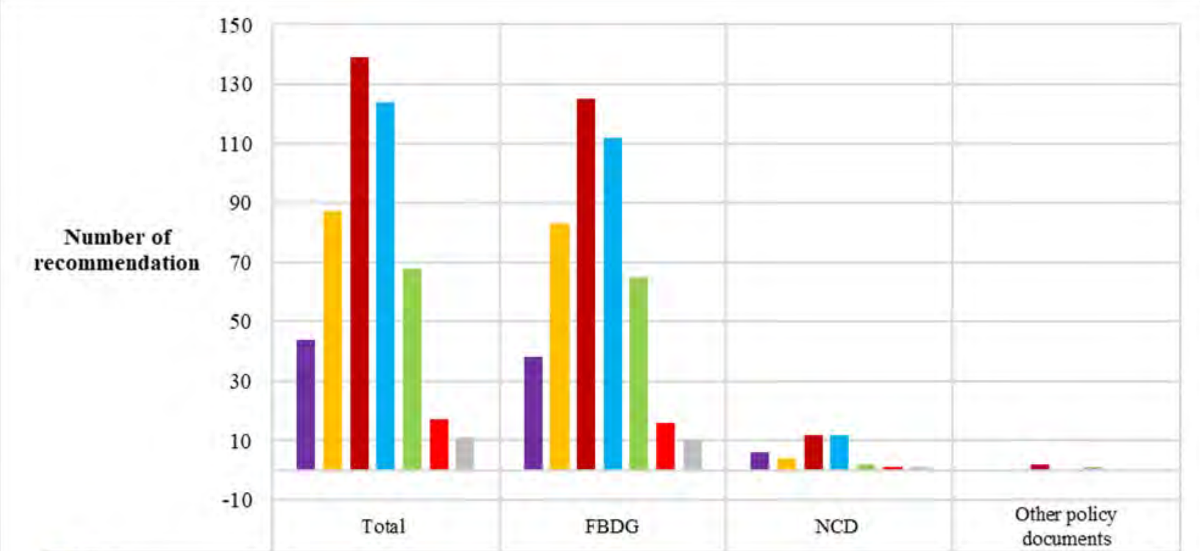
This subsection discusses the collated results obtained from the five databases analysed. Most recommendations are found in the FBDGs, which also contain the highest number of quantitative recommendations, mostly on milk, dairy products, eggs and meat (see Figures C5 and C6). One example of quantitative recommendations being "*the recommended daily intake for lean meat is 120-200g*". It should be noted that the other policy documents have fewer recommendations, which are mostly qualitative and largely generic guidelines. One example of qualitative recommendations being "*children 25-60 months of age should consume meat, milk and eggs when possible*".

Figure C5 Qualitative TASF recommendations by type of policy document



	Total	FBDG	NCD	Other policy documents
TASF	211	120	63	28
Eggs	116	105	10	1
Meat	263	222	28	13
Milk and dairy products	203	165	31	7
Poultry	76	68	5	3
Red meat	41	31	9	1
Others	63	57	4	2

Figure C6 Quantitative TASF recommendations by type of policy document



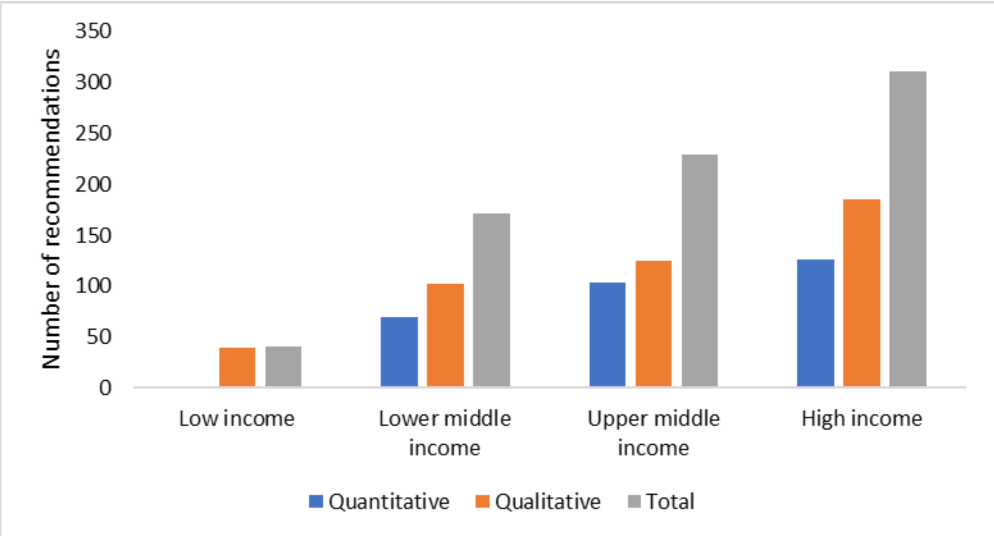
	Total	FBDG	NCD	Other policy documents
TASF	44	38	6	0
Eggs	87	83	4	0
Meat	139	125	12	2
Milk and dairy products	124	112	12	0
Poultry	68	65	2	1
Red meat	17	16	1	0
Others	11	10	1	0

Micronutrient-related recommendationsu

At least 95 countries acknowledge TASF consumption as part of the daily diet in their FBDGs. The nutrient benefits of TASF are also recognized in NCD and legal documents and policy frameworks, with approximately 20 countries linking TASF consumption to a healthy diet.

Micronutrient-related recommendations were incorporated in FBDGs irrespective of the countries' income classification. However, the granularity of these recommendations was found to be variable across the countries (Figure C7). For example, Sierra Leone states that "*animal source food tend to be better sources of some micronutrients than plant-source foods, particularly iron, zinc and calcium*" Kenya mentions that "*foods of animal origin, due to their high bioavailability in micronutrients and as an important source of protein play a key role in improving the nutritional condition of populations*" while New Zealand states that "*red meat is an excellent source of key nutrients like iron (in an easily absorbed form) as well as zinc; low iron levels are a problem for some New Zealanders, particularly young women*" and Belgium encourages citizens to "*have at least three servings of dairy per day, as these are a good source of calcium and vitamin D*". There were also two instances of legislation which encouraged dairy consumption in school meals to boost nutritional status in Kenya, "*free milk programme for nursery school children to boost health and increase enrolment*" and Honduras "*Law of the Glass of Milk for Strengthening School Lunch (Legislative Decree No. 45-2010)*." Further examples are provided in Annex Table C7.

Figure C7 Quantitative and qualitative micronutrient recommendations by country income classification



Quantitative recommendations such as suggestions to consume three servings of 250ml of milk per day were more present in FBDGs of middle- and higher-income countries (Cocking *et al.*, 2020). These recommendations were often linked to specific age-groups, such as "pre-schoolers should have two to three servings of milk and milk products per day" whilst lower-income countries tended to make qualitative generic recommendations such as "eggs are a rich source of vitamin A". Some of the most comprehensive recommendations on TASF consumption, covering specific food groups, vulnerable demographics and daily dietary guidelines came from high-income countries such as Denmark, New Zealand and the United Stated of America (Wyness, 2016) where average meat intake is already well over 150g/day (FAO, 2021e).

In the case of low- and middle-income countries, recommendations also tend to be region specific, with the majority of Latin American countries having some form of quantitative guidelines, whilst most African countries either lack FBDGs or do not have TASF recommendations in their policy frameworks and legal documents. Interestingly, small-island developing states (SIDS) in general tend to lack detailed recommendations related to not only to TASF consumption but also to most other food groups.

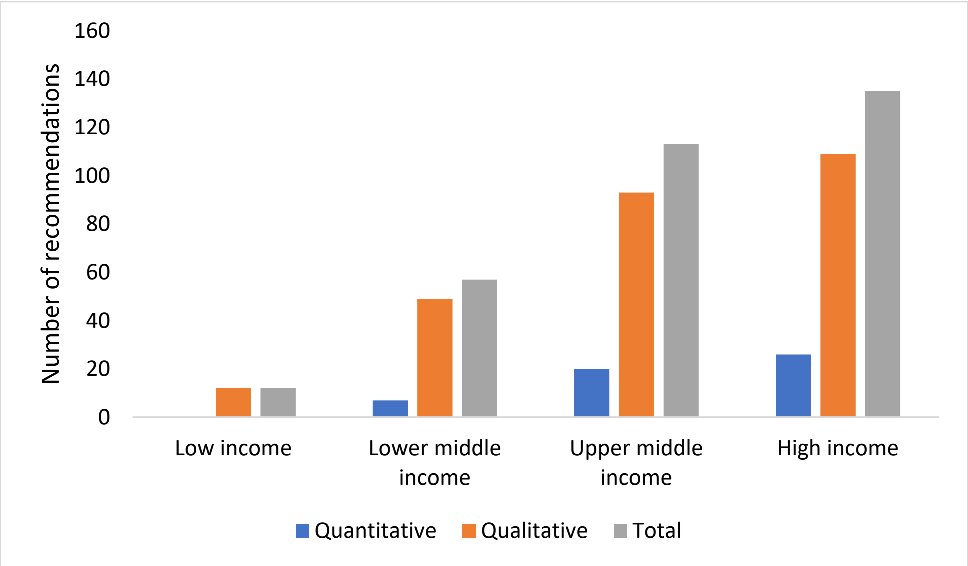
The above trends indicate several points for consideration. Firstly, country income status plays a role in the development of micronutrient related TASF guidelines, but it does not guide how consumption should be appropriately distributed across demographics, especially in vulnerable groups and poorer social classes and how issues related to over-consumption should be addressed to prevent overweight, obesity and NCDs. Secondly, development of such guidelines may vary even amongst low-income countries, with context perhaps playing a role; for example, overnutrition (overweight and obesity) tends to be a growing concern in Latin American countries (Caballero *et al.*, 2017), which may explain the greater emphasis on diet related guidelines and policy frameworks relative to SIDS and African countries.

Noncommunicable disease related recommendations

While food legislations and food and agriculture policy decisions did not discuss NCD risks, the FBDGs and the NCD-related policies contained several in depth recommendations on TASF selection and moderation in the diet. The search highlighted NCD related recommendations from 55 countries, with approximately 310 recommendations, which is almost 50 percent less than the number of countries with micronutrient-related recommendations.

As with micronutrient-related recommendations, NCD-related recommendations are evenly distributed between all countries irrespective of their income (Figure C8). Countries such as Guatemala and Ecuador suggest the general population to “consume lean meats up to four times per week” and “limit the consumption of red meat and avoid processed meats; do not eat more than 500g (cooked weight) per week red meat, such as beef, pork and lamb; eat small amounts or no meat and processed meat such as sausages, hams, and bacon”, whilst countries such as the United States of America and Singapore suggest to “*reduce saturated fat intake*” and that “*non-lean meats and dairy may cause weight gain*”.

Figure C8 Quantitative and qualitative NCD recommendations by country income classification



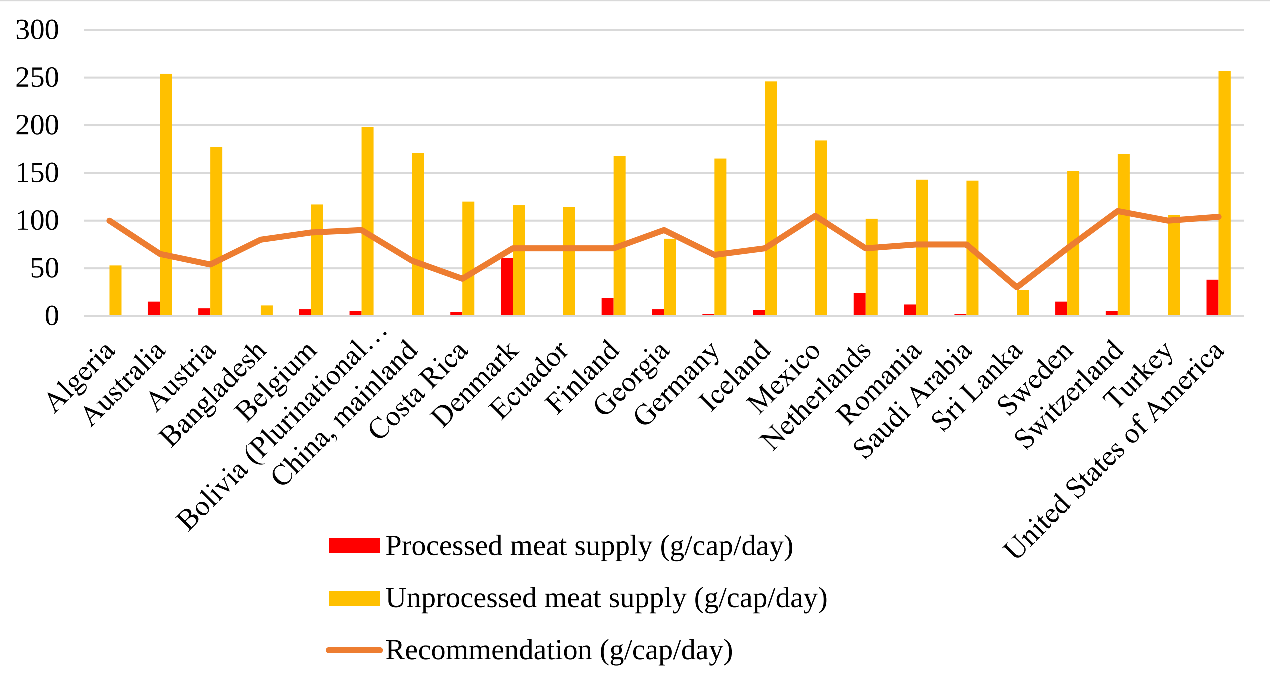
Unlike micronutrient-related recommendations, NCD-related recommendations lack granularity, do not adequately target vulnerable groups and do not consider risks associated to the double burden of micronutrient deficiency and overweight, obesity and NCDs). Many of the reviewed frameworks and guidelines focus solely on reducing animal fat and processed meat consumption as risk factors for overweight, obesity and NCDs. For example, the risk of obesity due to meat over consumption is well-recognised in the French ‘Revision of dietary guidelines for children 0-36 months and 3-17 years’, which says that “*adolescents should consume no more than 500g/week of meat*”. However, there is no acknowledgement of the risk to development or of anaemia from lack of meat consumption. Going by context alone, it is notable that some countries with a recognized double burden of malnutrition problem focus only on the obesity, overweight and NCD-related risks associated with TASF consumption.

Only 3 out of the 310 recommendations found in NCD-related policies linked TASF intake to undernutrition, including risks of micronutrient deficiencies. These recommendations are from: the Dominican Republic targeting undernourished individuals; Lesotho targeting children under five years of age; and Slovenia targeting older adults.

Meat consumption related recommendations

The distribution of quantitative recommendations by country for a critical TASF food group: meat are being presented in Figure C9. The data were obtained from a review of 123 FBDGs, 61 NCD documents, 41 policy frameworks and five nutrition policy recommendations documents from 127 distinct countries. There were 139 detailed quantitative meat recommendations in total, with variations in the recommended gram per capita day with a considerable gap between the recommended daily intake for meat and the average daily supply of unprocessed and processed meat as extrapolated from the Supply Utilization Accounts from FAOSTAT.

Figure C9 Consumption recommendations versus estimated average daily supply of unprocessed and processed meat



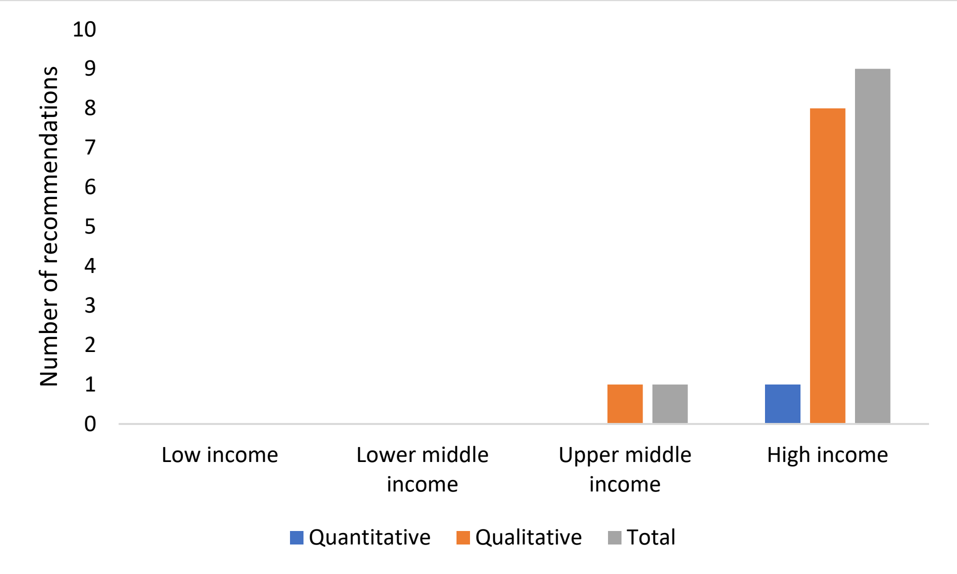
Note: All available quantitative data on recommended meat consumption (recommendation/ guideline specifically referring to 'meat' as the target food group) were obtained from national FBDGs; qualitative data were excluded. The data were compared to supply data collected, using the Supply Utilization Accounts, from FAOSTAT (FAO, 2022). Items from the element "food supply quantity (g/cap/day)" from 2019 were collected. The "unprocessed meat supply (g/cap/day)" category included: Meat nes; meat, ass; meat, bird nes; meat, buffalo; meat,camel; meat, cattle; meat, cattle, boneless (beef &veal); meat, chicken; meat, duck; meat, extracts; meat, game; meat, goat; meat, goose and guinea fowl; meat, horse; meat, mule; meat, other rodents; meat, pig; meat, pork; meat, rabbit; meat, sheep; meat, turkey; snails, not sea. The "processed meat supply (g/cap/day)" category included: Bacon and ham; meat nes, preparations; meat, beef and veal sausages; meat, beef, dried, salted, smoked; meat, beef, preparations; meat, chicke, canned; meat, dried nes; meat, homogenized preparations; meat, pig sausages; meat, pig, preparations. Across all countries standard data collections methods were used.

Recommendations related to environmental sustainability

The environmental sustainability concerns associated with livestock farming have come to the fore in recent years. As concerns over climate change grow, indicated by renewed commitments from countries at United Nations Framework Convention on Climate Change Conference of the Parties 26, TASF consumption has come under the spotlight.

However, the review of TASF consumption policy indicates that, to date, very few countries have had the chance to link TASF consumption directly to environmental concerns. Only eight countries have made the associaton thus far Canada, Denmark, the Netherlands, Norway, Italy, the Republic of South Africa, Sweden and Uruguay (Figure C10). The number of policy recommendations that connect TASF consumption and environmental sustainability is limited, likely because the global climate agenda for food systems is nascent and policy is updated periodically. Out of these recommendations, most were qualitative, for example "*to* *reduce the effect on the environment, eat a more plant-based diet and less meat*” from Denmark or “*reduce animal source food intake to lower environmental impact*” from Canada. There was only one quantitative recommendation, “*to limit environmental impact, reduce consumption of meat to a maximum of 500g per week, consume two to three portions of dairy products per day, more is not necessary and eat fish (only) once a week*”, from the Netherlands. A list of environmental sustainability recommendations are provided in Annex Table C8.

Figure C10 Quantitative and qualitative sustainability recommendations by country income classification



TASF consumption can be excessive in high-income countries. A relative reduction in consumption may therefore have a beneficial impact on the environment. However, such recommendations should be context-specific and within local and regional realities. For example, some populations depend on agropastoral livelihoods and animal protein from livestock. Many populations, including those most nutritionally vulnerable like children, adolescent girls and pregnant and lactating women, have lower average TASF consumption, especially in low-income settings. Contemporary TASF sustainability guidelines in policy are nascent and may run the risk of jeopardizing health due to environmental concerns (in addition to further risks such as economic and trade balances) (Adesogan *et al.*, 2020). More context-specific and granular recommendations are therefore suggested in all countries irrespective of their income classification.

Recommendations related to animal welfare

Animal welfare is a contemporary topic in food and nutrition policy (Buller *et al.*, 2018). Whilst the COVID-19 pandemic has raised some concerns, most of world do not account for animal welfare in their food and nutrition guidelines. In fact, out of 1,161 recommendations, there was only one guideline on animal welfare.

The Danish FBDG, ‘The official dietary guidelines – good for health and climate’, suggests that “the state animal welfare label will enable consumers to select animals that live up to the requirements for animal welfare; this includes milk and milk products”. This guideline attaches a label to TASF products, informing the consumer on the animal’s quality of life prior to slaughter or egg or dairy production. The Danish authorities suggest that the consumer select foods that have a high animal welfare score, although this is not mandatory. Likewise, the Swedish FBDG, ‘The Swedish dietary guidelines – find your way to eat greener, not too much and be active’, suggests that “if you cut back on meat, you’ll have enough money for meat produced more sustainably, with attention paid to the welfare of the animals”. This is a recommendation to reduce meat consumption and choose more ethically produced meat products.

It remains to be seen if labelling such as those of Denmark and Sweden will gain traction, and how soon such policies will be adopted in LMICs. It is, however, prudent to also consider economic and nutrition concerns associated with such labelling. As with environmental sustainability issues, introduction of animal welfare guidelines requires a multifaceted overview of the entire food system and all its drivers. Non-specific, generic guidelines might risk jeopardizing food and nutrition security.

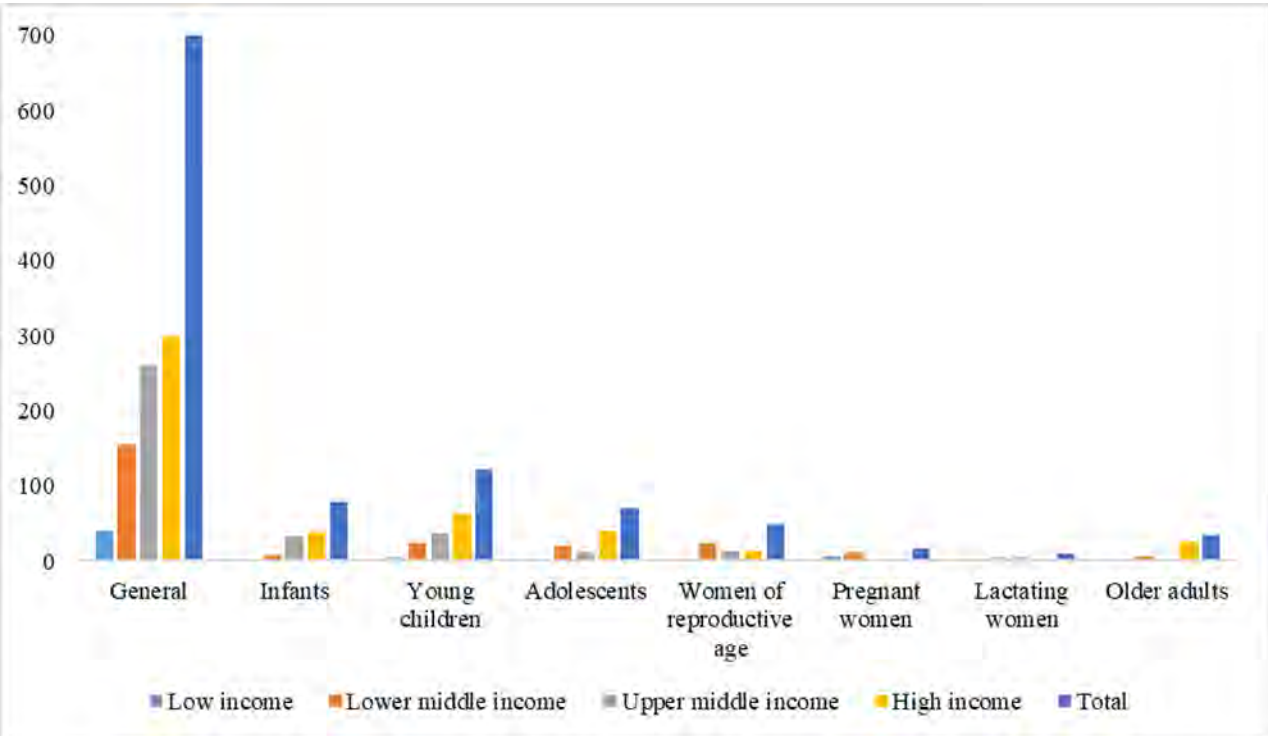
Life course analysis for vulnerable groups

Vulnerable group related recommendations are in the FBDGs of 50 countries. This includes pregnant and lactating women, infants, young children, adolescents and older adults. Of these groups, recommendations for adolescents, young children and infants were the most common. In total, there were 378 recommendations related to vulnerable groups, 282 of which came from FBDGs irrespective of the income classification of the country.

Countries such as Colombia and Cuba suggest "to prevent anemia, children, teenagers and young women should eat organ meats once a week" and "children aged 3-6 years should consume two servings of meat, poultry or eggs per day", whilst the Netherlands and Latvia suggest "girls aged 14-18 should consume 600g per day of milk" and "pregnant women consume protein-rich products – lean meat, fish, eggs, legumes, nuts and seeds, including three to four servings per day". Further examples are listed in Annex Table C9.

Whilst it was noted that high-income countries have more granular recommendations, there were many life-cycle related recommendations in low-income countries. In addition, there was a good distribution of both quantitative and qualitative recommendations, indicating that all countries consider the needs of vulnerable demographics (Figure C11).

Figure C11 Quantitative and qualitative life cycle recommendations by country income classification



Nevertheless, there are still many countries that lack TASF consumption guidelines for both the general population and vulnerable groups. Although clear guidelines on TASF consumption for vulnerable groups should be included in guidelines of every country, as with the other categories, the data indicate that driving factors within the food system such as economic status, food access, agricultural productivity and consumer education also play a critical role in TASF consumption (Comerford *et al.*, 2021; FAO, 2021e).

6 Gaps and needs in the evidence-base

Several limitations emerged from this evaluation of the literature for TASF effects on nutrition and health outcomes. The preponderance of evidence comes from observational studies with limitations for causal inference. There was considerable heterogeneity in design for context (HIC versus LMIC), intervention/exposure (quantity of TASF intakes) and counterfactual or control group. In most studies, the comparison group was usual diets that may or may not have been healthy. More data is needed to examine co-consumption of other foods in dietary patterns consumed with TASF, and TASF relative to healthy plant-based diets and other substitution or replacement foods. There was moderate-to-serious risk of bias in the evidence. Some TASF were overrepresented in the literature relative to other TASF which limits the evidence base for particular life course phases. A summary of the gaps and research needs follow:

General across all life course periods

- Rigorous evidence: Experimental trials are needed for all TASF and human health outcomes that have continuity in design including the comparator group or counterfactual, context-specific factors, dose (quantity of TASF), among others.
- TASF within diets and overall dietary patterns: A holistic examination of TASF (terrestrial and aquatic) within broader dietary patterns is needed in relation to health benefits and risks.
- Cognition, neurodevelopment, and mental health: Evidence points to positive effects of TASF on cognition and neurodevelopment, especially during childhood, but more evidence is needed across the entire life course. TASF effects on mental health is understudied.

Specific life courses

- Pregnancy/lactation: More research is needed to examine nutrition and health effects of TASF beyond milk and dairy products. The effects of TASF on the nutrition and health of the mother should also be examined to a greater extent. TASF impacts on foetal, neonate and infant brain development is needed.
- Infants and young children: There are gaps in the evidence for the nutrition and health effects from intakes of meats from pig, poultry, goats, sheep, wild animals and insects. There is a need for more research on the effects of TASF on bone health, brain development and immune system pathways. Minimal frequency and quantity of TASF needed is another gap in the literature for this life course phase.
- School-age children and adolescents: Gaps in the literature remain for the effects of eggs on school age and adolescents and other TASF such as pig, poultry, goat, sheep, wild animals and insects. This age-group should be studied for TASF impacts on brain development, school performance, endocrine system functioning and growth plasticity, body composition (bone density, muscle mass, fat mass) and anaemia and iron deficiency.
- Adults: Significant gaps remain for other meats beyond beef and on the effects on nutrition and health outcomes. Additional evidence may be merited for examining TASF in unhealthy populations (diabetic, overweight/obese) in view of high prevalence of conditions. Confirmative research is needed for the role of TASF on iron and zinc deficiencies. Research gaps remain for health effects in adults of consumption of meats from wild animals and insects.
- Older adults: There is a need to prioritize this life course phase in view of the global demographic trends. TASF effects in older adults should further examine bone health, muscle mass (sarcopenia), neurocognitive function and general health and well-being. Similar to adults, research may be needed in unhealthy populations to understand nutrition and health impacts of TASF.

Population representation

- Greater representation of certain populations globally may be needed, particularly in certain phases of the life course. For example, more evidence in the life course of older adults is needed from low-and middle-income countries. As well, research on TASF consumption and overweight/obesity and chronic disease outcomes is needed from low-income countries. Gaps also exist on the TASF intake and effects on nutrition and health outcomes among Indigenous Peoples and countries experiencing humanitarian crises.

7 Implications for food and nutrition policies and programming

Policy recommendations

- Small islands developing states and many African countries lack updated FBDGs and TASF recommendations are hardly present in food and nutrition policies. Further work in this area is recommended.

- National FBDGs should be updated with a view to adequately consider TASF and specific nutrient requirements during the life course where not yet considered. Recommendations should take into account the implications of under consumption and over consumption of TASF given the increasing coexistence of micronutrient deficiencies and NCDs. Given that the double burden of malnutrition affects most low-income and middle-income countries, recommendations on TASF should not focus only on NCD-related risks but should also consider the role of TASF in the prevention of under nutrition, especially among vulnerable age groups.
- In upcoming policy documents, it is critical that countries make context specific recommendations, accounting for the existing levels of TASF intake, the needs of vulnerable groups based on their life course and other socio-economic factors, the most prevalent forms of malnutrition in both rural and urban area and the potential trade-off with sustainability in terms of environment, socio-economic and cultural dimensions.
- Many countries' food and nutrition guidelines and policy frameworks need to be updated to reflect TASF consumption as part of healthy diets, but these documents alone will not guarantee adequate TASF consumption; other factors such as national programmes, the quality of the supply chain and food environment and consumer awareness also play a significant role.

Programming recommendations

- When appropriate, animal milk may be promoted as part of a diverse, healthy diets for improving the nutrition and health of pregnant and lactating women, with adaptations based on context. Adaptations might be based on cultural preferences, background nutritional status, dietary patterns, and access to TASF.
- Eggs, milk and meat may be promoted as part of diverse, healthy diets for infants and young children, school age children, and adolescents – with adaptations based on context. Adaptations might be based on cultural preferences, background nutritional status, dietary patterns, and access to TASF.
- Meat, in moderate quantities, could be promoted within diverse, healthy diets in programming for reduced iron deficiency anaemia across all life course phases.
- Healthy diets that include TASF intakes in moderate quantities could be promoted in apparently healthy adults and older adults.

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Section D FOOD SAFETY AND FOOD-BORNE DISEASES

Key findings

- One third of the food-borne disease burden is associated with the consumption of contaminated TASF which is mainly linked with bacterial causes and diarrhoea. While evidence on food-borne disease hazards and health outcomes as well as risk analysis methods have been documented, data on the burden (incidence and severity) is lacking in many countries. For example, main transmission routes along the value chain are crucial to improve national policies, yet not well understood.
- Changing agricultural practices especially the intensification of livestock production and increased use of inputs (e.g. feed, veterinary medicine), the lengthening and broadening value chains and shifts towards consumption of processed food, contribute to increasing exposure to food-borne disease hazards. Antimicrobial residues present additional challenges.
- Improving hygiene and sanitation and mitigating health risks at the interfaces between animals, humans and the environment, through a One Health approach, are measures needed to reduce food-borne disease burden. Sensitization of the public including education programmes that target food producers, transporters, processors, storage facility operators, distributors and consumers have the potential to improve food safety. These measures can be achieved through strengthening and enforcing national food control systems. Evidence that is verifiable is needed to support success of interventions.

Summary

Ensuring safe and nutritious food especially that of terrestrial animal origin is a global public health challenge. The interlinkage of food safety, nutrition and food security creates a vicious cycle of disease and malnutrition, particularly if food is unsafe affecting the young, older people, the immunocompromised and the sick. In order to make significant progress in improving nutrition, the United Nations Decade of Action on Nutrition 2016–2025 highlights the need to integrate food safety into the global food security and nutrition agenda.

Subsection 2 introduces the concepts and terms used, with respect to food safety and food-borne diseases. This includes, but is not limited to, aspects related to risk assessment, disease burden metrics (DALYs), zoonoses, markets, food control, food safety management, and surveillance. The methods employed in synthesising this subsection are also presented.

Subsection 3 highlights the significance of risk-based approaches in mitigating food-borne diseases. The concepts of food risks and food hazards are presented and differentiated, as well as the role of risk assessment which is the scientific basis for evaluation of known or potential health effects resulting from human exposure to food-borne hazards.

Subsection 4 and 5 synthesize of foodborne hazards and their impacts. An understanding of hazards and risks is important in risk management. Although conservative, the World Health Organization has recently demonstrated the public health impacts of unsafe food. It has been shown that, each year, about 600 million people become sick after eating contaminated food and 420 000 people die resulting in the loss of 33 million healthy life years. The economic burden of unsafe food is huge. An annual estimate of USD 110 billion has been estaimated for LMICs. The burden of food-borne diseases (FBD) is not equally distributed and children have been shown to bear the greatest burden of unsafe food.

Subsection 6 and 7 discuss agrifood systems and associated value chain activities including markets. Adopted in 2015, the United Nations Sustainable Development Goals (SDGs) call for transformations in agrifood systems in order to end hunger, achieve food security and improve nutrition, by 2030. Sustainable agrifood systems promote delivery of food security and nutrition ensuring that the economic, social and environmental bases to generate food and nutrition for future generations are not

compromised. Several of the SDGs including zero hunger, health and wellbeing, clean water and sanitation and responsible production can be achieved through improved food safety, including that of TASF. In developing countries, a significant percent of TASF is marketed through informal markets. Informal markets especially wet markets have been greatly linked to the emergence of important zoonotic pathogens. Public pressure is driving regulators to increase the scrutiny and enforce standards for food to ensure its safety. Interventions to ensure safe and hygienic operation of food markets can mitigate risks arising from both live animals and their products.

Subsection 8 presents aspects that should be considered in mitigating food-borne diseases. This includes the importance of risk-based approaches ranging to food safety management, regulations that specify and enforce food safety requirements, in addition to providing an enabling environment and One Health, which is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems.

Subsection 9 summarizes current evidence gaps. National food control systems need to be strengthened to ensure food safety and protect public health. A gap analysis identifies weak points and highlight areas of focus. Surveillance systems are needed to facilitate collection of country-specific epidemiological data and support updating FBD burden estimates, especially those for developing countries. Risk assessment studies are needed, for prioritization and to inform decision making. The need for traceability and food recall tools is highlighted.

1 Introduction

Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 1996).

Food and nutritional security are realized when foods are safe to eat and when consumers have confidence in their food supply (Jaffee *et al.*, 2019). According to the recent United Nations Decade of Action on Nutrition 2016–2025, food safety should be integrated into the global food security and nutrition agenda, in order to make significant progress in improving nutrition (CFS, 2017).

Food-borne diseases (FBD) present serious threats to public health, globally. More than 200 different food-borne diseases have been identified (Mead *et al.*, 1999). The majority of the diseases are caused by diarrhoea agents (WHO, 2015). The relationship between diarrhoea and malnutrition is bi-directional, while diarrhoea leads to malnutrition, malnutrition exacerbate the course of the diarrhoea (Nel, 2010). FBD can contribute to undernutrition by increasing the requirements for nutrients during an illness while also causing loss of appetite, reduced food intake, malabsorption and metabolic losses of nutrients (Gross *et al.*, 2000). Malnutrition affects the functioning of all body systems (Saunders and Smith, 2010).

The impact of FBDs has recently been studied. The Food-borne Disease Burden Epidemiology Reference Group (FERG) of the World Health Organization (WHO), analyzed in 2010 a total of 31 FBD hazards and estimated that these caused 600 million illnesses and 420 000 deaths, resulting in a burden of 33 million disability-adjusted life years (DALYs) (WHO, 2015). One DALY is equivalent to one year of healthy life that is lost. The study considered 11 diarrhoeal disease agents (one virus, seven bacteria and three protozoa), seven invasive infectious disease agents (one virus, five bacteria, one bacteria), ten helminths and three chemicals. The impact of food-borne metals on burden of disease are largely overlooked, however, results from a study by FERG in 2010 (Gibb *et al.*, 2019) indicated that ingestion of arsenic, methylmercury, lead, and cadmium resulted in more than one million illnesses, over 56 000 deaths, and more than nine million DALYs worldwide. The majority (91.7 percent) of the 600 million cases were caused by diarrhoeal disease agents such as norovirus which was responsible for 124 million cases and *Campylobacter* spp. was responsible for 96 million cases. Although diarrhoeal agents were responsible for 91.7 percent of the cases, they accounted for only 55 percent of the FBD burden. FBD burden is not equally distributed. Geographically children under 5 years are most likely to die from FBD in Sub-Saharan Africa, followed by South Asia (Jaffee *et al.*, 2019) (they bear 40 percent of the burden according to FERG data). African subregions have the highest DALY burden (1 200-1 300 DALYs per 100 000 population) followed by South-East Asia subregions (690-710 DALYs per 100 000 population). The North American subregion has the lowest with 35 DALYs per 100 000 population (WHO, 2015). Livestock and other animals used for food production may transfer hazards to TASF and present significant risks to public health (Abebe, Gugsa and Ahmed, 2020; Haileselassie *et al.*, 2013; Heredia and García, 2018). The burden associated with consumption of contaminated TASF is estimated at 168 DALYs per 100 000 population (about 35 percent of the global burden of FBD) (Li *et al.*, 2019).

Based on a World Bank study (Jaffee *et al.*, 2019), unsafe food costs USD 110 billion per year in LMIC and this estimate includes productivity losses (USD 95.2 billion) and treatment (USD 15 billion). Improved food safety will enable achievement of several of the SDGs, including zero hunger, health and wellbeing, clean water and sanitation, and responsible production.

Safe food can promote trade and enhance national and regional economies and development. Food safety standards are meant to protect the health and safety of citizens and ensure fair trade in food and food products, providing opportunities to promote national and regional economies (FAO and WHO, 2018b). The Agreement on the Application of Sanitary and Phytosanitary Measures[1] (the SPS Agreement) is designed to facilitate trade between developed and developing countries by improving transparency, promoting harmonization and prevention of countries from imposing arbitrary food standards. However, effective implementation of the SPS Agreement in developing economies requires commitments towards capacity building and appropriate national action (Athukorala and Jayasuriya, 2003). The Standards and Trade Development Facility assists developing countries to meet SPS standards, through capacity building and ensuring trade in safe products. SDGs 8 (decent work and economic development) and 12 (responsible consumption and production) suggest that improving well-being is achievable through trade (Wilson, 2017). Although, trade can enhance economic growth and development, labels and food safety standards may contribute to or hamper this growth, which affects the capacity to attain the relevant SDGs (Wilson, 2017).

Although conservative, FERG data is still the best estimate of FBD burden, to date. The burden is, however, not fully known in developing countries. However, experts believe that these countries bear the highest burden of FBD (Käferstein, 2003; WHO, 2015). This belief is consistent with the following evidence:

- high levels of hazards are often reported in developing country food (Grace *et al.*, 2010);
- high prevalence of potential food-borne pathogens are found in hospital and community surveys of children and adults with diarrhoea (Fletcher, McLaws and Ellis, 2013);
- lack of access to clean water for an estimated 750 million people (UNICEF and WHO, 2014);
- common use of human sewage and animal waste for horticultural production in developing countries;
- lack of effective government food control systems; and
- inadequate checks and balances (e.g. little opportunity for suing if food is unsafe).

A number of factors may contribute to underestimation of FBD burden. Treatment of illness is often not sought and not all treated cases are reported to health authorities; when treated, there is usually no laboratory diagnosis or way of telling if an illness came from food or another source, and there are no effective FBD surveillance systems in LMICs. FBD agents can be transmitted to humans through several routes, among them food, animal contact, human-to-human, and water (Hald *et al.*, 2016). Global disease burden estimates include only the share of illness caused specifically by contaminated

[1] https://www.wto.org/english/tratop_e/sps_e/spsagr_e.htm

food, based on the best and most recent estimates of experts, but are obviously less accurate than nationally representative empirical data.

FERG developed tools and resources to enable countries carry out national studies of burden of FBD. Pilot studies were conducted in four countries (Albania, Japan, Thailand and Uganda), but there were significant data gaps that hindered estimation of FBD burden in these countries. There is need for improved capacity and surveillance in many countries to provide data for estimation of the burden of FBD nationally and globally (WHO, 2015). For most countries, and at the global level, relevant studies and data for quantifying attribution of potential FBD to the major transmission routes do not exist (WHO, 2015). In this case, structured elicitation of scientific judgment may be used (Aspinall, 2010; Pires, 2013).

Food safety standards are measures enacted by governments to protect the health and safety of their citizens and the environment in which they live. Although the SPS Agreement facilitates trade between developing to developed countries, this largely depends on the ability of developing countries to participate effectively in the implementation of the Agreement. However, most LMICs have negligible or no livestock product exports and are increasingly becoming livestock product importers.

This section presents not only FBDs (i.e. diseases transmitted through food) but also diseases transmitted through animal-human contact focusing on animals used for food production.

2 Concepts, definitions and methods

According to WHO, FBD are diseases commonly transmitted through ingested food. These diseases are caused by food hazards which include microbial pathogens, parasites, chemicals and biotoxins (World Health Organization, 2014). The effects of FBD on individuals depend on factors such as their health, nutritional status, age, virulence of the pathogen and immunonological status.

Box D1 Disability-adjusted life years

Disability-adjusted life years (DALY) is a standard metric commonly used to measure the impact of diseases on population health. The concept of this metric is that: it represents the years lived with disability (YLD; this is decreased quality of life) and years of life lost (YLL) due to premature death as a consequence of a given disease or condition, at the individual or population level. One DALY can be thought of as one year of ‘healthy’ life lost, and the burden of disease as a measure of the gap between current health status and an ideal situation in which everyone lives into old age, free of disease and disability (WHO, 2008).

DALYs aggregate morbidity and disability, expressed as YLD, and mortality, expressed as YLL, into a single figure. DALY is calculated by adding the number of years of life lost to mortality (YLL) and the number of years lived with disability due to morbidity (YLD) (WHO, 2015).

DALY = YLD + YLL

Where:

YLD = the number of incident cases **x** average duration until remission or death with **x** disability weight

and

YLL = number of deaths **x** residual life expectancy at the age at death

Disability refers to any acute or chronic illness that reduces physical or mental health (Chen *et al.*, 2015). Disability weight reflects the severity of the disease on a scale of zero (perfect health) to one (death).

Both prevalence and incidence approaches may be used in computation of the DALY estimates (WHO, 2015). YLL are strongly influenced by a high mortality rate or death at a young age, whereas YLD are influenced by the number of sequelae, a high disability weight and long duration of disease (Devleesschauwer *et al.*, 2015). DALY is an established WHO metric with international application, for which reason it was used by FERG for the FBD burden estimation (WHO, 2015).

Box D2 Concepts, definitions and methods related to food safety and food-borne diseases

Food hazard is a biological, chemical or physical agent in food with the potential to cause adverse health effects (FAO and WHO, 1997). Codex Alimentarius defines **food** as any substance, whether processed, semi-processed or raw, which is intended for human consumption, and includes drink, chewing gum and any substance which has been used in the manufacture, preparation or treatment of "food" but does not include cosmetics or tobacco or substances used only as drugs (FAO and WHO, 2001).

Risk is a function of the probability of an adverse health effect and the severity of that effect, consequential to a hazard(s) in food (FAO and WHO, 2001, 2014a). It is possible for hazard contamination to be high yet the risk is low, and vice versa.

Risk analysis is a process consisting of three components: risk assessment, risk management and risk communication (FAO and WHO, 2014a).

Risk assessment is a scientifically-based process consisting of the following steps:

1. hazard identification,
2. hazard characterization,
3. exposure assessment, and
4. risk characterization (FAO and WHO, 2001, 2014a).

Risk assessment can be qualitative or quantitative, depending on the approach used, and availability of data.

Risk management is the process, distinct from risk assessment, of weighing policy alternatives, in consultation with all interested parties, considering risk assessment and other factors relevant for the health protection of consumers and for the promotion of fair trade practices, and, if needed, selecting appropriate prevention and control options (FAO and WHO, 2014a).

Risk communication is the interactive exchange of information and opinions throughout the risk analysis process concerning risk, risk-related factors and risk perceptions, among risk assessors, risk managers, consumers, industry, the academic community and other interested parties, including the explanation of risk assessment findings and the basis of risk management decisions (FAO and WHO, 2014a).

Zoonoses: the Second Report of the Joint WHO/FAO Expert Committee On Zoonoses defined zoonoses as those diseases and infections which are naturally transmitted between vertebrate animals and humans. Although some may not make the animal sick, they will make humans sick. The infections range from minor, often short-term illnesses, to a major life-changing one that can even cause death. Zoonotic pathogens may be bacterial, viral or parasitic, or may involve unconventional agents like prions, and can spread to humans through direct contact or through food, water or the environment (WHO, 2020a). Prions are transmissible particles that are devoid of nucleic acid and seem to be composed exclusively of a modified protein; spongiform encephalopathy in cattle, scrapie in sheep, and Creutzfeldt–Jakob disease in humans are among the key diseases (Prusiner, 1998).

Antimicrobial resistance (AMR): is the ability of microorganisms to persist or grow in the presence of drugs designed to inhibit or kill them (FAO, 2021). These drugs, called antimicrobials, are used to treat infectious diseases caused by microorganisms such as bacteria, fungi, viruses and protozoan parasites. AMR mainly develops when microorganisms adapt and grow in the presence of antimicrobials (WHO, 2015). It is a major global threat with implications on public health, food security and the economic wellbeing of communities.

Informal markets: the informal food sector exists in many forms and finding a clear definition of the concept is difficult, given the variety of activities and trades that the term embraces (FAO, 2003). Informal markets include economic activities that occur outside of formal regulations (i.e. acquiring licenses, registering business, and paying taxes) and is mostly guided by informal norms, values, and understandings (Sutter *et al.*, 2017). Informal food businesses are characterized by low capital investments and absence of specialization and can exist at various levels of the value chain including production, distribution and retailing (FAO, 2003).

Food control system: Food control is a mandatory regulatory activity of enforcement by national or local authorities to provide consumer protection and ensure that all foods, during production, handling, storage, processing, and distribution are safe, wholesome and fit for human consumption; conform to safety and quality requirements; and are honestly and accurately labelled as prescribed by law (FAO and WHO, 2003). A food control system is the integration of a mandatory regulatory approach with preventive and educational strategies to ensure protection of the whole food chain (FAO and WHO, 2003). A national food control system aims to protect the health of consumers by assuring the safety and quality of foods being traded both nationally and internationally. Such a system, when present, ensures that food available within a country is safe, wholesome and fit for human consumption, conforms to food safety and quality requirements and is honestly and accurately labelled as prescribed by the law. A tool has been developed to assist member countries in assessing the effectiveness of their food control system, to demonstrate performance and determine areas that require improvement (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2020).

Surveillance: WHO defines surveillance as the systematic, ongoing collection, collation, and analysis of data and the timely dissemination of information to those who need to know so that action can be taken (WHO, 2001). Animal health surveillance, according to the Terrestrial Animal Health Code of OIE, is a tool to monitor disease trends, to facilitate the control of infection or infestation, to provide data for use in risk analysis, for animal or public health purposes, to substantiate the rationale for sanitary measures and for providing assurances to trading partners (OIE, 2021).

Public health surveillance is the ongoing systematic collection, analysis, and interpretation of data, closely integrated with the timely dissemination of these data to those responsible for preventing and controlling disease (Thacker and Berkelman, 1988). It provides the scientific and factual database essential to inform decision making and appropriate public health action (Nsubuga *et al.*, 2006).

Surveillance for food safety is a systematic effort to collect, analyze and interpret data on food contaminants and food consumption and establish effective links with the public health system to improve the availability of attributable data on food-borne disease (Bishop and Tritscher, 2012).

An **integrated surveilance system** is one that links human and animal disease reporting systems. It can help identify and facilitate a response to known and emerging zoonotic diseases (Mauer and Kaneene, 2005).

Residues are traces in food, agricultural commodities or animal feed and result from the use of pesticides or veterinary drugs. Residues of pesticides can include any derivatives such as conversion products, metabolites, reaction products, and impurities of toxicological significance. However, veterinary drug residues include the parent compounds and/or their metabolites in any edible portion of the animal product and include residues of associated impurities of the veterinary drug concerned (FAO and WHO, 2001). The maximum residue limit is the concentration that is legally tolerated in a food product obtained from an animal that has received a veterinary medicine (FAO and WHO, 2018a).

Traceability and recall: Codex Alimentarius Commission defines traceability or product tracing as the ability to follow movement of a food through specified stage(s) of production, processing and distribution. Traceability within food control systems is applied as a tool to control food hazards, provide reliable product information and guarantee product authenticity (FAO and WHO, 2012).

Recall or Product Recall is defined as the action to remove food from the market at any stage of the food chain, including that possessed by consumers (FAO and WHO, 2012). Food recall is a fundamental tool in the management of risks in response to food safety events and emergencies. Reliable identification and traceability systems are essential to effective animal disease control systems, food safety systems and trade in live animals and animal products.

Food safety interventions are control measures added into a process to reduce and ultimately, prevent or eliminate food safety risks (Bucknavage and Cutter, 2011). Food safety interventions can be categorised based on where they occur within the food supply chain; pre-harvest interventions occur in the field or on the farm, while post-harvest interventions occur as raw materials undergo processing. Food safety interventions also refer to risk management, a process of weighing of policy alternatives, in consultation with all interested parties, considering risk assessment and other factors relevant for the health protection of consumers and for the promotion of fair trade practices, and, if needed, selecting appropriate prevention and control options (FAO and WHO, 2014a).

The approach used to generate this section was a synthesis of available evidence utilizing recent reviews of literature and guidance provided by international organizations in the area of food safety including from FAO, WHO, OIE and UNEP. The focus areas are hazards, risk analysis, policies and regulations impacting food safety including the One Health approach. The choice of priority hazards was based on recent FERG estimates and on the Global Burden of FBD data (WHO, 2015), with additions from the authors, given the limitations of FERG evidence.

3 Hazards versus risks versus risk assessment

A food hazard is a biological, chemical or physical agent in, or condition of, food with the potential to cause an adverse health effect (FAO and WHO, 2014a). Hazards, when ingested by susceptible consumers, have the potential to cause FBD, which include any illness arising from consumption of contaminated food (Adley and Ryan, 2016). The global burden of FBD, many of which are carried by livestock products, was 33 million DALYs in 2010, based on the first ever burden evidence by FERG, considered the best to date. Of that burden, 40 percent was borne by children under five years of age (WHO, 2015). Together the hazards caused 600 (95 percent uncertainty interval (UI) 420–960) million food-borne illnesses and 420 000 (95 percent UI 310 000 - 600 000) deaths in 2010. As explained in the previous subsection, risk considers the probability or likelihood of an adverse health effect occurring and the severity of that effect, following exposure, and risk assessment is a scientific process that allows for the estimation of the risk. A detailed description of hazard, risk, risk assessment is provided below.

3.1 Hazards

Food hazards can be biological, chemical or physical and more than 250 different food-borne hazards have been recognized (Hoffmann and Scallan, 2017; Todd, 2014). Biological hazards include micro-organisms such as bacteria, viruses, parasites, and fungi (Untermann, 1998). The pathogens can enter the food anywhere along the value/supply chain - during primary production, processing, distribution, storage and consumption. People with a food-borne illness (or other illness that impacts their immune system) as well as the environment can potentially also be a source of food contaminants (Schirone *et al.*, 2017). A few of the bacterial hazards (for example: *Staphylococcus aureus, Clostridium botulinum*), under certain conditions, can produce toxins and it is these that end up causing rapid onset food-borne illness from food intoxications (Rhodehamel, 1992). Toxins are problematic because they are not destroyed by cooking food.

There are many food-borne pathogens known to cause disease, but for most there is insufficient evidence to develop credible global estimates. The FERG selected 31 important hazards (28 biological pathogens) for which there was sufficient evidence to develop global estimates. The most important in terms of burden, in order of declining burden were, lead, non-typhoidal (NT) *Salmonella*, *Salmonella* Typhi, enteropathogenic *Escherichia coli*, norovirus and *Campylobacter* spp., Shiga toxin-producing *Escherichia coli*, methylmercury and *Vibrio cholerae*. Together, these ten hazards accounted for nearly 75 percent of the total global burden of FBD. The significant ones may vary depending on geography and the types of foods comprising the common diets of various populations, or that cause the most (estimated) DALYs which are primarily monitored by national authorities. Outbreaks should be assessed in depth to confirm their presence, identify root cause(s), assess trends over time and determine the actions needed to combat future outbreaks (Adley and Ryan, 2016). There is no single clinical syndrome for all FBD. Diarrhoeal disease agents particularly norovirus, *Campylobacter* spp., NT *Salmonella* spp. and *E. coli* are the most frequent causes (> 90 percent) of FBD (Havelaar *et al.*, 2015). Their source range from being a contaminant of food acquired from the live animal or to inadvertent or intentional addition during food production, processing, or preparation (Adley and Ryan, 2016). The proportion of human infection with a given pathogen attributed to food will differ depending on the agent, the food and its characteristics, the value/supply chain, and food handling, with only a few FBD being transmitted exclusively via foods (Hoffmann and Scallan, 2017).

Chemical hazards include, but are not limited to naturally occurring components of certain food ingredients (e.g. glucosinolates), toxins produced by microorganisms found in the environment (e.g. mycotoxins), pesticide residues, heavy metals (from raw food ingredients or use of improper food processing equipment or food packaging materials) and industrial chemicals (U.S. Food and Drug Administration, 2012). Chemical hazards in TASF may result from use of contaminated feed, uptake of chemical compounds when animals graze on contaminated soil or through veterinary medicines administered to the animals. A good example is dioxin in animal feed due to the illegal use of industrial oils that contaminated fats used as animal feed as was the case in Germany in 2010 (Kupferschmidt, 2011). Others include the use of furazolidone in animal feed and the melamine crisis in China in 2008 (Chen, 2009; Pei *et al.*, 2011).

Physical hazards include, but are not limited to metal parts (wire, needles etc.), sand, soil, stones, wood, plastic, rubber or glass parts and hair (Asselt *et al.*, 2016; Rhodehamel, 1992). Physical hazards may be introduced in the livestock value chain during the production process (e.g. metal parts from stirring machines, rubber from seals or broken needles) or from equipment. They may also be introduced through packaging materials especially where these are recycled (Geueke, Groh and Muncke, 2018) or because of their presence in raw materials or the environment.

3.2 Risks

An analysis of hazards occurring in food is important in identifying measures to reduce their exposure to humans. However, proper mitigation of FBD requires risk-based approaches, hence the need to understand and differentiate food risks from food hazards. As noted by Fazil (2005), risk is a frequently encountered concept, subconsciously, people assess risks and decide to proceed or not, daily. A better understanding of FBD risks is important in their prioritization and management for public health and also provides a framework for solving trade-related disputes.

The food value chain is very complex and involves many players. In such a system, many factors will affect both the likelihood and severity of the occurrence of food-borne disease (Fazil, 2005). Factors such as failure to observe good production practices, use of unsafe water to clean and process food, poor storage, and unhygienic food-handling practices can lead to increased FBD risks especially, when coupled with inadequate or poorly enforced regulatory standards and lack of industry compliance (Todd, 2020).

A risk profile is a description of the food safety problem and its context while a risk estimate is the quantitative estimation of risk resulting from risk characterization (FAO and WHO, 2014a). FBD risks are perceived differently by different categories of people, and this could be related to their level of food safety awareness and how well a particular risk has been publicised.

3.3 Risk assessment

For over half a century, FAO in collaboration with WHO has been instrumental in providing scientific advice as the basis for the international food safety standards, guidelines and codes of practice established by Codex Alimentarius Commission on issues related to the following (FAO and WHO, 2018d):

- safety assessments of chemicals in food such as food additives, veterinary drug residues, pesticide residues, contaminants, natural toxins;
- safety assessments of biological agents in food such as microorganisms, fungi, parasites and prions;
- assessments of practices and technologies used for the production of foods such as safety assessment of foods derived from biotechnology; and
- human nutrition such as probiotics, human nutrient requirements, food fortification.

Risk assessment is the scientific evaluation of known or potential health effects resulting from human exposure to food-borne hazards (FAO and WHO, 2001) and is the first step in the Codex Alimentarius risk analysis process, providing an estimate of the probability and impact of FBD. The process consists of the following four steps: hazard identification, hazard characterization, exposure assessment and risk characterization (FAO and WHO, 1999, 2001):

1. Hazard identification: the identification of the biological agent that may be present in a particular food or group of foods and capable of causing adverse health effects.
2. Hazard characterization: the qualitative or quantitative, or both, evaluation of the nature of adverse health effects associated with the biological agent that may be present in food and in such cases a dose-response assessment should be performed if the data are obtainable.
3. Exposure assessment: the qualitative or quantitative, or both, evaluation of the likely intake of the biological agent through food, as well as through exposure from other sources, if relevant.
4. Risk characterization: qualitative or quantitative, or both, estimation, including attendant uncertainties, of the probability of occurrence and severity of known or potential adverse health effects in a given population based on hazard identification, hazard characterisation and exposure assessment.

For guidance on microbiological risk assessment, FAO and WHO, in early 2000, launched a programme to guide microbiological risk assessment process and this resulted in guidelines that coincided with the various steps of the risk assessment process:

- guideline for hazard characterization (WHO and FAO, 2003);
- guideline for exposure assessment (FAO and WHO, 2008); and
- guideline for risk characterization (FAO and WHO, 2009a).

The guidelines recognized that reliable estimation of risk, combined with appropriate uncertainty analysis, is a necessary condition for risk management decision making as well as for effective risk communication within the risk analysis framework. Recently, a single updated guideline on risk assessment has been developed to obviate recourse to three separate guidelines (FAO and WHO, 2021) The development of the guidelines for risk assessment paved way for a number of microbial risk assessments in commodity-pathogen matrices (LeJeune *et al.*, 2021) such as - *Salmonella* in eggs and broiler chickens (FAO and WHO, 2002); *Listeria monocytogenes* in ready-to-eat foods (WHO and FAO, 2004); and *Campylobacter* spp. in broiler chickens (FAO and WHO, 2009b).

4 Biological food hazards and associated public health impacts

TASF are a good medium for microbial growth and can become contaminated with hazards at any stage along the food value chain, from primary production through to manufacture, distribution and retailing, and through handling during preparation and consumption. Biological food hazards include pathogenic organisms (bacteria, viruses, parasites, fungi and prions) and their toxins, which people are exposed to when they consume contaminated products (Abebe, Gugsa and Ahmed, 2020).

Microbial growth in food is influenced by a number of factors, both intrinsic (e.g. pH, nutrient content) and extrinsic (humidity, storage temperature) (Preetha and Narayanan, 2020). Livestock, farmed wildlife and hunted animals are important reservoirs for many of the pathogens (Heredia and García, 2018) that contaminate TASF including meat, dairy and egg based products. Although they provide some micro-nutrients that are inadequate or even difficult to find in plants such as Vitamin B-12 (Murphy and Allen, 2003). TASF, like foods of plant origin too, are prone to contamination and present significant risks to public health (Haileselassie *et al.*, 2013).

4.1 Bacterial hazards

Bacterial food hazards present the greatest concerns for food safety and human health (Desta Sisay, 2015) and are, of all the hazards, the most studied and monitored (Newell *et al.*, 2010). There are variations in terms of frequency and/or of seriousness of FBD (Abebe, Gugsa and Ahmed, 2020). The most common bacteria involved in food-borne disease include enteropathogenic *E. coli* (EPEC), *Campylobacter* species, Enterotoxigenic *E. coli* (ETEC), NT *Salmonella enterica* (non-invasive infections), Shiga toxin-producing *E. coli*, *Staphylococcus aureus*, *Vibrio cholerae*, cause enteric food-borne problems including nausea, vomiting, diarrhoea and abdominal pains. *Brucella* spp., *Listeria monocytogenes*, non-typhoidal *Salmonella enterica* (invasive infections), *Salmonella enterica* Paratyphi A and *Salmonella enterica* Typhi cause effects that are not enteric (WHO, 2015) but still result in food-borne illness. Some bacteria may cause severe complications including *Listeria monocytogenes* and *Vibrio cholerae* (Akbar and Anal, 2011). Production of toxins and structural virulent factors are responsible for the pathogenesis of bacteria such as *Samonella* spp., *Campylobacter* spp., *Staphylococcus aureus* and *Escherichia coli* (Abebe, Gugsa and Ahmed, 2020).

Staphylococcus aureus

Staphylococcus aureus (*S. aureus*) is a Gram-positive microorganism that is present as a commensal on the skin, nose, and mucous membranes of healthy humans and animals (Lozano *et al.*, 2016; Tessema and Tsegaye, 2017). It is considered an opportunistic food-borne pathogen (Rodríguez-Lázaro *et al.*, 2017; Wang *et al.*, 2017) and can cause diseases with diverse severity, in both humans and animals (Abraha *et al.*, 2018; Lozano *et al.*, 2016), as an infectious agent or through its toxins. *S. aureus* is able to grow in a wide range of temperatures (7 °C – 48 °C with an optimum of 30 °C – 37 °C), pH (4.2 - 9.3, with an optimum of 7.0 - 7.5) and sodium chloride concentrations (up to 15 percent NaCl). These characteristics enable the bacteria to survive in a wide variety of food, especially those that require manipulation during processing, including fermented food products like cheese (Argaw and Addis, 2015). The bacteria have a wide range of hosts including humans and livestock, i.e. pigs, cattle, goats, chicken and ducks (Wang *et al.*, 2017).

Contamination of food with *S. aureus* may occur directly from infected animals or from poor hygiene during production processes or during retail and storage of food (Massawe, Mdegela and Kurwijila, 2019). Cows with mastitis are a common source of *S. aureus* in raw milk (Tarekgne* *et al.*, 2015). *S. aureus* in food products is a serious concern due to the food-borne intoxication caused by enterotoxigenic strains of coagulase-positive staphylococci, mainly *S. aureus* (Tsepo *et al.*, 2016) and very occasionally by other staphylococci species such as *S. intermedius* (Genigeorgis, 1989; Khambaty, Bennett and Shah, 1994). These are responsible for food spoilage, reduced shelf life, and food-borne poisoning (Beyene *et al.*, 2017). A variety of food items can be contaminated by staphylococcal enterotoxins with moist food containing starch and proteins (Wu *et al.*, 2016), unpasteurised milk and dairy products (Abunna *et al.*, 2016), pork, beef, mutton, poultry, and eggs having been implicated in staphylococcal food poisoning (Wang *et al.*, 2017). *S. aureus* growth and toxin production is influenced by factors such as the composition of the food, temperature, and time (Hennekinne, De Buyser and Dragacci, 2012) which are an indication of areas that should be targeted to mitigate exposure and improve health.

Globally, many cases of staphylococcal food poisoning have been reported (Hennekinne, De Buyser and Dragacci, 2012). Staphylococcal food poisoning results from the ingestion of enterotoxins preformed in food by enterotoxigenic strains of *S. aureus* (Hennekinne, De Buyser and Dragacci, 2012). Staphylococcal enterotoxins are resistant to environmental conditions (freezing, drying, heat treatment and low pH) that easily destroy the enterotoxin-producing strain. They are also resistant to proteolytic enzymes hence are able to remain active in the digestive tract after ingestion (Hennekinne, De Buyser and Dragacci, 2012). Generally, heat treatments commonly used in food processing are not effective for complete destruction of staphylococcal enterotoxins at levels expected to be found in food involved in food poisoning outbreaks (0.5–10 litre per 100 ml or 100 gram) (Hennekinne, De Buyser and Dragacci, 2012).

The widespread use of antibiotics and ability of the bacteria to acquire antimicrobial resistance have led to emergence of resistant strains, such as methicillin resistant *S. aureus* (Abraha *et al.*, 2018; Rodríguez-Lázaro *et al.*, 2017; Wang *et al.*, 2017). The resistant strains of *S. aureus* have been associated with high mortality and morbidity due to multidrug resistance (Tsepo *et al.*, 2016). Delaney and others (2008) studied a cohort of patients with methicillin resistant *S. aureus* (n = 1439) and with no methicillin resistant *S. aureus* (n = 14 090); within one year, 21.8 percent of methicillin resistant *S. aureus* patients had died as compared with 5 percent of the non-methicillin resistant *S. aureus* patients. The risk of death was also increased (adjusted hazard ratio 4.1). Methicillin resistant *S. aureus* has been reported in animals (Weese, 2010).

Staphylococcal infections have a short incubation period of two to four hours after consumption of contaminated foods (Desta Sisay, 2015). The bacteria can cause various diseases with symptoms that range from simple skin infections to more serious potentially life- threatening infections such as septicemia, necrotizing fasciitis, infective endocarditis, necrotizing pneumonia, and toxic shock syndrome mainly caused by methicillin resistant *S. aureus* strains or multidrug resistant *S. aureus* (Che Hamzah *et al.*, 2019; Wang *et al.*, 2017). The disease is characterized by nausea and vomiting, chills and headache (Dhama *et al.*, 2013), and abdominal cramping with or without diarrhoea (Kadariya, Smith and Thapaliya, 2014), however, with no fever (Wang *et al.*, 2017). The disease is more severe among more susceptible individuals such as children and older persons (Wang *et al.*, 2017).

Control and prevention of *S. aureus* mainly requires strategies that interrupt its various modes of transmission since organisms are ubiquitous and impossible to eliminate from the environment (Argaw and Addis, 2015). Preventing contamination and cross-contamination, and cooking food thoroughly are effective ways to prevent staphylococcal infections. Public awareness regarding safe meat-handling and other public health interventions could be a foundation in preventing outbreaks (Kadariya, Smith and Thapaliya, 2014). It is noteworthy, that although *S. aureus* is one of the most important food-borne pathogens, it was not considered in FERG probably because global data was lacking. This illustrates how FERG, still our best guide to the burden of FBD, underestimates the true burden.

Salmonella species

Salmonella is a Gram-negative bacterium that can survive several weeks in a dry environment and several months in water. *Salmonella* are divided into typhoidal (*S.* Typhi and *S.* Paratyphi) and non-typhoidal *Salmonella* serotypes (Feasey *et al.*, 2012). Most *Salmonella* serotypes are present in a wide range of hosts and typically do not cause complicated infections to warrant treatment but some are host specific, for example, *S.* serotype Dublin which resides in cattle and *S. enterica* serotype Choleraesuis which resides in pigs (WHO, 2018a). When these particular serotypes cause disease in humans, it is often invasive and can be life-threatening (WHO, 2018a). Non-typhoidal *S. enterica* usually cause gastroenteritis (European efSafety Authority and European Centre for Disease Prevention and Control (EFSA and ECDC), 2018; Lane *et al.*, 2014). S. enteritidis and S. typhimurium are the two most commonly reported serovars of *Salmonella* spp. transmitted through food, globally (European efSafety Authority and European Centre for Disease Prevention and Control (EFSA and ECDC), 2018).

Salmonella is the most common cause of FBD in both developing and developed countries, although incidence rates vary according to the country (Addis *et al.*, 2011). *Salmonella* is one of the four key global causes of diarrhoeal diseases (others are norovirus, enteropathogenic *E. coli* and *Campylobacter*) (Tadesse and Gebremedhin, 2015; WHO, 2018a). Globally, non-typhoidal *Salmonella* spp. were estimated to cause approximately 78 million cases of illness, 59 000 deaths and four million DALYs per year (Havelaar *et al.*, 2015) with most of the data coming from developed countries. The numbers were also high in the WHO European Region, where non-typhoidal *Salmonella* spp. occupied the first position in the ranking of DALYs and deaths due to food-borne hazards, causing 107 000 DALYs and 1 854 deaths per year (WHO, 2017a). In 2017, 28 Member States of the European Union reported a total of 93 583 human salmonellosis cases; 91 662 confirmed cases resulting in an European Union notification rate of 19.7 cases per 100 000 population. This was a slight decrease by 0.7 percent compared with that reported in 2016 (20.4 cases per 100 000 population) (European efSafety Authority and European Centre for Disease Prevention and Control (EFSA and ECDC), 2018).

Livestock and other animals used for food are a major reservoir for many food-borne *Salmonella* spp. (Heredia and García, 2018). Humans are the only reservoir of typhoid *Salmonella including Salmonella* Typhi and *Salmonella* Paratyphi serovars (Gal-Mor, Boyle and Grassl, 2014). The rest of *Salmonella* serovars are known as non-typhoid and have animals as the main reservoirs (Eng *et al.*, 2015). *S. enterica*, subspecies *enterica* serotypes, are principally related to warm-blooded animals whereas the other non *enterica* subspecies are more related to cold-blooded animals, although some exceptions have been found (Lamas *et al.*, 2018). The incidence of diseases caused by non-typhoid *Salmonella* varies between countries; for example, it is estimated to cause 690 cases per 100 000 population in Europe, while in Israel, non-typhoid *Salmonella* infection is around 100 cases per 100 000 annually (Eng *et al.*, 2015). *S.* typhimurium is the most dominant serovar around the world, and it is associated with food-borne outbreaks in both developing and developed countries (Mohammed, 2017). The transmission of non-typhoidal *Salmonella* infection to humans can occur through the ingestion of food or water contaminated with waste of infected animals, by direct contact with infected animals or by consumption of food from infected animals (Eng *et al.*, 2015; Garedew *et al.*, 2015; WHO, 2018a). This bacterium has been isolated from a wide range of animals: poultry, ovines, porcines, fish, aquatic animals and their food products, and also from some other cold-blooded animals (Flockhart *et al.*, 2017; Nguyen *et al.*, 2016; Zając *et al.*, 2016).

Salmonella spp. infections are characterized by acute onset of fever, abdominal pain, diarrhoea, nausea and sometimes vomiting (WHO, 2018a). Non-typhoidal salmonellosis is usually self-limiting and does not require specific treatment other than oral fluids (WHO, 2018a). *Salmonella* spp. infection can, however, cause severe disease, especially in children, older persons and immunocompromised individuals. In invasive salmonellosis, the bacteria enter the bloodstream to several organs and systems, resulting in bacteremia, meningitis, osteomyelitis or septic arthritis and sometimes even death. In this case, treatment with antimicrobial agents is justified, although antimicrobial resistance in

Salmonella spp. is increasingly becoming a public health concern (WHO, 2011). Invasive non-typhoidal *Salmonella* is endemic in Africa, and children and human immunodeficiency virus (HIV)–infected adults carry most of the burden of invasive disease (Morpeth, Ramadhani and Crump, 2009). A systematic literature review and meta- analysis reported multidrug resistance in 75 percent of non-typhoid *Salmonella* isolates in Sub-Saharan African regions, from the year 2000 (Tack *et al.*, 2020). In Vietnam, 71 percent of patients included in a study on invasive non typhoid infection had HIV (Phu Huong Lan *et al.*, 2016); *S.* Enteritidis (48 percent; n = 102) and *S.* Typhimurium (25 percent) were the main serovars.

For prevention of the infection, it is recommended that food is properly cooked and served when hot, and that hands are thoroughly and frequently washed, using soap in particular after contact with pets or livestock, and after visiting toilets (WHO, 2018a).

Campylobacter species

There are 17 species and six subspecies assigned to the genus *Campylobacter*, of which the most frequently reported in human diseases are *C. jejuni* (subspecies *jejuni*) and *C. coli* (WHO, 2020b). They are found in the environment, and many species act as reservoirs or are susceptible, and wild birds are known to be natural hosts (Gebremichael, Berhe and Amede, 2019; Ogden *et al.*, 2009). Poultry (Desta Sisay, 2015), cattle, sheep, pigs and other animals used for food (Khoshbakht *et al.*, 2016; Silva *et al.*, 2011; Woldemariam, Asrat and Zewde, 2009), as well as wild animals and birds (Gebremichael, Berhe and Amede, 2019), are reservoirs of *Campylobacter*. Companion animals (cats and dogs) and rodents may also act as reservoirs of *Campylobacter* spp. (Woldemariam, Asrat and Zewde, 2009).

Large numbers of *Campylobacter* bacteria can be found in the intestinal tract of animals (Gölz *et al.*, 2014). *Campylobacter* seldom causes disease in animals. Most often, carcasses or meat are contaminated by *Campylobacter* from faeces during slaughtering. Table eggs are not considered as an important source of the organism (Dhama *et al.*, 2013). A worldwide meta-analysis study on prevalence of *Campylobacter* spp. in animal food products reported a pooled prevalence of 29.6 percent (95 percent CI 27.6 percent - 31 percent); *C. jejuni* (19 percent) and *C. coli* (9.7 percent) (Zbrun *et al.*, 2020). Poultry flocks are highly colonized with the bacteria (Gölz *et al.*, 2014) and contaminated broiler meat is considered the most important source of *Campylobacter* to humans (Abebe, Gugsa and Ahmed, 2020; WHO, 2017b). However, levels of of colonization can vary by production system and species. Most reported cases are associated with chicken, especially those raised under organic and free range rather than those raised under intensive production systems probably because of increased environmental exposure (Hendrixson and DiRita, 2004). The withdraw of chicken and eggs from retails following the 1999 dioxin crisis in Belgium resulted to a 40 percent reduction in human campylobacteriosis cases (Vellinga and Van Loock, 2002).

In most cases of campylobacteriosis, the first symptoms occur two to five days after infection. The most common clinical symptoms are diarrhoea (frequently with blood in the faeces), abdominal pain, fever, nausea and/or vomiting (WHO, 2020b). The symptoms typically last three to six days. Treatment is not generally required, except electrolyte replacement and rehydration. Antimicrobial treatment is recommended in invasive cases where the intestinal mucosa cells are invaded and tissue is damaged. Death from campylobacteriosis is rare and is usually confined to very young or older patients or to those with another serious disease such as AIDS (WHO, 2020b). Complications such as bacteremia, hepatitis, pancreatitis and miscarriage have all been reported at varying frequency. Post-infection complications may include reactive arthritis, which can be a long term (indeterminate) sequela and last more than a couple of months, and neurological disorders such as Guillain-Barré syndrome, a form of paralysis that can result in respiratory and severe neurological dysfunction or death in a few cases (WHO, 2011).

A recent review of *Campylobacter* spp. shows that the incidence and prevalence of camplybacteriosis have increased in both developing and developed countries (Kaakoush *et al.*, 2015). According to

FERG, in 2010, food-borne *Campylobacter* spp. were responsible for more than 95 million cases of illness and slightly more than 21 000 deaths worldwide. The global burden of this hazard was estimated to be over 2.1 million DALYs per year, consisting mostly of years of life lost (YLL) due to the disease (WHO, 2017b). In the WHO European Region, *Campylobacter* spp. are the second leading hazard in terms of food-borne illness (nearly 4.7 million cases per year), deaths (459 per year) and burden (more than 82 000 DALYs per year). It is undoubtedly a major threat to public health in the region, where the median was nine DALYs (95 percent UI 6 - 13) per 100 000 population in 2010 (Havelaar *et al.*, 2015). In 2017, human campylobacteriosis data were reported by 27 European Union Members States with 246 158 confirmed cases, resulting in an European Union notification rate of 64.8 cases per 100 000 population, a slight decrease though compared with 2016 (66.3 cases per 100 000 population) (European efSafety Authority and European Centre for Disease Prevention and Control (EFSA and ECDC), 2018).

The risk factors that contribute to the susceptibility of humans to campylobacteriosis include; travelling, consumption of undercooked chicken, environmental exposure and direct contact with livestock (Shad and Shad, 2019). Prevention of disease from *Campylobacter* is based on control measures at all stages of the food chain with the most effective being heating of TASF to temperatures that will completely innactivate all types of *Campylobacter* spp. (WHO, 2020b). Enhanced biosecurity to avoid transmission of *Campylobacter* from the environment to the flock of birds on farm can reduce the prevalence of *Campylobacter* in poultry, but this option is feasible only where birds are kept in closed housing conditions. Good hygienic slaughtering practices reduce contamination of carcass by faeces, although it does not guarantee absence of *Campylobacter* from meat and meat products. Bactericidal treatment such as heating, like cooking or pasteurization, or irradiation is the only effective method of eliminating *Campylobacter* from contaminated foods (WHO, 2020b).

Listeria monocytogenes

Listeria monocytogenes are widely distributed in nature and cause listeriosis in both animals and humans (Derra *et al.*, 2013; O'Grady *et al.*, 2009). *Listeria* spp. are Gram-positive rod-shaped bacteria. The occurrence of *L. monocytogenes* is worldwide (Lee *et al.*, 2019), with most cases of listeriosis being sporadic, although outbreaks may occur (Dhama *et al.*, 2015). In general, the incidence is relatively low with 0.1 to 10 cases per 1 million people per year depending on the country and region of the world, but the hospitalization and fatality rates are high (WHO, 2018).

Unlike most other food-borne pathogens, *L. monocytogenes* can grow in food at fairly low moisture levels, at high salt concentration and at refrigeration temperatures. The ability to persist and multiply in the food environment when other bacteria and pathogens do not grow makes *L. monocytogenes* more difficult to control (Schlech and Acheson, 2000). Unlike infection with other common food-borne pathogens, *L. monocytogenes* are one of the most virulent pathogens of public health concern globally (Mulu and Pal, 2016). It is associated with a high case fatality rate of approximately 30 percent partly because of its ability to cause spontaneous abortion of human foetuses (Odu and Okonko, 2017). Where active surveillance of sepsis and meningitis has been carried out, attack rates of about 0.7 cases per 100 000 population have been reported (Gellin *et al.*, 1991). The infection is much more common in infants (10 cases per 100 000 population) and older persons (1.4 cases per 100 000 population) and has a predominance among males (Schlech and Acheson, 2000).

According to FERG estimates (Havelaar *et al.*, 2015), listeriosis resulted in more than 14 000 cases of illness, over 3 170 deaths and over 118 000 DALYs globally in 2010. The proportion of perinatal cases was approximately 20 percent. In the European Union, it is evident that listeriosis has public health impact. The disease caused an estimated 1 781 cases of illness, 399 deaths and almost 15 000 DALYs in 2010. Listeriosis was the fourth leading food-borne hazard in terms of deaths and the fifth in terms of DALYs (WHO, 2017a). There were 2 161 confirmed human cases of listeriosis reported in 2014, and a statistically significant increasing trend in cases of listeriosis was observed between 2008 and 2014 (EFSA and ECDC, 2015).

Listeria species are commonly found in raw food, vegetables contaminated by soil and water as well as raw animal products (Seyoum *et al.*, 2015; Vaidya *et al.*, 2018). *L. monocytogenes* is frequently isolated from food of animal origin such as ready-to-eat products: ground beef (Pal and Awel, 2014; Şanlıbaba and Uymaz Tezel, 2018), meat and meat products (sausages) (Carrique-Mas and Bryant, 2013; Dhama *et al.*, 2013), fish and fish products (Nayak *et al.*, 2015) and milk, and dairy products like soft cheese and ice cream (Mashhadany *et al.*, 2016; Mulu and Pal, 2016). Occupational exposure from animal sources has been reported in livestock keepers, butchers, poultry workers and veterinary surgeons (Mashhadany *et al.*, 2016; Şanlıbaba and Uymaz Tezel, 2018). Healthy people infected with *L. monocytogenes* may experience febrile gastroenteritis, which is usually mild and self-limiting. However, in patients with impaired cell-mediated immunity, *L. monocytogenes* can lead to severe illness, including severe sepsis, meningitis or encephalitis and, therefore, have lifelong consequences and even death (de Noordhout *et al.*, 2014). In the Republic of South Africa, an outbreak of listeriosis was reported between January 2017 and July 2018 with 1 060 confirmed cases and 216 deaths recorded (Tchatchouang *et al.*, 2020). Epidemiological investigations indicated that ready-to-eat processed meat products from a food production facility contaminated with *L. monocytogenes* was responsible for the outbreak (Tchatchouang *et al.*, 2020).

Listeriosis occurs mainly in risk groups, such as: pregnant women, older people, immunocompromised people in cases of AIDS and other immonocompromised conditions, solid organ transplantation, diabetes mellitus, cirrhosis and renal failure, foetuses and neonates (Goulet and Marchetti, 1996; Şanlıbaba and Uymaz Tezel, 2018). Infection during pregnancy can result in spontaneous abortion, stillbirth or preterm birth (Chan and Smith, 2018; Maertens de Noordhout *et al.*, 2014). Infants may acquire the infection in two ways; their mothers, after they have consumed contaminated food, can develop occult sepsis resulting in chorioamnionitis and delivery of a septic infant or foetus, and when infected mothers contaminate the skin and respiratory tract of their babies during childbirth (Schlech and Acheson, 2000). These infants can then develop bacterial meningitis, two to three weeks after exposure at the time of birth (Schlech and Acheson, 2000). In North America, *L. monocytogenes* is the third most common pathogen causing bacterial meningitis among neonates, after Group B streptococcal infection and *Escherichia coli* (Dawson *et al.*, 2018; Goulet and Marchetti, 1996). Food-borne listeriosis can be prevented by controlling the organism at all the stages in the food chain – ensuring Good Hygienic Practices (GHPs), Good Manufactruing Practices (GMPs) and a food safety system based on Hazard Analysis Critical Control Points (HACCP), with careful attention to preparation and choice of foods in the household and, in specialized circumstance, antibiotic prophylaxis is used (WHO, 2018; Schlech and Acheson, 2000).

Escherichia coli

Escherichia coli is part of the normal bacterial flora in the gastrointestinal tract of humans and other warm blooded animals; most strains are harmless except in immunocompromised individuals (Kaper, Nataro and Mobley, 2004). However, some strains can cause illness and even severe food-borne disease, globally (Abreham *et al.*, 2019; Disassa *et al.*, 2017; Taye *et al.*, 2013, WHO, 2017). Transmission of *E. coli* is by oral-fecal route through consumption of contaminated foods. Meat can be contaminated with *E. coli* during slaughter, as a result of the carcass and environment being soiled with fecal material (Johnson *et al.*, 1996). People can become infected with diarrhoeagenic *E. coli* by consuming or handling contaminated food or water or by contact with infected animals (Abreham *et al.*, 2019; Dhama *et al.*, 2013). Person-to-person transmission is also possible (WHO, 2017a).

E. coli are categorized into groups according to their virulence mechanism (Kaper, Nataro and Mobley, 2004). Diarrhoeagenic *E. coli* groups include amongst others enteropathogenic *E. coli* (EPEC), enterotoxigenic *E. coli* (ETEC) and Shiga toxin-producing *E. coli* (also known as verotoxin-producing *E. coli* (STEC/EHEC). Cattle and other ruminants are the natural reservoirs of Shiga toxin-producing *E. coli* (Abreham *et al.*, 2019; Bekele *et al.*, 2014; Desta Sisay, 2015; Dhama *et al.*, 2013). Globally, this type of *E. coli* is associated with several life-threatening food-borne outbreaks especially in young children and older people (Elmonir, Abo-Remela and Sobeih, 2018; WHO, 2017a). Certain strains of STEC are zoonotic (Fairbrother and Nadeau, 2006). *E. coli* O157 is the most commonly reported serogroup, but other serogroups, such as O26, O103, O145, O91, O146 and O111, can also cause human infection (Assefa and Bihon, 2018; Bedasa *et al.*, 2018; Bekele *et al.*, 2014; İnanç and Mustafa, 2018). TASF typically associated with Shiga toxin-producing *E. coli* include raw milk and dairy products, and poorly cooked ground meat products (Abdissa *et al.*, 2017; Ayscue *et al.*, 2009; Bogere and Baluka, 2014). The major contributing factors for *E. coli* O157:H7 infection include consuming undercooked meat and unpasteurised milk, mass catering, complex and lengthy food-supply procedures with increased international movement, and poor hygiene practices (Haile, Kebede and Wubshet, 2017).

According to the 2010 global estimates by FERG (Havelaar *et al.*, 2015), enterotoxigenic *E. coli* were the group of *E. coli* that caused the most cases of food-borne illness (86.5 million cases and 26 000 deaths), followed by enteropathogenic *E. coli* (24 million cases and 37 000 deaths) and Shiga toxin-producing *E. coli* (1.2 million cases and 13 000 deaths). The annual burden of DALYs due to enterotoxigenic, enteropathogenic and Shiga toxin producing *E. coli* was 2.1 million, 2.9 million and 12 953, respectively (Kirk *et al.*, 2015, FAO and WHO, 2018). In the WHO European Region, Shiga toxin-producing *E. coli* caused more than 150 000 cases of illness per year, representing the seventh of the ten most common causes of illness (FAO and WHO, 2018, EFSA and ECDC, 2015). The annual burden of Shiga toxin-producing, enteropathogenic and enterotoxigenic *E. coli* in the WHO European Region was estimated to be 1 000, 46 and 35 DALYs, respectively (Havelaar *et al.*, 2015). In 2017, 6 073 confirmed cases of Shiga toxin-producing *E. coli* infections were reported in the European Union. The European notification rate was 1.66 cases per 100 000 population, which was a 6.2 percent decrease compared with the 2016 evidence (FAO and WHO, 2018, EFSA and ECDC, 2015). In the same year, 20 deaths due to Shiga toxin-producing *E. coli* infection were reported, which resulted in an European Union case fatality rate of 0.5 percent (FAO and WHO, 2018, EFSA and ECDC, 2015). The most commonly reported Shiga toxin producing *E. coli* serogroup in the European Union is O157, although its proportion relative to other serogroups appears to be decreasing (FAO and WHO, 2018, EFSA and ECDC, 2015).

E. coli infection has an incubation period (time from infection to the manifestation of symptoms) of two to ten days followed by onset of diarrhoea, abdominal pain, vomiting, hemorrhagic colitis and the more severe form of hemolytic uraemia syndrome with acute kidney failure and thrombotic thrombocytopenic purpura a rare disorder that causes blood clots in small vessels of the body (Abreham *et al.*, 2019; Mersha *et al.*, 2010). Septicemia (presence of bacteria in the blood with multiplication that can lead to organs damage/death) starts with bacteremia (presence of bacteria in blood) and ends with toxemia (presence of bacterial toxins in blood), and its severity depends on the effect of bacteria localization in a variety of tissue spaces throughout the body (Desta Sisay, 2015).

Although prevention and control of *E. coli* infections is similar to that of other food-borne bacterial diseases, special precaution is required due to their severe consequence in young children (Desta Sisay, 2015). Control measures include good sanitation measures during food preparation, handling practices, and transport management (Saeedi *et al.*, 2017). In cattle, intervention measures such as probiotics, vaccination, antimicrobials, sodium chlorate and bacteriophages may reduce the prevalence of infection and subsequently support control of *E. coli* O157:H7 (Karmali, Gannon and Sargeant, 2010). Measures such as training of food handlers, food premise inspections, and community-based education programmes promoting proper food handling and preparation techniques are effective in reducing public exposure to food-borne pathogens (Karmali, Gannon and Sargeant, 2010).

4.2 Viral hazards

Viruses are composed of genetic materials, i.e. DNA or RNA enclosed by a protein, sometimes combined with lipids to produce one or more membranous coats. Besides, being much smaller, they are different from bacteria in that they are incapable of reproducing on their own; they first need to infect a living cell and introduce their genetic material into that cell's replication system, whereas bacteria only need a suitable environment to multiply and grow copies of themselves (FAO and WHO, 2008). Viruses, being strictly intracellular, use the living cell's resources to replicate in order to invade more cells. And since they require a living cell to replicate, the viruses are not able to grow in food and water. Even though the number of viruses in contaminated food will not increase, the infective dose of most viruses is presumably low (10 to 100 infectious viral particles). Most food-borne or water-borne viruses are relatively resistant to heat, disinfection and pH changes (FAO and WHO, 2008).

Food-borne infection through ingestion of products from an animal infected with a zoonotic virus is rare, however, hepatitis E virus has been reported, after consumption of pork, wild boar or deer (Ruggeri *et al.*, undated; Van der Poel, 2014) Hepatitis E virus is a small, spherical and non-enveloped RNA virus of approximately 7.2 kb. It is classified within the family of the *Hepeviridae*, genus *Hepevirus*. Hepatitis E virus has emerged as a potential zoonotic threat (Bosch, Pintó and Guix, 2016) and is known to be a major cause of acute human hepatitis in regions with inadequate water supplies and poor sanitary conditions (Guthmann *et al.*, 2006; Purcell and Emerson, 2001). It has been found to be highly prevalent in pigs in several countries where hepatitis E virus in humans is rare (Hazards (BIOHAZ), 2011). Hepatitis E virus variants found in pigs, are almost identical viruses found in some humans (Meng *et al.*, 1997), a finding that provided the first evidence of zoonotic transmission of hepatitis E virus.

4.3 Parasites

Parasitic organisms include protozoa (*Toxoplasma*, *Giardia*, *Cryptosporidium*, amoebae and *Cyclospora*) and helminths i.e., roundworms (*Trichinella* spp., and *Anisakis* spp.,) and tapeworms (*Diphyllobothrium* spp., *Taenia* spp. and *Echinococcus* spp.) (WHO, 2020a). Usually, these parasites are transmitted by food, through water, soil or person-to-person contact, but some parasites, such as fish-borne trematodes, are only transmitted through food (WHO, 2017b). According to FERG data (WHO, 2015), parasitic diseases with the largest symptomatic incident cases attributable to contaminated food in 2010 are acquired toxoplasmosis and ascariosis. The global burden of 11 parasitic diseases was 8.78 million DALYs of which an estimated 6.65 million DALYs were attributed to food (WHO, 2015).

Toxoplamosis

Toxoplasmosis is a food-borne infection caused by a protozoa, *Toxoplasma gondii*. Cats are the primary hosts.Animals, including food animals, are intermediate hosts for the protozoa. Human infection takes place when contact is made with their faeces. Human transmission occurs through consumption of raw or undercooked meat (Attias *et al.*, 2020; WHO, 2020a); and raw milk (Saad, Hussein and Ewida, 2018). In many people, it does not cause any problems, and no treatment is required. The parasite can reach the foetus through the placenta (Attias *et al.*, 2020). Transplacental infection can result in foetal death if it occurs in early stages of pregnancy and may cause hydrocephalus and blindness in children (McAuley, 2014; Scallan *et al.*, 2011).

It is estimated that *T. gondii* infections cause approximately 87 000 illnesses, 4 400 hospitalizations, and 330 deaths each year in the United States of America, making it the second leading cause of food-borne mortality and the third leading cause of food-borne hospitalizations (Scallan *et al.*, 2011). The global burden of toxoplasmosis, both congenital and acquired combined, in 2010, was 1.68 million (95 percent UI 1.24–2.45 million) DALYs (WHO, 2015). Preventative measures include proper cooking of meat to a minimal internal temperature of 70 °C or freezing at –20 °C and avoid eating food potentially contaminated with oocysts from cat faeces (Mirza Alizadeh *et al.*, 2018; Schmidt and Rodrick, 2003).

Cryptosporidiosis

Cryptosporidium parvum is zoonotic mostly transmitted through contaminated water, food or fomites (Zambriski *et al.*, 2013). Cattle are important reservoirs of the pathogen. The systematic literature review reported a pooled prevalence of 22.5 percent (19.6-24.6) for conventional microscopy and 29 percent (23.1-35.6) for detections done using PCR method (Hatam-Nahavandi *et al.*, 2019). Another review focusing on studies done in Iran found a prevalence of 14.4 percent (95 percent, CI = 11 percent, 18.6 percent) (n=40 studies) (Haghi *et al.*, 2020). *C. parvum* is the species mostly responsible for diarrhoeal diseases in animals and humans (Laberge *et al.*, 1996). Calves are mostly affected by *C. parvum* and manifest as watery diarrhoea, inappetence, lethargy, and dehydration (Lombardelli *et al.*, 2019; Robertson *et al.*, 2020) sampled a total of 1 073 calves and found 26 percent to be positive for oocysts, using microscopic examination.

The major symptoms of infection in humans are fever, diarrhoea, abdominal pain and anorexia. Gastrointestinal symptoms usually last about seven to 14 days, unusually five to six weeks, while persistent weakness, lethargy, mild abdominal pain and bowel looseness may persist for a month (Casemore, 1990). In young, malnourished children, symptoms may be severe enough to cause dehydration, malabsorption and even death. Illness and oocyst excretion patterns may vary owing to factors such as immune status, infective dose, host age and possible variations in the virulence of the organism. However, oocyst shedding can be intermittent and can continue for up to 50 days after the cessation of symptoms (mean: seven days) (Clive and Peter, 2002). In humans, the prepatent period is between seven and 28 days. The mean incubation period is 7.2 days (range 1–12) with a mean duration of illness of 12.2 days (range 2–26) (Jokipii and Jokipii, 1968). Cryptosporidiosis in the immunocompromised can be a common and life-threatening condition in developing countries, causing profuse intractable diarrhoea with severe dehydration, malabsorption and wasting. AIDS triple therapies can reduce the severity of the clinical consequences of cryptosporidiosis. Oocyst excretion can continue for two to three weeks after the disappearance of symptoms (Soave and Armstrong, 1986).

The global burden of cryptosporidiosis was estimated to be 128.4 per 100 000 population with a range of 50.3-601.6 (WHO 2015). Clinical outcomes indicated the infections causes severe diarrhoea (0.5 percent), moderate diarrhoea (8.5 percent) and mild diarrhoea (91 percent). Disability weight was GBD2010 disability weight of 0.281 (95 percent UI 0.184–0.399) for diarrhoea, severe, GBD2010 disability weight of 0.202 (95 percent UI 0.133–0.299) for diarrhoea, moderate, GBD2010 disability weight of 0.061 (95 percent UI 0.036–0.093) for diarrhoea, mild (Hotez *et al.*, 2014). The cryptosporidiosis mortality was estimated to be 0.015 per 100 000 population with a range of 0.003-0.08 (WHO, 2015). However, the proportion of FBD burden due to *Cryptosporidium* spp. attributable to TASF (in particular dairy products) is less than 10 percent in all subregions (lowest proportion among all hazards, with a global burden of 0.3 DALYs per 100 000 population) (Li *et al.*, 2019).

Trichinosis

Trichinosis or trichinellosis, is one of the most widespread global parasitic diseases of humans and animals (Foreyt, 2013). It is a zoonoses caused by the larval stage of parasitic roundworms called *Trichinella* spp. (FAO, WHO and OIE, 2021). *T. spiralis* is the most important cause of human disease (Gottstein, Pozio and Nöckler, 2009). Trichinosis is mainly associated with the ingestion of contaminated raw or insufficiently cooked pork or meat from wildlife. Consumption of meat from horses and other animals can also be an uncommon source of human infection, depending on cultural practices, diet and changes in livestock husbandry (Foreyt, 2013). For example, in China, outbreaks of human trichinosis attributed to *T. nativa* have been caused by consumption of dog meat (Cui and Wang, 2001). While in France and Italy, human infections have been linked to consumption of horse meat (Dupouy-Camet, 2000). *T. spiralis* is the predominant species in the United States of America, but *T. pseudospiralis* and *T murrelli* have also been identified (Worley *et al.*, 1986). Following the ingestion of meat containing encysted larvae, the cysts dissolve in the intestine, releasing the larvae, which then enter the gastrointestinal tract epithelium. Here, the parasites mate and deposit larvae in the lymphatic system. Through lymphatic circulation, the larvae infect other body tissues. Initial symptoms are gastroenteritis and it may develop to irregular fever (39-41 °C), muscle pain, difficulty in breathing, talking or moving. The disease duration ranges from 21.5 to 70 days (Murrell and Pozio, 2011). The larvae in muscles can be killed by a number of methods: heating to 65.5 °C, freezing at -15 °C for three weeks or at -30 °C for one day. According to Murrell and Pozio (2011), 51 percent of the cases of infection in humans were found to be male and majority of the cases were between 20 and 50 years of age.

Trichinosis is a public health threat, with as many as 11 million human infections worldwide (Dupouy-Camet, 2000). In many countries, such as the United States of America, the number of reported cases has decreased significantly during the last 50 years largely because of the prohibition on feeding pigs with untreated garbage (swill), improvements in surveillance, public education, livestock husbandry systems and hygiene (Foreyt, 2013). However, trichinosis is an emerging and re-emerging disease in many countries, especially in eastern Europe, where an increased prevalence of up to 50 percent in pig herds in Belarus, Croatia, Latvia, Romania, Russian Federation and Ukraine was reported (Pozio, 2001). In Argentina, Chile, Mexico and the Plurinational State of Bolivia, trichinosis is still endemic and prevalent due to an increase in the number of small farms which often lack good management practices, lack of sanitary regulations, lack of regulations for home slaughter and misconception that trichinosis is no longer a disease of concern (Gajadhar and Gamble, 2000). Increased prevalence of the disease in many other countries is attributed to lack of veterinary controls, economic problems and war, change in livestock husbandry, changes in marketing and distribution systems, human practices, complacency and increase in wildlife reservoirs (Pozio, 2001).

The prevention and control of trichinosis can be achieved through education and hygiene in environment and in the home. Transmission of trichinosis to garbage-fed pigs can be prevented by cooking the garbage (swill) to an internal temperature of 71 ^{o}C to inactive the *Trichinella* larvae (Pozio, 2001). Cooking all meat to 71 ^{o}C (Gajadhar and Gamble, 2000) will kill larvae and prevent human infections; however, its more effective for meat producers and suppliers to prevent infected meat from reaching the consumers. Control in pigs can be enhanced through biosecurity measures, rodent control and avoidance of feeding wastes to pigs (van Knapen, 2000).

4.4 Prions

Prions are infectious pathogens associated with specific forms of neurodegenerative disease and mediated by an entirely novel mechanism (Prusiner, 1998). Prions are composed of a modified protein and are devoid of nucleic acid (Prusiner, 1998). Bovine spongiform encephalopathy (BSE or "mad cow disease") is a prion disease in cattle, thought to have originated from feeding animal protein derived from sheep infected with scrapies. BSE appears to have had the ability to mutate in a manner to be infectious in a number of different mammalian species, transfering from sheep to cattle then to humans. The disease is associated with the variant Creutzfeldt-Jakob Disease in humans. Consuming bovine products containing specified prion-containing risk material, e.g. brain tissue, nerve ganglia, spinal tissue appear to be the most likely route of transmission of the prion agent to humans (WHO, 2020a).

5 Chemical hazards and associated public health impacts

Chemicals have both beneficial and negative impacts on human health (World Health Organization, 2014). Contamination of food can occur at various levels of the value chain. The public health concern of chemicals is related to their presence where they should not be or are present but in amounts that are higher than the recommended amount (Rather *et al.*, 2017). The categories of substances involved in contamination of food include:

- agrochemicals such as pesticides and herbicides;
- veterinary medicine and residues of veterinary medicines;
- environmental contaminants: mainly heavy metals, persistent organic pollutants, and natural toxins; and
- processing contaminants as a result of cooking, processing, or packaging such as nitrosamines, chloropropanols, acrylamide, furanes, or poly-aromatic hydrocarbons (Nerín, Aznar and Carrizo, 2016).

5.1 Agrochemicals

Residues of pesticides

According to FAO and WHO (2014), pesticide means any substance or mixture of substances of chemical or biological ingredients intended for repelling, destroying or controlling any pest, or regulating plant growth. At the international level, the Joint Meeting on Pesticide Residues in Food has been responsible for the risk assessment of pesticide residues in food and estimating maximum levels of residues to prevent toxicological health risk (FAO, 1997). The Codex Alimentarius Commission through the Codex Committee on Pesticide Residues aims at reaching consensus between governments on the maximum residue limit allowed in food (risk management).

Pesticides are used in agriculture, to protect plants and ensure produce is not destroyed by pests and in public health to control vector-borne diseases (Nicolopoulou-Stamati *et al.*, 2016). Pesticides can be natural or synthetic and include insecticides, herbicides and fungicides (Cabras, 2003; Stoytcheva, 2011). Over 1 000 pesticides are known to exist. When not properly used, pesticides can contaminate the environment with negative impacts on soil, water, and vegetation (Aktar, Sengupta and Chowdhury, 2009). The public health concern is related to their persistence as residues (Aktar, Sengupta and Chowdhury, 2009). Dichloro-diphenyl trichloroethane (DDT) and hexachlorocyclohexane (HCH) use was restricted in the late 1990s, (Gill *et al.*, 2020), however, in countries such as India, dichloro-diphenyl trichloroethane use is still permitted for the control of malaria-borne vectors even though resistance of the vectors has been reported (van den Berg, Manuweera and Konradsen, 2017; Curtis, 2002).

Use of pesticides in agriculture can result in contaminated feeds, which, when consumed by animals, can be excreted in milk. A study in the United Kingdom found 21 percent of feeds to contain pesticide residues (which could potentially end up in cow milk) (FAO, 2004). Another study involving different feed types reported contamination in 56 percent (n=533) of samples analyzed but many of the samples had levels below the regulatory limits (Nag and Raikwar, 2010). In Punjab, 6.7 percent milk samples were reported to be contaminated with residues of chlorpyrifos (Bedi *et al.*, 2015). Another study in India, involving peri-urban areas in five states, reported residue prevalence rates of 6.3 - 11.2 in milk (Gill *et al.*, 2020). Another study analyzed a total of 325 milk samples and found 206 (63 percent) to be contaminated with different pesticide residues (Nag and Raikwar, 2008).

Most insecticides are neurotoxic and action by attacking the nervous system of target organisms. Chemical compounds that act on the nervous system of insects also have similar effects on humans (Costa, 2008). In addition, pesticides affect different organs such as skeletal muscles, gastro-intestinal tract, bladder, secretory glands, and respiratory systems. Cancer and asthma are among the diseases associated with pesticide exposure in humans (Kim, Kabir and Jahan, 2017). The health outcome is dependent on the type of pesticide, the duration and route of exposure and the health status of the individual (Nicolopoulou-Stamati *et al.*, 2016).

Residues of veterinary medicines

The use of veterinary medicines in livestock production is aimed at preventing, controling or treating disease, improving feed uptake and promoting growth. However, the benefit of improved production runs the risk of residue presence in the products. In recognition of the public health risk that may arise due to residues of veterinary medicine in food, the Codex Alimentarius Commission established the Codex Committee on Residues of Veterinary Drugs in Foods to advise member governments and the Commission on issues of public health hazards and barriers to international trade as a consequence of these residues in foods of animal origin. Subsequently, the Joint FAO/WHO Expert Committee on Food Additives has held regular meetings to specifically address residues of veterinary drugs in foods of animal origin (FAO and WHO, 2000).

Several studies have documented prevalence and not actual levels of veterinary medicine residues in TASF making it difficult to assess the risk to humans. Prevalence studies for veterinary product residues in TASF have been reported in eggs, beef (Mensah *et al.*, 2014; Omeiza *et al.*, 2012; Omeiza, Ajayi and Ode, 2012) and in milk (Abebew, Belihu and Zewde, 2014). Some veterinary medicine residues arise from the unintended presence of residues of approved veterinary drugs in food animals, resulting from carryover of veterinary drugs in feed (FAO and WHO, 2019). Drug residues that are still present at the time of slaughter pose significant health risks to the consumers related to the evolution of antimicrobial resistant bacteria, especially if the levels exceed what has been recommended.

Hypersensitivity reactions, carcinogenicity, mutagenicity, teratogenicity and disruption of intestinal flora are the main concerns associated with presence of veterinary medicine residues in animal source food (Tufa, 2015). It is important that value chain actors are sensitized about observance of drug withdrawal periods, to ensure sale of products that are safe for human consumption.

5.2 Environmental contaminants

Dioxins and PCBs[2]

Dioxins are widely distributed contaminants and are a consequence of human activities, especially of industrial processes, and incomplete combustion processes like waste incineration as well as improper disposal of transformer oil used in the electrical distribution industry (Marinkovic, 2010). Over 95 percent of human exposure to dioxins and PCBs is through the ingestion of high fat foods including meat and meat products, fish, milk and dairy products (Zennegg, 2018).

A number of food and animal feed contamination incidents did occur in 1997 and 2010 in Europe and these highlighted the need to monitor dioxins and PCBs in food and feed (Zennegg, 2018). An outbreak involving dioxin and PCB in animal feeds occurred in Belgium in 1999 (van Larebeke *et al.*, 2001). Cattle from extensive farming systems have been found to have higher levels of dioxin-like PCBs (dl-PCBs) compared to conventional raised cattle, implying exposure through grazing, and indicating that the chemicals are less in concentrate feed when compared to silage and green fodder (Zennegg, 2018).

According to the WHO, short-term exposure of humans to high levels of dioxins may result in skin lesions, such as chlor acne and patchy darkening of the skin and altered liver function. Long-term exposure is linked to impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions.

Heavy metals

Heavy metals is a term that describes a number of metals and if present in food or feed beyond a recommended threshold may present a significant risk to human health. They can persist for long in the environment and have the potential to bioaccumulate in food value chains (WHO, 2007). Heavy metals interfere with normal body functions and affect health. According to WHO burden estimates (WHO, 2015), ingestion of arsenic, methylmercury, lead, and cadmium resulted in 1 122 436 illnesses, 56 192 deaths, and 9 164 162 DALYs worldwide with the greatest impact on DALYs in the Western Pacific B subregion (Gibb *et al.*, 2019).The estimates further indicate that all of the metals were found to have high DALYs per case in comparison with other FBD agents, including infectious and parasitic agents (Gibb *et al.*, 2019). Lead, arsenic, and methylmercury were found to have high DALYs per 100 000 population in comparison to other FBD agents (Gibb *et al.*, 2019).

Lead

Lead (Pb) occurs primarily in the inorganic form in the environment. It is the most toxic heavy metal in the environment (Wani, Ara and Usmani, 2015). Human exposure is mainly through food and water, with some occurring through air and soil. From the WHO burden study, lead accounted for 54 percent of the illnesses, none of the deaths and 60 percent of the DALYs (Gibb *et al.*, 2019).

A recent systematic review over a ten-year period (2010-2019) on occurrence of lead in TASF in Iran reported a number of studies that showed concentrations above maximum recommended limits in meat and milk, and their products (Sarlak *et al.*, 2021).

Lead is absorbed more in children than in adults and accumulates in soft tissues and, over time, in bones (Wani, Ara and Usmani, 2015). Lead and calcium compete for protein; lead can displace the calcium from protein so that the calcium will not be able to function properly. The central nervous system is the main target organ for lead toxicity (Tong, 2000). In the body, lead has a long half-life which results to chronic toxicity (Sanders *et al.*, 2009). Studies have shown a link between blood lead

[2] Polychlorinated biphenyls

concentration and chronic kidney disease at relatively low blood lead levels (Buser *et al.*, 2016; Harari *et al.*, 2018; Rastogi, 2008). In adults, lead associated neurotoxicity was found to affect central information processing. In children, lead exposure affects cognitive functions (Sanders *et al.*, 2009). The Joint FAO/WHO Expert Committee on Food Additives establishes the provisional tolerable weekly intake (PTWI) for lead at the international level (FAO and WHO, 2011a).

Cadmium

Cadmium (Cd) is a heavy metal found as an environmental contaminant, both through natural occurrence and from industrial and agricultural sources. It has no known biological function in animals and humans. Foods are the main source of cadmium exposure for the non-smoking population (Agency for Toxic Substances and Disease Registry, 2012; UNEP, 2019). From the WHO burden study, cadmium accounted for 1 percent of the illnesses, 4 percent of the deaths and 1 percent of the DALYs (Gibb *et al.*, 2019). Poultry, cattle, horses, and wildlife are among the animal bio-accumulators of cadmium (ATSDR, 2012; Raicu, Vlagioiu and Tudor, 2020). Meat normally contains lower cadmium contents, however, animal offals (kidneys and liver) can exhibit high cadmium concentrations (as these are the organs where the chemical concentrates most) (Drapal *et al.*, 2021). Cadmium absorption after dietary exposure in humans is generally low (3–5 percent) but, even then, it gets retained in the kidney and liver in the human body, with a very lengthy biological half-life ranging from 10-30 years (ATSDR 2012). Cadmium exposure has been associated with accumulation in the proximal tubular cells overtime and may cause renal malfunction and osteoporosis through bone demineralization and neurotoxicity (European Food Safety Authority (EFSA), 2009; Genchi *et al.*, 2020).

Mercury

Mercury (Hg) is widely distributed in the earth crust, seawater, fresh water and air. In Poland, bioaccumulation of mercury in the food chain was analyzed for a period of ten years (2009-2018) through monitoring of muscle tissue and liver of different livestock and game animals (Nawrocka *et al.*, 2020). The results in muscle tissue were below the limits of quantification. However, the mean mercury concentrations in muscle tissue and liver were between 0.6 and 5.6 μg kg^{-1} and 0.8–16.4 μg kg^{-1} of wet weight with the lowest levels recorded in chicken and highest in wild boars. A recent study on bioaccumulation and toxicity of heavy metals in edible chicken liver showed mercury concentrations of 110 +/- 83 ug/kg (Ali *et al.* 2020); while another study showed mean levels of mercury of 125 ug/kg in meat (Alturiq and Albedair 2012). A ten-year review of mercury concentrations in muscle tissue in Poland showed a range from 0.6-5.6 μg kg^{-1} of wet weight and the mean liver mercury concentrations were within the range of 0.8–16.4 μg kg^{-1} of wet weight, with lowest levels in chicken and highest in wild boars (Nawrocka *et al.*, 2020) although these levels of mercury in the food did not pose a health risk.

Mercury is a concern to women of reproductive age and children (Feingold *et al.*, 2020). Mercury toxicity usually manifests itself mainly as neuronal disorder, immunotoxicity and kidney damage (Clarkson, 2002). Poisoning with organic mercurial compounds results in a wasting brain disease and loss of control of the motor nerves. For example, in mercury poisoning in Minamata, Japan, in a small fishing town, affected persons suffered progressive weakening of the muscles and paralysis. Over 40 percent of those exposed died, and others suffered permanent damage from the poison. This poisoning (Minamata disease) was one of the worst that occurred in Japan in the 1950s (Kessler, 2013).

Arsenic

Arsenic (As) is a heavy metal that occurs in different inorganic and organic forms. Arsenic is especially prevalent in the environment both from natural occurrence and anthropogenic activity. It can easily enter the agrifood system through contaminated soil or water. From the WHO burden study, arsenic accounted for 20 percent of the illnesses, 96 percent of the deaths and 14 percent of the DALYs (Gibb *et al.*, 2019).

A study in West Bengal, India evaluated alternative source of arsenicosis in human food chain through milking cattle and poultry (Datta *et al.*, 2012). The study showed that poultry egg yolk, albumen, and all poultry organs contained arsenic. Consumption of eggs and milk might have produced arsenicosis and could be considered as alternative source of arsenic contamination (Datta *et al.*, 2012). Another study, also in India, assessed arsenic in chicken meat and reported highest accumulation of arsenic in the meat of the chicken breast followed by stomach, with the meat of the legs and heart showing lower levels of arsenic accumulation. The implication of this to human health is that if a person takes 60 g of chicken meat daily, then the person may consume 0.186–0.372 µg of total arsenic per day (Mondal, 2020).

The main public health effects associated with long term exposure of inorganic arsenic in humans are skin lesions and cancer (Hong, Song and Chung, 2014; Naujokas *et al.*, 2013). A causal role for oral exposure to arsenic on skin, lung and bladder cancers has been established, although there is also indications for liver, kidney and prostate cancers (Hong, Song and Chung, 2014). There are other adverse health effects related to chronic ingestion of arsenic such as cardiovascular diseases, developmental toxicity, abnormal glucose metabolism, type 2 diabetes and neurotoxicity (FAO and WHO, 2011b).

Nitrates and Nitrites

Nitrate (NO3) is a polyatomic anion that can form salts with a number of elements. They naturally occur in the environment, occur in most foods (plants and animal tissue), and nitrites are endogenously formed within the human body. Nitrates are involved in the nitrogen cycle and can build large deposits especially in the form of sodium nitrate (NaNO3) (EFSA, 2020).

They have various uses in feed and food, such as in the production of fertilizers and food preservatives. Nitrates and nitrites have found use as additives in food of animal origin. The European Union has authorized the use of nitrites (sodium nitrite—E249, potassium nitrite—E250) and nitrates (sodium nitrate—E251, potassium nitrate—E252) as food additives under Commission Regulation (EU) No. 1129/2011. They are acceptable for use as food additives in some countries to stabilize various types of processed meat, to keep it red and give flavour, while nitrates are used to prevent certain cheeses from bloating during fermentation (EFSA, 2017).

The major human risk associated with exposure to nitrates is considered to be production of methaemoglobin, a molecule with very limited oxygen carrying capacity. Clinical symptoms include anoxia, tachycardia, dyspnoea, muscle tremors, reduction in blood pressure, weakness, vomiting, unstable gait, cyanosis (exhibited by brown-coloured arterial blood), polyuria, lethargy and death (Bruning-Fann and Kaneene, 1993).

Studies have shown when it reacts with secondary amines under acidic conditions, nitrite can form N-nitrosamines (Gupta *et al.*, 2010; Robles, 2014). This reaction could be potentially of toxicological significance because some of the dialkyl- or cyclic N-nitrosamines are genotoxic and carcinogenic. Nitrosating agents produced from nitrite under acidic conditions in the stomach could react readily with nitrosatable compounds, especially secondary amines and amides, to form N-nitroso compounds, some of which are potential carcinogens (Shephard, Schlatter and Lutz, 1987).

Natural toxins

Natural toxins are toxic compounds that are naturally produced by living organisms (WHO, 2018b). These toxins though not harmful to the organisms themselves, they may be toxic to other creatures when exposed to them, including humans. Some of these toxins are produced by plants as a natural defense mechanism against predators, insects or microorganisms or as consequence of infestation with microorganisms, such as mould or in response to climate stress (such as drought or extreme humidity). Other natural toxins may include microscopic algae and plankton in oceans and lakes that produce chemical compounds that are toxic to humans but not to fish or shellfish that eat these toxin-producing organisms. The natural toxins affecting livestock production and livestock products are described below.

Mycotoxins

Mycotoxins are chemical metabolites of food- and feed-borne fungi that can cause toxic and carcinogenic effects in humans and animals (WHO, 2018). In the context of livestock production for human nutrition, the animals can be exposed to mycotoxins through contaminated feed and humans can in turn be exposed to a subset of these mycotoxins through the consumption of the resulting food.

Although mycotoxins, particularly aflatoxins, are responsible for a large burden of human disease worldwide causing more than 600 000 DALYs and 19 000 deaths per year (WHO, 2015) as well as substantial economic losses to farmers, most of these losses are suffered due to mycotoxin exposures through crops such as cereals and nuts. Through crop-based exposures, humans suffer a variety of mycotoxin-related health risks spanning cancers, acute liver failure, immunosuppression, gastrointestinal illness and growth impairment (Wu, Groopman and Pestka, 2014). With respect to human exposures through TASF, only two mycotoxins – aflatoxin M1 (FAO and WHO, 2018c) and ochratoxin A – pose potential risks.

Aflatoxin M1 (AFM1) is a metabolite of aflatoxin B1 (AFB1), the most toxic and carcinogenic of aflatoxins. Aflatoxins (B1, B2, G1, G2) are a group of chemicals produced primarily by the fungi *Aspergillus flavus* and *A. parasiticus* in food and feed crops such as maize, groundnut, tree nuts, and oilseeds. Aflatoxin was first discovered in 1960, following the deaths of over 100 000 turkey poults that had consumed aflatoxin-contaminated peanut meal (Kensler *et al.*, 2011). In the subsequent decades, it was discovered that aflatoxin causes hepatocellular carcinoma – liver cancer – in humans and multiple animal species (IARC, 1993). In the liver, AFB1 is biotransformed by cytochrome P450 enzymes into multiple metabolites, including AFM1. When dairy animals consume AFB1 in their feed, they secrete AFM1 in milk. Thus, through milk and dairy consumption, humans are exposed to AFM1.

An overview of AFM1 occurrence in different forms of milk including raw milk, and resultant AFM1 exposure based on milk consumption country by country is given by Saha Turna and Wu (2021). The authors report exposure ranging from 0.0021-125.6 ng/kg bodyweight per day. Unsurprisingly, the countries where animal feed is most highly contaminated with aflatoxin and where humans consume the most milk are where populations are most highly exposed to AFM1 – including India, Pakistan and several sub-Saharan African countries.

The question is whether any human health risk exists from AFM1 exposure. AFM1 is much more weakly carcinogenic than its parent compound AFB1. Only two studies have demonstrated that AFM1-related tumors could be induced in mammalian species (Cullen *et al.*, 1987; Lutz *et al.*, 1980). To date, not a single epidemiological study has linked AFM1 exposure in humans to liver cancer. In the absence of human data, the Joint FAO/WHO Expert Committee on Food Additives (1998) used the existing animal studies to estimate that AFM1 had a cancer potency that was one-tenth that of AFB1. Using this cancer potency factor, it was estimated that AFM1 exposure through milk consumption would cause, at maximum, only 13 to 32 additional liver cancer cases worldwide per year (Saha Turna *et al.*, 2022). However, other potential health effects of AFM1 exposure remain to be examined. There are limited studies suggesting that AFM1 exposure through breastmilk may predispose infants to growth impairment (Khlangwiset, Shephard and Wu, 2011), although the evidence is mixed.

Ochratoxin A (OTA) is produced primarily by the fungi *Aspergillus ochraceus* and *Penicillium verrucosum* in a wide variety of foodstuffs (FAO and WHO, 2007). Of relevance to TASF, Ochratoxin A has been found in dairy and meat products worldwide. A study involving dairy farms in Latvia found Ochratoxin A in six of the 40 (11–58 ng/l) conventional and in five of the 47 (15–28 ng/l) organic milk samples analyzed. A study involving 132 French farms (Boudra *et al.*, 2007) found three to be Ochratoxin A positive (n=264 milk samples), in levels of 5.0-6.6 ng/l but no metabolite Ochratoxin A was detected. Contamination of cheese with Ochratoxin A was reported by Altafini *et al.* (2021). The study in Turkey found mean Ochratoxin A contamination levels to be 137±57 ng/l (in raw milk), 135±8 ng/l (pasteurized), and 85±4 ng/l (in UHT) milk samples (Turkoglu and Keyvan, 2019). Ochratoxin A transfer in milk of ruminants is however limited, due to the action of ruminal microflora (Sorrenti *et al.*, 2013).

Ochratoxin A contamination (mean 0.05 µg/kg) in organic pork (4/7) was reported in Denmark (Duarte, Lino and Pena, 2012). A recent study of the United States of America (Mitchell *et al.*, 2017) found Ochratoxin A exposure from pork to be highest in >12 month to 5-year-old children; the mean was 0.16 ng/kg bodyweight per day and 0.6 ng/kg bodyweight per day for heavy consumers. The same study found milk-based Ochratoxin A exposures in adults, average and heavy milk consumers, to be 0.02 and 0.04 ng/kg bodyweight per day, respectively.

There is little evidence for human health risks as a result of Ochratoxin A exposure (Bui-Klimke and Wu, 2015). Ochratoxin A has, however, been associated with renal diseases in both livestock and human populations (Cabañes, Bragulat and Castellá, 2010). Some studies have linked Ochratoxin A exposure with the Balkan endemic nephropathy and chronic interstitial nephropathy (a chronic renal disease of unknown aetiology found in geographically close areas of Croatia, Bosnia and Herzegovina, Bulgaria, the Republic of North Macedonia, Romania, Serbia and Slovenia and chronic interstitial nephropathy) (Fuchs and Peraica, 2005). The International Agency on Research on Cancer (IARC, 1993) has classified Ochratoxin A as a Group 2B possible human carcinogen: suggestive evidence for Ochratoxin A-related cancers have been found in animal studies, but none in humans.

6 Changing agrifood systems

Climate change affects the social and environmental determinants of the health of human, animal and plant population. The impact is reflected in form of novel, emerging and re-merging diseases (vector borne, soil borne, water-borne and FBD that threaten the health of the vulnerable groups of people and aggravate economic and social inequalities (FAO, 2018). Higher local temperatures are also associated with increased rates of resistant infections hence increased antimicrobial resistance (Blair, 2018).

Agrifood systems have transformed rapidly driven by several factors including increased incomes and rapid urbanization rates which have caused nutritional shift as consumption patterns change significantly (FAO, 2017b). There is increased consumption of processed and foreign foods and, therefore, posing challenges in meeting the necessary food safety and nutrition standards.

Food safety issues have been associated with the traditional agrifood system with limited technological advancement. However, development of modern agrifood systems brings with it new risks. Intense production and extensive international transfers of animals and animal products facilitate long distance pathogen transmission (Dury *et al.*, 2019). Intensification of production has come along with waste management challenges especially in LMICs. Much of this waste, which contains large quantities of pathogens, is disposed of on land without any requirements for pretreatment, posing an opportunity for human contact and transmission to wild animals, both avian and mammalian (Nachman *et al.*, 2005; Zheng *et al.*, 2006). Large scale high-input dependent livestock production systems tend to create unique ecosystems for close interaction of pathogens, humans and animals leading to emergence or spill over of zoonotic diseases such as Nipah virus infection in 1999, severe acute respiratory syndrome (SARS) in 2002, and highly pathogenic avian influenza (HPAI) although they are not food-borne.

FBD are mainly related to consumption of contaminated animal products, vegetables and fresh fruits (Dury *et al.*, 2019). The consumption of the foods is increasing as part of the dynamism of food transition in urban settings, and at the same time longer supply chains. Different activities within the agrifood systems could contribute to unsafe food. In rural areas, the significance of the post-harvest activities is increasing with urbanisation and market economies. Post-harvest activities enhance product storage and transportation, in addition to improving their organoleptic, nutritional and sanitary quality. In communities, food is a means of promoting and building one's identity and belonging to a particular community. Different societies process food products in different ways because of the cultural differences.

Since the early 1930s, antibiotic use has intensified in veterinary and human clinical setting, household products and agricultural production with several benefits to patients, producers and consumers (Allen *et al.*, 2013). In livestock production, antibiotics are used in disease treatment, control, prevention and growth promotion (Allen *et al.*, 2013) with the aim of increasing production hence economic benefit. Repeated use of antimicrobial agents in livestock including non-therapeutic doses for growth promotion, is reported to significantly contribute to development of antimicrobial resistance (Agyare, 2016; Elliott, Kenny and Madan, 2017; Lekshmi *et al.*, 2017). The emergence of drug resistant infection has led to substantial cost to human and animal health. Antimicrobials in livestock may result in residues in food products such as milk, meat, eggs and their products which may eventually cause health-related problems. Additional, FBD could increase, with the rise in antimicrobial resistance (O'Neill, 2014; Sachi *et al.*, 2019). Hence, from a scientific standpoint, there is need to significantly and urgently reduce antimicrobial use in agrifood systems in order to combat rising levels of drug resistance. Global effort towards combating antimicrobial use and resistance are evident in the One Health approach with the Tripartite FAO/WHO/OIE Joint Secertariat promoting best practices (WHO, 2012).

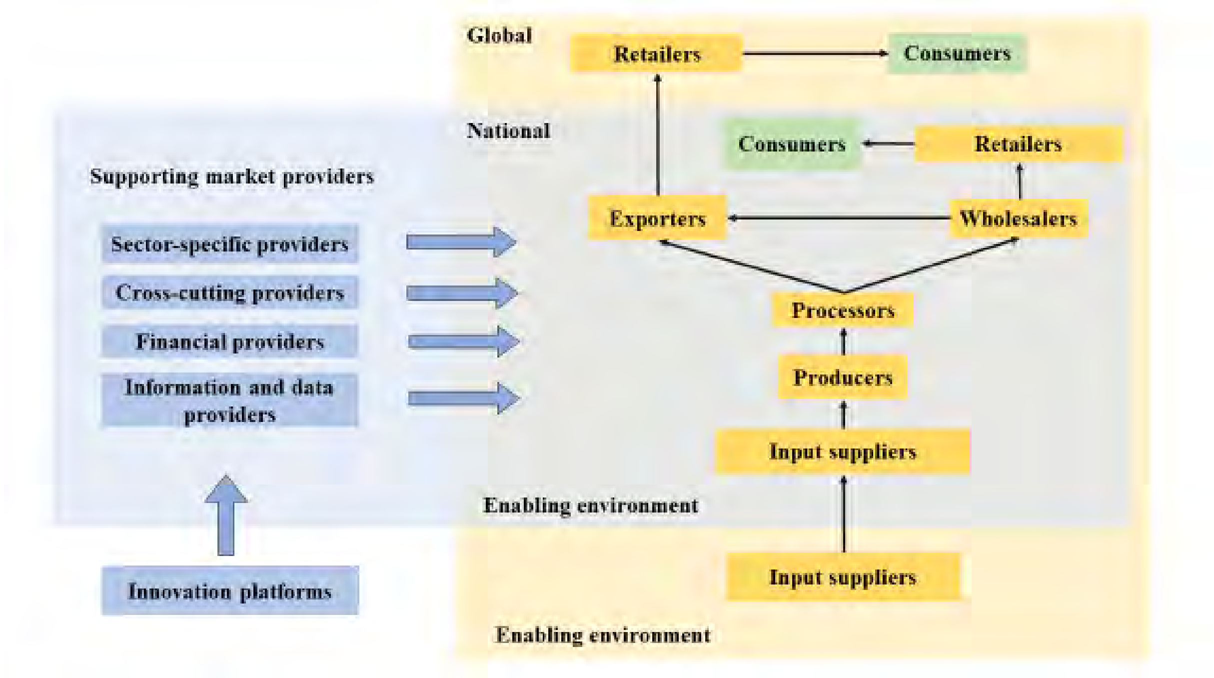
7 Food markets

TASF are vital components of the diets and livelihoods of people globally (Staal, 2015). Terrestrial TASF are frequently traded in formal regulated markets as well as local, unregulated markets. Consumption of these tends to be higher in cities than in rural areas (AGRA, 2020). Informal markets, common in many developing countries, are not necessarily dangerous although they can pose significant health risks to the consumers (Roesel and Grace, 2014). Formal markets are also not necessarily safe. In both cases care must be taken to ensure safety of products released through these markets. In this subsection both markets are discussed.

Marketing of livestock and livestock products is a dynamic process (Alexandratos and Bruinsma, 2012) and largely driven by demand although other factors play a role (Staal, 2015). Formal markets are managed based on international standards and are driven by the demand beyond local boundaries. Increasingly, consumer demand is driving a move towards higher standards, which is being channeled back through more integrated production and supply chains, including greater roles for supermarkets. Regulators in turn are responding to public pressure by increasing scrutiny and standards for food safety (Staal, 2015). Many formal markets comply, or try to comply, with government regulations when these are available and known, but generally there is lack of effective food safety management systems in developing countries. In developed countries, food safety is largely governed by the private sector, while government enforces the legal framework under which the sector operates (AGRA, 2020).

Although formal food markets focus on managing supply chains, they also need to address the complexity of handling and regulating highly perishable products, which at times also present greater human health implications than crop products (Staal, 2015). Formal markets are organized with regulatory infrastructure along the value chain and link the steps a product takes from the producer to the consumer (Baltenweck, 2014) as illustrated in Figure D1.

Figure D1 Formal food markets and global value chain



Adapted from Kula, Downing and Field (2006)

Global value chains in the context of formal food markets for livestock products facilitate an improved understanding of competitive challenges, help in the identification of relationships and coordination mechanisms and assist in understanding how chain actors deal with powers and who governs or influences the chain. Formal food markets are focused on developing value chains to improve access to markets and enabling a more efficient product flow while ensuring that all actors in that chain benefit. Another important aspect of formal markets are food safety standards and the critical control points based on code of practice documents (i.e. food safety protocols). A given exporters' food safety protocol is based on the requirements of its destination market which include but often exceed good agricultural practices. The volume of food sold through modern formal retail (supermarkets and convenience chain stores) in Africa is still low (Tschirley, Haggblade and Reardon, 2013).

Food markets in the informal sector play a vital role in the livelihoods of the poor in developing countries. Informal markets (also called traditional markets[3]) provide affordable, accessible and diverse food for the urban poor, while at the same time supporting the livelihoods of millions of small-scale producers, traders and vendors (Resnick, 2017) who include the youth and women. They are convenient, accessible and play critical roles in nutrition and livelihoods. In Zambia, for example, the informal sector is a major source of employment and livelihoods and almost 80 percent of informal workers are employed in agricultural-related activities (Mwango *et al.*, 2019). However, the conditions under which the informal sector operates raise concerns relating to the safety and quality of food sold, including terrestrial animal source food. The informal sector focusses on fresh food sales, while supermarkets and other formal stores supply more processed products (Romanik, 2008). Traditional food markets have also been associated with important food-borne and zoonotic outbreaks, including most recently COVID-19 although COVID-19 is not a food-borne disease (WHO, 2021).

[3] A traditional food market includes wet markets, informal markets and farmers' markets that sell foods of animal origin/non-animal origin/dried goods and where live animals are sometimes housed and slaughtered on site (WHO, OIE and UNEP, 2021).

A safe and healthy traditional food market should provide a given population with food that is not only safe but also nutritionally adequate (WHO, 2021). To achieve this, several aspects have to be considered including physical layout and facilities, hygiene practices, culture, and handling of ready-to-eat food. The implementation of a combination of diverse interventions, encompassing research, regulation and education and operating at different stages of the food chain, has the potential to yield the best results (WHO, 2021). In addition, informal markets, especially those in developing countries, should be monitored (Baltenweck, 2014) to ensure food safety is maintained.

The term wet market is defined differently by different authors. The definitions also differ by location or regions especially when referring to the range of products sold within these markets. For instance, a wet market can be defined as a public market that sells, among other products eggs, meat and fish, in an open-air setting (Zeng, 2016).

Emerging and re-emerging zoonotic infections have increased in frequency in the past centuries (Bengis *et al.*, 2004). A number of factors contribute to zoonotic disease transmission; presence of the pathogen, presence of the host (animals), sanitation and hygiene in the environment, population size (humans, market size, animals), other parallel activities, improper storage of animals, overcrowding, improper disposal of faeces and carcasses, level of biosecurity, among others (Sobsey *et al.*, 2006). For example, increased demand and trade in meat from wildlife increase chances of exposure to disease-causing pathogens that these foods may carry with them. In addition, the increasing human population has augmented the contact between humans and animals through increased demand for foods of animal origin as well as increased encroachment on the wildlife habitats for human activities and settlement (Naguib *et al.*, 2021a).

Wet markets in China and meat from wild animals in Africa are strongly implicated in many recent zoonotic transfers and spill overs including COVID-19, although not yet proven to be food-borne (Haider *et al.*, 2020). Such zoonotic diseases exert a significant burden on human health and have considerable socioeconomic impact, globally. The interaction of humans, live domestic animals for sale, food products, and wild and scavenging animals, creates a risk for emerging infectious diseases. SARS-CoV2 was initially associated with a wet market in Wuhan province (Rabi *et al.*, 2020). One leading theory is that the virus 'jumped' from a bat to a pangolin or other wild animal, which in turn was sold in a wet market (Rabi *et al.*, 2020). Similar theories have been reported in the past on the origin of Ebola and other outbreaks including HIV-AIDS (Zhang *et al.*, 2020). Middle East Respiratory Syndrome (MERS) and acute respiratory syndrome (SARS)-CoV-2 have been reported globally to originate from wet markets (Hui *et al.*, 2020). All these follow the relatively recent emergence of SARS, MERS, Nipah virus, 'Swine Flu', and highly pathogenic avian influenza (H5N1) (Dhama *et al.*, 2020). In addition, the avian influenza H5N1 outbreak (2003-2006) that culminated into 113 human deaths was linked to contact with infected poultry (Naeem *et al.*, 2007).

It is no doubt that if no action or intervention is undertaken to improve the safe and hygienic operation of these markets, these might endanger the already fragile agrifood systems, human health and rights, and ultimately negatively impact on sustainable development at global scale (Akhtar, 2012). Several strategies have been instituted in order to minimize public health impacts arising from these markets. For instance, the Convention on Biological Diversity called for a move to reduce the number of live animals in wet markets and for stricter controls on the sale and consumption of wild species (Everard *et al.*, 2020). WHO has recently developed food safety and hygiene standards that wet markets must adhere (WHO, 2021).

Despite the role played by wet markets globally in food security and livelihoods development, they play a critical role in the emergence and spread of respiratory virus epidemics and other zoonotic health risks that must be prioritized by global health researchers and policymakers. It is important to understand the epidemiology and pathogenesis of these zoonotic pathogens especially those linked to wet markets. These pathogens can move directly from animal species to infect humans or through intermediate hosts or amplifier hosts.

It is important to assume that the risks to different infections may compound cumulatively and wet markets can be ranked according to their combined risks and be prioritized as being less or high-risk thus triggering action from public health officials (Artois *et al.*, 2009). Calls to ban wet markets might be met by local or national resistance in countries where such markets abound, thereby blocking opportunities to target the types of wet markets that actually pose serious risks to people or biodiversity.

Indeed, it is right time to reconsider guidelines on biosecurity and hygiene at wet markets especially in high-risk regions, to prevent future pandemics. However, measures such as, installing handwashing facilities and toilets, requiring adequate drainage, separating live animals from meat and produce and implementing protocols for cleaning food and slaughtering animals are relevant in reducing the extent of pathogen exposure and transmission. Other interventions would include, strengthening zoning and land use planning, development of a legislative framework, integrating healthy design standards into infrastructure, improving the quality and distribution of public spaces; strengthening wet market regulation, surveillance and regulation of agrifood systems. In order to evaluate the zoonotic risks of wet markets, a science-based risk-assessment is recommended, to enable risk management and decision making (Naguib *et al.*, 2021b). The integration of the One Health approach in the risk assessment framework would provide data on the environment risk factors, wild-animal disease and human health (Naguid et al. 2021). In addition, policies should focus on minimising harmful disruptions to communities while best mitigating future health and biodiversity risks posed by emerging and re-emerging zoonoses and foodborne diseases.

All of these solutions would stand to benefit from a clearer classification of the different types of wet markets that exist and the differential risks they pose. Lin and others (2021) have provided a typology where "*wet markets sell consumption-oriented, perishable goods in a non-supermarket setting. While wildlife markets sell non-domesticated wild animals, either captive-bred or wild-caught, dead or alive, and live-animal markets sell live animals*". Solutions that do not differentiate between wet market types, or treat wet markets as the single modality from which pandemics might arise, ultimately could lead to unfeasible or ineffectual real-world policy decisions. Outright ban of wet markets could destroy people's livelihoods that depend on them, or even lead to a black market facilitated by corruption with even greater risks (Aguirre et al., 2020). Furthermore, a ban of wet markets risks these operations to evade public scrutiny making conditions even harder to quantify, regulate, and reform (Roe *et al.*, 2020). A middle ground could be to allow the informal markets to operate with improved food safety, hygiene standards, reduced crowding of animals, regular inspections with increased surveillance all focused on reduction of the risk of emerging zoonotic diseases and the impact of foodborne diseases.

In countries where incomes are low, governments enforcement of regulation is weak, the informal sector is large. In these markets, many actors are not licensed and do not pay taxes; traditional processing, products and retail prices predominate; and effective health and safety regulations are often evaded. Previously undervalued, the informal sector is now recognized as an important provider of employment and an engine of economic growth, accounting for up to 39 percent of local gross domestic product. More than 80 percent of the TASF produced in poor countries is marketed through informal markets (Mwango et al., 2019). Thus, measures should be put in place to safeguard the sector with changing food systems while ensuring safety of products and protecting public health.

8 Food safety management

Current evidence highlights the need to invest in food safety through education and strong food control systems. Food safety is strongly linked to the way agro-food supply and distribution chains are organized – hence the need to consider this in future mitigation efforts. Agriculture is key in meeting the Sustainable Development Goals and this has led to increased investments in intensification and diversification of production (Vipham, Chaves and Trinetta, 2018) and compromised food safety. Improving food safety requires participation of all stakeholders – who have to follow good practices during production (farmers and pastoralists), transportation, processing (manufacturers) and distribution (traders) (Oloo, 2010). Agribusiness firms are restructuring their production processes and distribution systems by transforming their contractual relations from market-based arrangements (e.g. traditional arms-length transactions) to integrated supply systems (e.g. vertical integration, formal contract or preferred supplier), and from food markets with no quality or safety standards to ones using publicly or privately provided standards (Abebe, Bijman and Royer, 2016). National food control systems are critical in ensuring better health of consumers and supporting trade (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2020). Care of slaughter animals through primary production and transportation up to the abattoir and in markets is thus central to achieving safe and good quality meat.

Food safety management is critical for sound policy formulation. Food safety decision-making premised on risk analysis provides a framework for assessing food safety risks, managing those risks, and communicating both the risks and decisions taken to mitigate them (FAO, 2017a). Therefore, policymakers and risk managers should always put into consideration the complexity and dynamic nature of different factors that can influence food safety decisions.

Risk is a function of the probability of an adverse health effect and the severity of that effect, consequential to a hazard(s); while risk analysis is a process consisting of three components: risk assessment, risk management and risk communication (FAO and WHO, 2014a). Risk analysis is an international strategy for food safety and plays an important role in food trade. It is based on science and provides a basis for international trade of food products. Countries require an effective and efficient food safety system based on a scientific risk assessment and management. However resources are limited. The desired outcome of the risk assessment is a measure of the probability of effects on human health attributable to a specific hazard, food, process, region, distribution pathway or some combination of these (Häsler *et al.*, 2017).

The Codex Alimentarius Commission and other bodies, such as Codex Committee on General Principles, the Joint Expert Committee on Microbiological Risk Assessment, the Joint FAO/WHO Expert Committee on Food Additives, and the Joint FAO/WHO Meeting on Pesticide Residues, adopted a risk analysis approach to food safety, consisting of three stages: risk assessment, risk management and risk communication (FAO and WHO, 2014a). The process of assessing risk is divided into four steps applied throughout the food chain to determine the risks of a hazard to human health and capture the dynamics in the chain, as explained in subsection 3.3 above.

Effective communication of information and scientific opinion on risks associated with real or perceived hazards in food is an essential and integral component of the risk analysis process. Risk communication may originate from official sources at international, national or local levels, including other sources such as industry, trade, consumers and other interested parties (FAO and WHO, 1999).

The major challenges to food safety center around but are not limited to inadequacies, inconsistencies, inequities, and inefficiencies in the entire agrifood system (Vipham, Chaves and Trinetta, 2018) and this also includes livestock systems. Food safety systems, both the policy and operational levels of food safety management, at the national level, require a solid foundation of epidemiological data to inform proper regulation, which often is lacking (FAO and WHO, 2003). In many developing countries, especially in sub-Saharan Africa, unsafe water is usually associated with diarrhoeal illness, yet reviews of water, sanitation and hygiene (WASH) programmes have reported varying (between 20 – 60 percent) findings on the percentage of diarrhoea that can be attributed to unsafe water (Engell and Lim, 2013).

Lack of infrastructure for laboratory testing as well as little resources for routine monitoring and/or enforcement (e.g. properly trained inspectors) in most developing countries is still a big gap within food safety systems (Bartoloni and Gotuzzo, 2010). Alhough some governments have adapted Codex Alimentarius guidance into their national health plans, the lack of infrastructure makes operationalization of standards difficult.

There are also inconsistencies in standards, regulations, and certification in food safety systems worldwide (e.g. formal market versus informal market standards and controls, and domestic food production versus export food production) (Vipham, Chaves and Trinetta, 2018). Inconsistencies exist both within a country, as well as across countries, and are highly influenced by trade agreements, customer willingness to pay and government priorities.

The failures in food safety have highlighted the need for new regulations to safeguard human health. A number of meat related standards have therefore been developed by governments in many developing countries. These standards are intended to achieve a workable balance between food safety, consumer health and the various stakeholders in the market portion of the value chain including producers, commercial transporters and traders.

FAO and WHO established the Codex Alimentarius Commission to address safety and nutritional quality of foods and develop international standards to promote trade among countries. The Codex Alimentarius Commission develops standards for microbiological specification in foods, maximum limits for contaminants and toxins, maximum residue limits for pesticides and veterinary products, and maximum levels for food additives. The standards are meant to protect consumer health and ensure fairness in food trade. At national level, governments develop food safety legislation to enforce standards and monitor compliance with official standards[4] through approaches such as the Hazard Analysis Critical Control Points (HACCP), food inspections, pre-requisite programs, and General Hygiene Practices (GHP).

However, taking Sub-Saharan Africa as an example, there is need to create awareness amongst local based government regulators and other private sector value chain actors of the existence of standards and, thereafter, enforcement of the same. Standards can be adapted for other countries, taking Uganda as an example as illustrated in Table D1.

Therefore, the future of food safety surveillance will see the processing industry and regulators embracing data collection and analysis technology as a tool to get more depth and more specific and more accurate (Detwiler, 2020).

[4] https://www.fao.org/fao-who-codexalimentarius/codex-texts/en/

Table D1 Localized risk management standards for Uganda

Standard	Description
Handling and transportation of slaughter animals (US 733:2007 standard)	• Labeling (coding of animals coming in and going out); • Using designated cattle transport trucks; • Separation of calves and adults/goats/sheep; • Overcrowding (animals are crammed into vehicles; many are injured or trampled to death) • Exhaustion and dehydration (they can be in transit for days, suffering extremes of temperature and often without sufficient food, water or rest; many animals die as a result); • Pain and stress (animals are sentient beings and feel pain and stress just like we do);
Design and operation of abattoirs and slaughterhouses (US 734:2007 Standard)	• Availability of equipment for stunning, breeding, skinning and processing; • Hygienic machines easy to clean; • Well-designed structures; • Food grade colours; • Floor and drainage channels;
Hygienic requirements for butcheries (US 736:2007 standard)	• Clean environment (butcheries); • Clean hygienic clothing; • Personnel hygiene; • Refrigerated trucks for meat transporting; • Food grade colours; • Chill and freezers;
Hygienic requirements for the production of packaged meat products (processed or manufacture) (US 737:2007 standard)	• Food grade packaging materials; • Disposable paper towels; • Acceptable material cutting boards;
Requirement for animal stock routes, check points and holding grounds (US 778:2007 standard)	• Gazetted livestock routes for movement between production sites, marketing or other user sites or areas and terminal market destinations; • Designate animal species and area it occupies (also referred to as the carrying capacity); • Designated accredited animal and/or meat inspectors; • Permanent animal check points shall be situated along major stock routes;

One Health

One Health is not a new concept and was recently defined by FAO, OIE, WHO and UNEP[5] as follows:

> *One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems.*
>
> *It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and inter-dependent.*
>
> *The approach mobilizes multiple sectors, disciplines and communities at varying levels of society to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for clean water, energy and air, safe and nutritious food, taking action on climate change, and contributing to sustainable development* (see Figure D2)

The term is used when approaches to tackling zoonotic diseases consider all components that might lead to, or increase the threat of disease (Cunningham, Daszak and Wood, 2017). The One Health approach was first described in 2004 by Atlas (2013) as become increasingly important given the emergence and re-emergence of zoonotic infections. It has been shown that 61 percent of human infections and over 70 percent of emerging infections are zoonotic (Jones *et al.*, 2008; Taylor, Latham and Woolhouse, 2001).

Understanding the complex nature of food-borne pathogens truly requires a One Health transdisciplinary approach which would involve microbiologists, pathologists, epidemiologists, veterinarians, animal, plant and environmental scientists (Garcia, Osburn and Jay-Russell, 2020). For example, in 2018, Summa, Henttonen and Maunula (2018) reported finding human noroviruses in 31 out of 115 (27 percent) wild birds, two out of 100 rats, and were absent in mice from faecal samples collected from animals at a dump site in southern Finland. Of the wild bird samples, 25 were positive for noroviruses Genogroup II and the two rat samples were positive for noroviruses Genogroup II. The sequences of these genotypes were identical to previously published human noroviruses sequences (Summa, Henttonen and Maunula, 2018).

Wildlife intrusions into production fields are a threat to pre-harvest produce safety (Garcia, Osburn and Jay-Russell, 2020). For example, wildlife such as pigs, birds and rodents, can move from garbage sites to cultivated fields and even into urban areas before returning to their wild habitat, all the while eating, defecating, and spreading feacal pathogens in the environment (Jones *et al.*, 2008; Taylor, Latham and Woolhouse, 2001).

One Health is being implemented – to varying degrees – in different settings including local, national and international. Its application to the prevention and control of zoonotic diseases with pandemic potential has gained momentum in the past three years as governments and other stakeholders have increased their emphasis on health risks that emerge at the human–animal–ecosystem interfaces as part of a longer-term strategy to prepare for severe outbreaks of human disease.

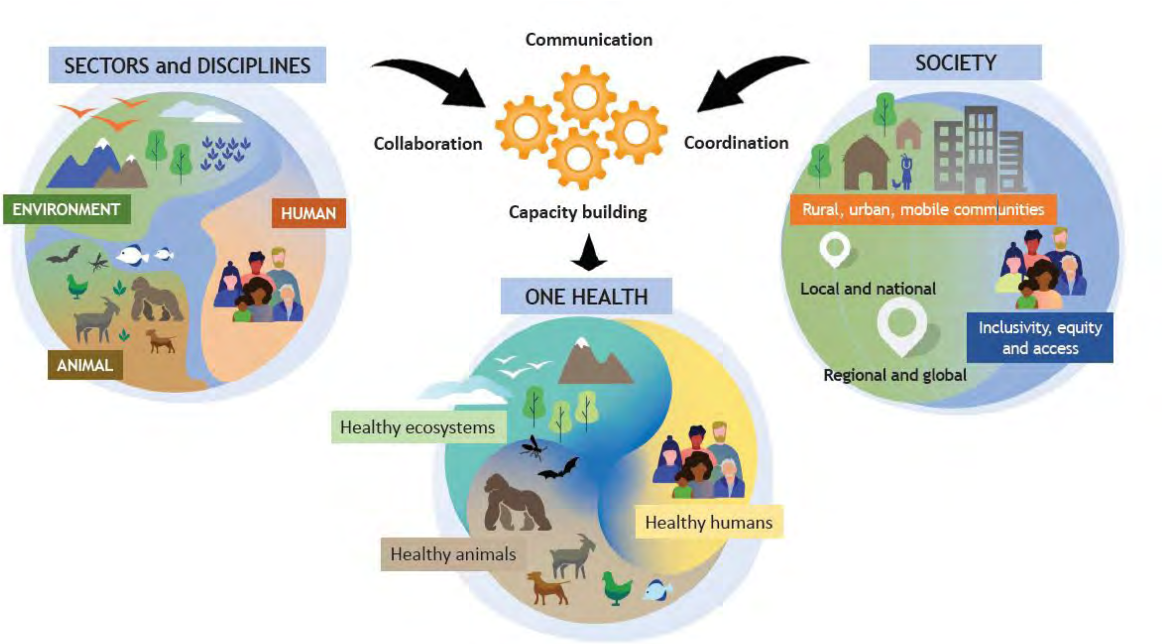
One Health plays a major role in the formulation and adaptation of policies for sustainable, safe and equitable livestock rearing practices both now and in coming decades (Nabarro and Wannous, 2014). The approach encourages a systematic focus on the links between agricultural livelihoods (especially those of small-scale producers), animal health and welfare, wildlife conservation, people's food security and the access to nutritious foods and both local and global public health. It requires constant

[5] https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health

attention to mitigation of and adaptation to – climate change, to land tenure and to efficient and safe uses of water, access to energy and infrastructure and the maintenance of environmental services.

The critical role of One Health is that it is a multi-sectoral strategy in addressing public health concerns which is very important in food safety management. Hence governments should look for ways to link together their efforts related to agricultural productivity, efficient agrifood systems; infrastructure development; access to energy, water and affordable health care; and the sustenance of environmental services (including the mitigation of any further stimuli for changes in the global climate) (Nabarro and Wannous, 2014).

Figure D2 One Health



Source: FAO et al.*, 2021. Note: The environment includes plants.*

In the context of food safety management, when animals and more so TASF are healthy and safe, people are simultaneously safe and healthy. When the environment in which people, plants and animals live is safe, then animals, plants and people are safe too. Therefore, it is very crucial that all stakeholders in the livestock sector plan and interface with the food safety aspects. Food safety management systems must strongly embrace the notion of One Health. Its application is thus very vital in sustainable livestock production and in improvement of quality and safety of TASF.

9 Gaps and needs in the evidence-base

The global emergence and reemergence of food-borne pathogens have made microbiological safety and quality of food of public and health important (Odeyemi and Bamidele, 2016; Odeyemi and Sani, 2016). International trade and travel increase the spread of FBD and contribute to the emergence of new hazards, further challenging prevention, control and surveillance (WHO, 2017b).

The WHO initiative estimating the global and regional burdens of FBD was an important step for food safety. Reports by FERG represent comprehensive sources of information to better understand the situation of FBDs, globally as well as in the different WHO regions (WHO, 2015, 2017b). These estimates indicate the importance of preventing and mitigating risks to food safety. They also guide the development and implementation of food safety policies and strengthening of food safety systems, which can contribute to consumer protection by lowering the burden of FBD (WHO, 2017b).

However, the same reports indicate that data on FBDs incidence and burden presented could probably be an underestimate due to limitations in surveillance systems as not all ill people seek medical care and there are possible errors in diagnosis of cases (WHO, 2015). Furthermore, the WHO analysis was based on modelling and expert attribution of the role of food in disease. In developed countries there are also studies based more on clinical data, and these generally suggest higher levels than estimates in the WHO report (Grace, 2017).

Comparison of regions with the European region rankings reveals major differences in the burden of food-borne disease. For instance, apart from non-typhoidal *Salmonella* spp., the 10 leading food-borne causes of DALYs in the European region are hazards that are systematically ranked lower than at global level (WHO, 2017b). The burden in the European region is dominated by invasive infectious diseases, while that at global level is dominated by diarrhoeal diseases. Microbial pathogens are responsible for the majority of the FBD burden in developed countries where they cause 20 – 40 percent of intestinal disease as well as a similar or greater burden due to non-intestinal manifestations of FBD (Kirk *et al.*, 2014; Scallan *et al.*, 2011; Tam *et al.*, 2014; Thomas *et al.*, 2013). The proportion of diarrhoea due to food in LMICs, however, remains unknown (Grace, 2015b).

Evidence on FBD in LMICs is still limited (Grace, 2015b). However, recent studies have increased concerns about FBDs mostly due to biological hazards. A few studies reported from Southeast Asia relied on the opinion of victims to determine if disease is food-borne: these also suggest higher levels of FBD (Ho *et al.*, 2010). One survey in China reported FBD as the second greatest risk people faced in daily life (after earthquakes) and 92 percent of respondents expected to soon become a victim of food poisoning (Alcorn and Ouyang, 2012). Consumption of fresh, perishable foods sold in informal markets increase the risk of FBDs in developing countries (Grace, 2015b). Research gaps in food safety have been reported to include:

- data on FBD at country level which would allow evidence-based prioritization of FBD;
- diagnostic and reporting systems that would allow more accurate assessments of FBD, including FBD in the community; and
- ways to raise awareness of the importance of FBD through more effective risk communication (Grace, 2017).

FBD has been increasing in some developed countries and is likely to increase in developing countries as the result of massive increases in the consumption of TASF and of lengthening and broadening value chains, bulking more food and increasing the distance between production and consumption (Grace, 2015b). Over the years, safety and quality of food produced for human consumption in developing countries continue to increase because of FBD outbreaks attributed to unsafe raw food, abused temperature, poor storage infrastructures, inadequate cooking, poor personal hygiene, improper handling methods, and cross contamination of cooked food with uncooked raw food (Lamuka, 2014; Odeyemi and Bamidele, 2016; Odeyemi and Sani, 2016). There is need to continuously sensitize both food handlers and consumers about the need for personal hygiene and food safety awareness, as studies have shown that there is a strong correlation between food safety awareness and food safety attitude (Baş, Şafak Ersun and Kıvanç, 2006; Parry-Hanson Kunadu *et al.*, 2016). In Kenya's milk value chain, preharvest activities were recognized to have post-harvest food safety implications, mainly milk quality due to microbial, adulterant and aflatoxin contamination and antimicrobial residues. Capacity building for various stakeholders on aspects of milk safety in order to detect any food safety deviations and to take actions was suggested as the intervention for food safety (Kang'ethe *et al.*, 2020). Another study on improving the productivity, quality and safety of milk in Rwanda and Nepal reported gaps in milk value chain of food safety concern which included suboptimal hygiene, challenges with milk cooling, lack of proper cleaning through all phases at milk processors and lack of basic dairy management education. The recommendation was also training of all stakeholder on food safety in the milk value chain (De Vries, Kaylegian and Dahl, 2020).

In developing countries, the structure of the agrifood systems compounds the problem of FBDs. The food control systems in most of the developing world are heterogeneous, fragmented and with large numbers of actors (Grace, 2015b). The structural challenges are compounded by generally poor capacity to enforce regulation. The governance challenges in food systems regulations include inadequate policy and legislation; multiple organizations with overlapping mandates; outdated, fragmented or missing legislation; inappropriate standards; lack of harmonization and alignment of standards; failure to cover the informal sector; limited civil society involvement; and limited enforcement (Jaffee *et al.*, 2019). In China and Vietnam, for example, changing industry structure, rapid market development, rapidly changing prices of products and inputs, low profit margins, lack of bargaining power in key players and lack of government support to stabilize markets all put high pressure on value chain actors to cut corners and sacrifice food safety (Grace, 2015b). Standardisation of food controls and methods of assessment across different jurisdictions is a major gap that requires greater focus.

In developed countries, considerable investments have been done in food safety. Despite this, regions and countries such as members of the European Union and the United States of America have seen no change or a deterioration in the number of cases of most FBDs over the last five or ten years, in the European Union and the United States of America respectvely (EFSA and European Centre for Disease Prevention and Control (ECDC), 2014). One argument is that investments in food safety over the last 20 years have had limited impact, not because the strategies are ineffective, but because of other factors such as globalization, changes in eating habits and changes in farming practice increasing risk (Newell *et al.*, 2010). In Europe and the United States of America food safety was an issue of intense concern during the periods of most rapid industrialization and urbanization and this concern is now evident in more rapidly industrializing developing countries, many of which are undergoing rapid agricultural intensification, which may increase the risk of FBD (Jones *et al.*, 2013). A review of agricultural intensification and human health in the Greater Mekong region found links between irrigation and fish borne parasitosis; livestock manure and contaminated produce; antimicrobial use and transfer of resistant bacteria through food; and pesticide use and contaminated foods (Richter *et al.*, 2015). Another multi-country review found that a 1 percent increase in crop output per hectare was associated with a 1.8 percent increase in pesticide use and that pesticides were weakly regulated in countries undergoing intensification, implying greater risk of food contamination (Schreinemachers and Tipraqsa, 2012).

Some developed countries have succeeded in reducing the burden of FBD over relatively short periods (Grace, 2015a), such as the United Kingdom for the decline of nontyphoidal Salmonella, through legislation, food safety advice and voluntary private sector-led vaccination programme (O'Brien, 2013). In Denmark, *Salmonella* was reduced to below 5 percent in broiler flocks, below 2 percent in layer flocks, and below 1 percent in pork products by monitoring herds and flocks, eliminating infected animals, and differential processing depending on *Salmonella* status. This resulted in savings of USD 25.5 million (Wegener *et al.*, 2003). From these examples, control was along the value chain with emphasis on reducing disease in the animal reservoir rather than retailed product. Although these control approaches are mainly feasible for industrialized countries with intensive farming systems and good enforcement capacity, they are likely to be useful in developing countries as well (Grace, 2015a). The control measures along the value chain are particularly important. This is because not all food handlers and consumers understand the roles they must play, such as adopting basic hygienic practices when buying, selling and preparing food to protect their health and that of the wider community (FAO and WHO, 2003). Developing countries often cite the lack of information on the cost of FBD a major reason for lack of engagement by national policymakers. Country-level data on the cost of FBD is important and should ideally be integrated with assessments of health burden as well as standardized methods for assessing economic costs of FBD in developing countries would be helpful as use of different methods leads to wide variation in estimates (Grace, 2017).

Legislation and policies on food may also come with consequences if they are unwanted. A study to monitor improvements of food safety in the largest abattoirs and meat markets in Nigeria showed that policy environment had become disabling, partly as a result of authorities attempts to move butchers to a modern, hygienic but more distant abattoir which was resisted by butchers escalating into riots. It was concluded that an enabling environment and stakeholder collaborations in attempting to improve food safety are important (Grace, Dipeolu and Alonso, 2019). According to WHO (WHO, 2017b), addressing and tackling FBD should be a shared responsibility of all stakeholders along the entire food chain, from production to consumption. Collaboration between governments, the food industry, academia and civil society are essential as well as awareness raising among all stakeholders, and consumer education about food safety risks and how to prevent and reduce them.

There are a number of factors that contribute to hazards presence in foods including improper livestock practices; poor hygiene at all stages of the livestock food chain; lack of preventive controls in food processing and preparation operations; misuse of chemicals especially veterinary drugs; contaminated raw materials, ingredients and water; and inadequate or improper storage (Birlouez-Aragon *et al.*, 2010). Specific concerns about food hazards have usually focused on: microbiological hazards; pesticide residues; misuse of food additives; chemical contaminants, including biological toxins; and adulteration and these should be fully addressed by every legislation be it national or local (FAO and WHO, 2003).

International trade along with an expanding world economy, liberalization of food trade, growing consumer demand and developments in food science and technology means that food safety systems and control measures of food hazards continue to be complex (FAO and WHO, 2003). To enhance cross-border trade, focus on food safety especially in developing countries is very essential. Creating and sustaining demand for food products in world markets relies on building the trust and confidence of importers and consumers in the integrity of their agrifood systems (Unnevehr and Ronchi, 2014). The Codex Alimentarius Commission plays an important role of coordinating food standards at the international level and ensures that the health of consumers is protected and that fair practices in food trade are fully exercised (FAO and WHO, 2003). Therefore, Codex Alimentarius standards should be used by governments to determine and refine policies and regulations within their national food control systems.

Globally, the incidence of FBD hazards is increasing, and international food trade is disrupted by frequent disputes over food safety and quality requirements (FAO and WHO, 2003). In order to strengthen food control systems, it is essential that food safety programmes towards risk management of physical and chemical food hazards be strengthened from time to time. The major role of food control is to enforce the food standards protecting the consumer against unsafe, impure and fraudulently presented food by prohibiting the sale of food not of the nature, substance or quality demanded by the purchaser and this increases consumer confidence (Havelaar *et al.*, 2015). In instances where FBD outbreaks involving agents such as *Escherichia coli*, *Salmonella* and chemical contaminants have occurred, the consumers have come to an understanding that food safety within modern farming systems, food processing and marketing should provide adequate safeguards for public health (FAO and WHO, 2003).

Surveillance and traceability of hazards is very important. For example, within dairy value chains the majority of chemical and physical hazards are controlled by the implementation of quality assurance systems at the farm and the dairy factory. Food safety control, as performed by the Netherlands Food and Consumer Product Safety Authority, is essential. However, this authority cannot control all food safety hazards at the different stages of the dairy chain and, therefore, inspections are organized on a risk basis, focusing on the most important food safety hazards at the main steps of the dairy chain (Asselt *et al.*, 2016). Table D2 provides a summary of the gaps and needs in the evidence base.

Table D2 Summary of gaps and needs in the evidence base of food safety and food-borne disease

Gaps	Needs
Inadequacy in monitoring FBD and food safety hazards	Strong monitoring systems at both the policy and operational levels of food safety management
Inadequate epidemiological data	Continuous collection of data for implementing food safety programmes across agriculture value-chains
Insufficient food legislation that enforces food safety and reduces food hazards	Develop relevant and enforceable food laws and regulations
Codex Alimentarius standards are not fully adapted into the national legislations	National governments should fully take advantage of Codex Alimentarius standards
Inadequacies in value-chain engagement, laboratory capacity and training	Capacity building should be combined with targeted global efforts to train and educate farmers, transportes, processors, distributors and consumers about food safety principles and their application
Lack a systematic way to control food safety hazards	Design and implement food safety programmes that are adaptable within the local context based on hazard analysis critical control points
Lack of clean water, reliable energy sources, wars or ethnic conflicts and civil unrest	National governments should invest in water and power infrastructure and ensure that conflicts are resolved peacefully
Inadequate laboratory services for food monitoring	Investment and training in laboratory and testing services for food safety as required
Lack of incentives	National governments should provide for incentives to value chain actors that comply with the food safety requirements and regulations

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Section E EMERGING TOPICS RELATED TO TERRESTRIAL ANIMAL SOURCE FOOD

Key findings

- While cost and access remain a barrier, milk powder has been used extensively as ingredient in fortified and blended foods with evidence for effectiveness in management of severe acute malnutrition when used in ready-to-use therapeutic food and nutrition outcomes among mothers, infants and young children when used in supplements. Egg powder and fish powder have been used to a significant lesser extent as ingredients in fortified and blended foods likely due to palatability, shelf life and involved processing techniques.
- The science is relative new for TASF alternatives, including plant-based food and cell-cultured ‘meat’. Evidence suggests that these products cannot replace TASF in terms of nutritional composition. Microalgae is a TASF alternative highly considered for its rich nutritional composition and also the advantages algae may offer in terms of the environment as a natural carbon sink. Nevertheless, plant-based meat alternatives that are largely available in the market, have been found to be deficient in some essential nutrients and rich in saturated fat, sodium and sugar. Further research is also needed to complete the food safety risk assessment for cell-cultured ‘meat’ within a context of industrial production scale.
- While insects can provide many essential nutrients and there is some evidence on nutrition outcomes, cultural barriers and individual preferences interfere with current consumer acceptability. The environmental sustainability appeal for use of insects as human food seems compelling and may drive up demand in coming years. Nevertheless, food safety concerns should be considered in the scaling up of insects as food or feed.
- Current 'omics' applications are promising to characterize nutritional quality and safety, develop precision or personalized nutrition especially for defined targeted groups of people (e.g. young children) and compare nutritional composition of alternatives to TASF.
- Microbiome science has recently revealed that some of the effects of the diet on health might be mediated by the gut microbiome – trillions of microorganisms living in the human gut. Diverse TASF, including meat and fermented dairy products, have an impact on the gut microbiome composition and functions and subsequently human health via the production of microbial metabolites. High intake of red and processed meat as well as animal saturated fats could induce deleterious effects when fermented dairy products seem to be associated with reduced inflammation. Positive or negative impacts on health might be modulated by the overall quality of the diet (as fats, sugars and fibers).
- The assessment of the contribution of TASF in sustainable healthy diets needs to consider regional variation in natural resources, background health and nutrition, nutritional needs over the life course, availability and accessibility of food and the ecosystem role of livestock. Emerging evidence on the sustainability of diets shows that the diversity of species (plants-based food, terrestrial animal source food and aquatic food) in the diet contributes to higher nutrient adequacy.

Summary

This section features emerging and ongoing themes in science related to the contribution of TASF to healthy diets for improved nutrition and health outcomes. A plethora of TASF products now appear in markets or within portfolios of international aid and development projects as part of fortified and blended products. Direct causal inference for the TASF ingredient and human health outcome is challenging to establish, but there have been compelling findings for improved child growth in association with small quantity lipid supplements that includes milk powder. The science is relatively new for alternatives to TASF, though evidence suggests these products cannot replace TASF in terms of nutritional composition. Insect and insect products may hold greater promise for contributing to nutritional requirements and offsetting environmental impacts of other TASF.

The emerging topic of ‘omics’ shows potential to yield more nuanced discoveries for how various components of TASF interact with other foods in the diet. With wider application, deeper insights may be

achieved for how TASF interact with the genome, epigenome and metabolome to ultimately impact human health. Evidence for the topic of TASF and the gut microbiome has grown rapidly in recent years. The gut microbiome has been shown to play a mediating role for the effects of meats and fermented dairy product consumption on human health. The emerging research around TASF and sustainable healthy diets is vital in the context of climate change discourse and action. This section is not meant to be exaustive in the presentation of each emerging topic. Ongoing investments in all these areas of research are needed for a deeper understanding on the role TASF plays in human nutrition and health.

A comprehensive overview of the current scientific evidence is summarized in Sections B - D, and particular gaps in research and policy identified. In this section, a brief description of some emerging topics related to TASF, nutrition and health is provided. Existing reviews and reports were compiled to briefly summarize key elements of the issues. A similar search strategy and evaluation of the quality of the evidence as described in section C was applied here. Some topics were covered in other sections (e.g. insects), so only novel aspects are highlighted here. We acknowledge that this section is not all-inclusive of the full range of emerging issues.

1 Terrestrial animal source food products

With advances in biotechnology and food science, a range of TASF products or TASF-related products have been developed. We describe two categories of products: 1. fortified or blended foods containing TASF as ingredients; and 2. TASF alternatives (plant-based, cell-cultured, and other related products). The products vary in the motivation for development. In the first, the rationale has largely been to improve the nutritional quality of products used particularly in the context of food aid and/or supplementary feeding targeted to vulnerable individuals. The second category is motivated by environmental and health concerns larger in HIC contexts.

Fortified and blended foods containing TASF as ingredients

Fortified foods have added micronutrients, generally with the aim of improving the nutrient composition of the product. Blended foods might combine several different food ingredients into one product such as pastes, cereals, or biscuits. TASF, specifically milk powder, has been used for decades to improve the nutritional quality of food aid products and supplements, with some evidence for effectiveness in management of severe acute malnutrition (Hoppe *et al.*, 2008; Iannotti, Muehlhoff and Mcmahon, 2013; Scherbaum and Srour, 2018). Ready-to-use therapeutic foods (e.g. Plumpy'Nut), which combine peanut paste with milk powder, oil, sugar, and other fortificants, have been used for community-based treatment of children affected by severe acute malnutrition. More recently, small quantity lipid-based nutrient supplements (e.g. Nutributter) with similar ingredients notably the milk powder have been used as supplements to prevent malnutrition. A meta-analysis of fourteen randomized controlled trials among children ages 6-24 months (n = 37 066) showed the product reduced stunting by 12 percent, wasting by 14 percent, and underweight by 14 percent (Dewey *et al.*, 2021). Cost and access to milk powder remain as significant barriers to large-scale production and its wider distribution and use especially in LICs and in contexts with high burden of acute malnutrition (Potani *et al.*, 2021).

Compared to milk powder, other TASF have been used to a lesser extent to enhance the nutritional quality of foods. For example, egg and fish powders have been used as ingredients in the fortified blended foods used as food aid or nutritional supplements, though palatability and shelf life may be an issue (Chitrakar, Zhang and Adhikari, 2019). There may also be changes in the nutrient and bioactive composition of the TASF ingredients with the processing involved in producing the foods.

In our assessment, we identified a relevant systematic review and meta-analysis of TASF (including aquatic foods) and supplements (fortified supplements containing fish or milk powder, milk formula-based supplementation). The study was conducted to examine the collective impacts from this range of interventions among mothers, preterm and term infants (defined as born after 37 weeks gestation) and growth outcomes at birth and during early childhood (Pimpin *et al.*, 2019). Investigators synthesized evidence from 62 trials with over 30 000 individuals across samples and showed greater evidence for effects on weight compared to height outcomes. Maternal supplementation with fortified blended foods or TASF increased the weight of the child at birth by 60 gram. Supplementation of infants (6-12 months) and young children with fortified blended foods or TASF increased weight by 0.14 kg. Weight-for-length Z score was increased in food supplementation trials by 0.06 among term infants. TASF supplementation increased height-for-age Z score 0.06 and reduced odds of stunting by 13 percent.

TASF alternatives: plant-based and other products

TASF alternative products have emerged in limited markets around the world primarily for commercial reasons as there is a growing awareness on healthy food, reducing environmental footprints and improving animal welfare (He *et al.*, 2020; Ismail, Hwang and Joo, 2020; Kyriakopoulou, Dekkers and van der Goot, 2019; Lee *et al.*, 2020). Despite product claims, however, there remains substantial research gaps in the empirical evidence base (Rubio, Xiang and Kaplan, 2020; Santo *et al.*, 2020). It is unclear whether the products yet diminish environmental impacts – especially in high-income contexts where the livestock-related environmental issues are predominant—or adequately meet nutritional requirements in human health. Life-cycle analyses suggest that production of plant-based meat alternatives have lower greenhouse gas emissions than beef finished in feedlots, but not per se when compared to cattle finished on well-managed pastures (van Vliet, Kronberg and Provenza, 2020). Demand for the products is growing in some regions, and the products are being incorporated into some niche diets such as flexitarian, vegetarian, and vegan diets (Chriki and Hocquette, 2020; Rizzo and Baroni, 2018). Box E1 summarizes the current state of knowledge on the nutritional quality of cell cultured ‘meat’and related food safety issues.

Box E1 Nutritional quality of cell cultured 'meat' and related food safety issues

Cell multiplication to produce cell cultured ‘meat’ requires a growth medium with nutrients including vitamins, amino acids, minerals, glucose, growth factors and hormones. Some of the additives in the medium are substrates necessary for cell development and viability. The most efficient and widespread medium is derived from bovine blood. Research is ongoing to replace it by medium derived from plants (Chriki and Hocquette, 2020).

The nutrient content of the resulting tissue should reflect that of the growth medium, but uptake of different micronutrients by cells still needs to be fully understood, including that of essential micronutrients that are only found in TASF (e.g. conjugated linoleic acid produced in the rumen, heme-iron and vitamin B12) (Post and Hocquette, 2017). Laboratory production conditions can impact the nutrient content in the cells: a low oxygen environment is needed to enable myoglobin expression and iron uptake by the cell requires further research (Post and Hocquette, 2017). There is no current evidence on the maintenance of matrix effects with increased bioavailability of micronutrients in cultured cells compared to meat in the diet (Chriki and Hocquette, 2020; Warner, 2019).

The aseptic conditions and environmental control required for the production of cell cultured ‘meat’ is likely to reduce the risk of foodborne pathogens contamination (Warner, 2019), especially microbiological hazards (e.g. *Salmonella spp.*, *Listeria monocytogenes*). However, the use of animal blood components as growth medium (foetal bovine serum widely used to date) can be a source of hazards (e.g. virus, prions) (Hadi and Brightwell, 2021). The addition of biochemical compounds in the medium to enable cell growth and antimicrobials to impair bacterial infection of the resulting tissue, needs further risk analysis on each of this compound in terms of toxicity for the consumer and antimicrobial resistance (Post and Hocquette, 2017).

The potential occurrence of unexpected dysregulation of biological mechanism (e.g. cell multiplication similar to that of cancer cells) that has been also reported needs to be included in human health risk assessment (Chriki and Hocquette, 2020). The potential use of genetic engineering (improvement of the means of production, potential use of exogenous genes) triggers a need of continuous risk assessment of food derived from genetically modified cultured cells (Hadi and Brightwell, 2021).

Despite the growing literature on the process of cultured cells, evidence on nutritional value and food safety outcomes is more theoretical than practical. Further research is needed to complete the food safety risk assessment especially within a context of industrial production scale and enable regulators to address public health issues.

TASF alternative products may use fungal or plant derivatives such as mycoprotein and soy leghemoglobin (for the meat alternatives) and nuts or soy (for milk alternatives). Mycoprotein, found in some markets as sausages or patties, is a protein-rich food made of filamentous fungal biomass. The organism *Fusarium venenatum* is used together with egg albumen, colour and flavour compounds. The use of agro-industrial residues as substrate for mycoprotein may reduce environmental impacts below that of other TASF (Souza Filho *et al.*, 2019). Soy leghemoglobin, developed by Impossible Foods, Inc., is used to emulate taste and texture of beef. One review of the literature found no evidence for risk of allergenicity or toxicity for the leghemoglobin and other host proteins (Jin *et al.*, 2018). Microalgae is another TASF alternative considered especially for its rich nutritional composition of long-chain n-3 and n-6 fatty acids. In addition to the advantages algae may offer in terms of the environment as a natural carbon sink, it has been recognized for its value in human and animal feed. The species of *Chlorella*, *Arthrospira* and *Aphanizomenon* contain quality proteins, while *Haematococcus* and *Dunaliella* are dense in antioxidants including carotenoids (Kusmayadi *et al.*, 2021).

TASF alternatives are relatively new to global food markets, thus the literature on their health impacts is limited. Some studies have analysed the nutrient composition of plant-based meat alternatives relative to TASF and human requirements. One analysis of the food chemistry compared plant-based products (Beyond Meat Burger, Impossible Foods Burger, and Morning Star's Black Bean Burger) to meats (Swing *et al.*, 2021). They found sodium and saturated fat to be greater in the plant-based products. Moreover, while essential amino acid levels were higher, there were some nutritionally important ones – methionine and lysine – unavailable in the plant-based alternatives. Another study underscored some of these findings through modeling a reference omnivore diet compared to flexitarian, vegetarian and vegan diets using traditional and novel plant-based foods (Tso and Forde, 2021). While many nutrient needs were met for the diets (except vegan diets), there were deficits in calcium, potassium, magnesium, zinc and vitamin B12, and higher intakes in saturated fat, sodium and sugar compared to the reference diet. Plant-based milk alternatives, often containing sugar and micronutrient fortificants, may not be able to completely replace animal milk with regards to nutrient composition and flavour (Tangyu *et al.*, 2019).

Few experimental trials have been conducted to examine the impacts of the TASF alternatives on human health. One small cross-over randomized trial (n = 36 adults) compared the effect of consuming plant-based alternative to meat on serum trimethylamine-N-oxide (TMAO) and other biomarkers and anthropometric outcomes (Crimarco *et al.*, 2020a). They found significantly lower TMAO concentrations associated with consuming the plant-based products versus TASF. TMAO has been implicated as a cardiovascular risk factor in adults, but there has been some question regarding its specificity and responsiveness to diet, and significance in infant and child health is unknown (Blesso, 2015; Hamaya *et al.*, 2020; Landfald *et al.*, 2017). Low-density lipoprotein-cholesterol concentrations and weight were significantly lower in the plant-based alternative phase compared to the meat phase. An RCT based on a sample of adults in the United Kingdom (n = 155) evaluated the impact of a 4-week intervention with TASF alternatives and messaging on the benefits of consuming less meat on meat intake, consumption of TASF alternatives, and a set of nutrition and health outcomes (Bianchi *et al.*, 2019). The study found significant reductions in meat consumption for the intervention group relative to the control group—reductions of 63g/d and 39g/d at four- and eight-week follow-ups, respectively. There were no significant differences in lipid profiles and blood pressure parameters between the two groups, though small and significant changes were observed in the body weight.

Acceptability of TASF alternatives and consumer behaviour will be covered in Component Document 2, but here we describe relevant findings. One systematic review examined "alternative proteins," as termed by the authors, for consumer acceptance. These included pulses, algae, insects, plant-based alternatives, and cultured meats. They found acceptability of cell-cultured meat to be low, ranking only above insects discussed below. Issues of taste, unfamiliarity and affective processes of food neophobia and disgust were described (Onwezen *et al.*, 2021). Furthermore, the ethics of these TASF alternatives should be explored in greater depth, as highlighted in a recent review of the literature (Lonkila and Kaljonen, 2021). Trade-offs and equity issues should be considered in the context of environmental and health repercussions.

2 Insects: novel products, acceptability and scalability

Insects are among the TASF consumed over millennia by hominins. Yet in many societies, there is no longer widespread consumption in the context of urbanization and increased access to other TASF. In recent years, there has been a return to consume insects in the form of novel products motivated by consumer demand for environmental friendly, nutrient-rich foods (this will be discussed in greater detail in Component Document 2). It is estimated that almost one quarter of the world's population consumes insects across 1900 species, most commonly from the orders of Coleoptera (beetles), Lepidoptera (butterflies, moths), Hymenoptera (bees, ants, wasps); Orthoptera (grasshoppers, locusts and crickets); and Hemiptera (cicadas, leafhoppers, planthoppers, scale insects and true bugs) (Huis, 2013) (see Figure B1).

As discussed in Section B, insects can fulfill requirements for many essential nutrients (Orkusz, 2021). Depending on the species and stage of maturation, they may be especially rich in protein, polyunsaturated fats, vitamin C, dietary fiber, and several minerals such as zinc, iron, copper, magnesium, manganese, phosphorous, and selenium (Rumpold and Schlüter, 2013). While the evidence base remains limited in terms of epidemiological evidence for health impacts associated with insects, their potential have been noted in recent narrative review (Nowakowski *et al.*, 2021). Smaller scale intervention studies were highlighted in Section C of this document suggesting positive effects on young child nutrition living in low resource settings (Bauserman *et al.*, 2015; Harmiyati *et al.*, 2017).

Cultural barriers and individual preferences interfere with broad acceptance and bringing to scale some of the products (Jantzen da Silva Lucas *et al.*, 2020; Onwezen *et al.*, 2021). However, commercial companies have developed products from insects such as mealworms, crickets, locust and black soldier fly, with higher acceptability including powders, patties, bars, breads, pastas, and snacks. Food safety concerns should be considered in the scaling up of insects as food or feed. Key contaminants may be biological (bacteria, virus, fungi, parasites) or chemical (mycotoxins, pesticides, heavy metals, antimicrobials), and allergenic risks have also been described (FAO, 2021).

The environmental sustainability appeal for use of insects as human food seems compelling and may drive up demand in coming years. In particular, the high feed conversion rates, or how efficiently the organisms transform feed into human food, has been noted for insects (Nowakowski *et al.*, 2021). One analysis showed that for the same protein yield, crickets need six times less feed than cattle, four times less than sheep, and two times less than pigs and broiler chickens (Rumpold and Schlüter, 2013). Insects also produce less greenhouse gas emissions than livestock and may be grown on organic waste. Another analysis compared the effects of production systems for TASF, insects, and TASF alternatives (plant-based and cell-cultured "meats") on agricultural land, showing high potential for insects particularly relative to conventional TASF production (Alexander *et al.*, 2017). Insects can efficiently transform agricultural by-products and food waste into edible food merits more research and future investments.

3 Foodomics as relates to TASF, diets, and effects on health

Foodomics was first defined by Cifuentes (2009) as "a discipline that studies the food and nutrition domains through the application and integration of advanced omics technologies to improve consumer's well-being, health, and knowledge." It is a scientific approach to studying the relationship between food and health through application of 'omics': genomics, proteomics, metabolomics, metagenomics, and transcriptomics (Gunn, 2020). Under this topic, we add two nutrition-specific specialities to this discussion: nutrigenomics and nutrigenetics. All of these disciplines use various methods to characterize and quantify molecules that contribute to human health (See Box E2).

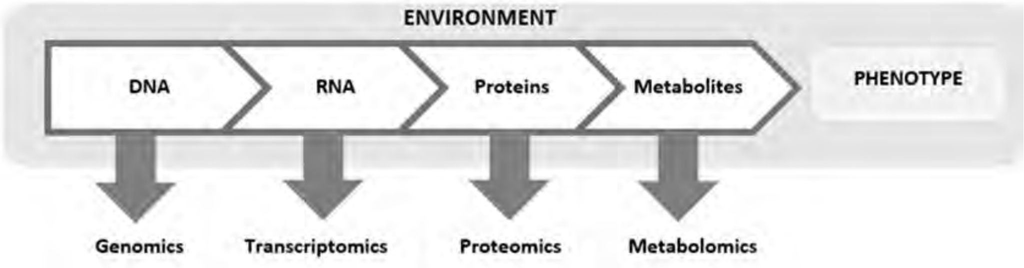
Box E2 What are 'Omics'

Omics is a scientific discipline or field of research that analyzes complete genetic or molecular profiles in humans and other organisms. Depending on the specific component analyzed it is commonly divided into:

- Genomics: study of the genome (complete set of DNA);
- Transcriptomics: study of the transcriptome (complete set of RNA);
- Proteomics: study of the structure, function and interactions of proteins produced by the genes of a particular cell, tissue or organism;
- Metabolomics: study of the set of metabolites within an organism.

These components in interaction with the environment determine the phenotype of an individual which is the observable characteristics of an organism.

Overview of Omics



Two areas of research focus on the relationship between human genes and nutrition:

- Nutrigenetics: study of gene variants linked to differential response to specific nutrients and relation of this variation to different diseases, for example, obesity and NCDs;
- Nutrigenomics: study of the effects of nutrients and other components of food on gene expression, and how genetic variations may affect human health. Nutrigenomics is important to study the prevention and treatment of NCDs

Systems biology is increasingly being applied to understand the constellation of factors influencing human nutrition. In combination with this trend, improvements in analytical methods such as ^{1}H nuclear magnetic resonance spectroscopy and mass spectrometry and major advances in big data science have motivated a growing evidence base for 'omics' and human nutrition.

This section will briefly describe applications of 'omics' – genomics, nutrigenomics, metabolomics, proteomics, and transcriptomics – to TASF nutrition (Mayneris-Perxachs and Swann, 2019; Rådjursöga *et al.*, 2018). The science of 'omics' has application in the broader fields of livestock management and health, but here we discuss briefly its use in relation to TASF and human health (Banerjee, Pal and Ray, 2015; Bergen, 2017; Goldansaz *et al.*, 2017; Menchaca, 2021; Nowacka-Woszuk, 2020; Rothschild and Plastow, 2014; Sun and Guan, 2018).

To date, the various 'omics' methods have been primarily used to examine the nutrient and bioactive components of TASF, as relevant to topics covered in Section B. For example, a study in bovine milk that found 296 metabolites and metabolite species used metabolomics analyses from nuclear magnetic resonance, liquid chromatography-mass spectrometry, and inductively coupled mass spectrometry (Foroutan *et al.*, 2019). Metabolomics can be used to identify biomarkers of nutritional quality and safety of TASF. One study identified the following candidate biomarkers for potential use in milk quality, safety and traceability: choline, citrate, valine, hippuric acid, 2-butanone, lactate and some fatty acids (Zhu *et al.*, 2016b). Another application of metabolomics was used to compare plant-based TASF alternatives to ground beef from grass-fed production system, finding substantial differences in metabolite abundances (171 out of 190 profiled metabolites; false discovery rate adjusted $p < 0.05$) (van Vliet *et al.*, 2021). Only the beef samples contained DHA, niacinamide (vitamin B3), glucosamine, hydroxyproline and several anti-oxidants, while plant-based TASF alternative only contained vitamin C, phytosterols, and several phenolic anti-oxidants. Proteomics and transcriptomics have been used to study proteins in milk (Anagnostopoulos *et al.*, 2016; Bertram and Jakobsen, 2018; Manoni *et al.*, 2020; Soggiu, Roncada and Piras, 2018) and eggs (Gautron *et al.*, 2010). Scientists have described the potential application of nutrigenomics and nutrigenetics in animal milks to enable precision or personalized nutrition both for humans and animals (Benitez, Nunez and Ovilo, 2017; Bordoni and Gabbianelli, 2019, 2021).

There has been more limited application of 'omics' in experimental, population-based studies for the effects of TASF on human nutrition and health. Targeted metabolomics was used for analyses of the egg trials in Ecuador (Lulun Project) and Malawi (Mazira Project) described in Section C for young child nutrition. In the Lulun Project, a hypothesized set of metabolites were tested using liquid chromatography–mass spectrometry to assess the effects of eggs on the biomarkers in child plasma concentrations. The study found eggs improved several metabolites in the methyl group metabolism pathway (Iannotti *et al.*, 2017). Findings from the Mazira study, using both targeted and untargeted metabolomics, are still being analyzed. One small cross-over design study (n = 32) compared serum metabolites using nuclear magnetic resonance across three diets: vegan, ovo-vegetarian, and omnivore (Rådjursöga *et al.*, 2018). They found betaine, choline, and creatine higher in the omnivore diet while 3-hydroxyisobutyrate, carnitine, proline, and tyrosine were increased in the ovo-vegetarian diets. The application of 'omics' and precision nutrition may be promising and appropriate for well defined targeted groups of people (e.g. young children), it is not yet feasible as a population health solution.

4 Terrestrial animal source food and the human microbiome

Over the past 15 years, there has been a growing awareness of the role of the gut microbiome on inter-connections between food and human health. The term microbiome refers to the microbial community (that includes bacteria, archaea, protozoa, fungi, and viruses) and its "theatre of activity" (genome, proteins, metabolites) in a given environment (Berg *et al.*, 2020). Most studies on the human gut microbiome examine the bacterial population found in the human colon. Recent progress in DNA sequencing and "omics" technologies (see Box E2) have revolutionized our capacity to investigate microbial communities that live in symbiosis with humans. It is now possible to know which species of microbes are present (even unculturable species), their functional potential, and their metabolic activity at a given time in the gut.

The gut microbiome is involved in several host functions: synthesis of certain vitamins, nutrient and xenobiotics metabolism[1], maintenance of the gut barrier integrity and protection against pathogens. Its action is not limited to local effects in the gut. Microbial metabolites – either diet-dependent or diet-independent, can reach the bloodstream, and act on other parts of the body, modulating several important host functions (glucose and lipid metabolism, systemic immunity, bone metabolism and even lung physiology and brain functions) (Cryan *et al.*, 2019).

Increasing amount of evidence in both animal and human studies show that aberrant (dysbiotic) gut microbiomes are associated and may even contribute to the pathogenesis of various common metabolic disorders (including obesity, Type 2 Diabetes, cardiovascular diseases, undernutrition, obesity, cancer, auto-immune diseases and even neurodegenerative diseases (reviewed in Fan and Pedersen, 2020; Morais, Schreiber and Mazmanian, 2020; Ruff, Greiling and Kriegel, 2020). High species diversity and gene richness, as well as high abundance of short chain fatty acid producing bacteria, and low abundance of potential pathogens are features usually associated with health.

Multiple environmental and host factors are shaping the human gut microbiome, diet being one of the main drivers across the lifetime. Both specific nutrients and whole diet could modify the microbiome composition and function with possible consequences on health (reviewed in (Zmora, Suez and Elinav, 2019)). As microbiome science is a still new science, evidence on the impact on health come from converging studies both in humans (observational and radomized control trials) and animal models that provide mechanistic explanation and help to evaluate causality. Only data related to TASF are discussed in this subsection. Subsection 5.1 presents the impact of the TASF products on the gut microbiome (composition and function) and Subsection 5.2 discusses possible consequences on health.

4.1 Effect of terrestrial animal source food on the gut microbiome

Data suggest that TASF have contributed to shape the gut microbiome in human evolution. As an example, in hunter-gatherer and some rural communities, there is a very low level of the *Actinobacteria*, including low levels of *Bifidobacterium* (Afolayan *et al.*, 2019; De Filippo *et al.*, 2017; Martínez *et al.*, 2015; Schnorr *et al.*, 2014) when in adults from urban environment, *Bifidobacteria* commonly make up 1–10 percent of the gut microbiome population. Lack of *Bifidobacterium* in pre-agriculture communities might be due to the absence or low intake of dairy products (De Filippo *et al.*, 2017). Indeed, in vegan populations the representation of *Actinobacteria* and *Bifidobacterium* are really low (Zimmer *et al.*, 2012). In human cohorts, omnivores had lower gene richness (alpha diversity) than long term vegan and vegetarian (Zhang *et al.*, 2018), but in another study, differences between the three cohorts (vegan, vegetarian and omnivore), were greatest at the genus and species level and relatively minimal on broader compositional features, such

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[1] Xenobiotics are referred to as chemical substances, mostly synthetic, not normally present in the environment of living organisms. The gut microbiome has a strong metabolizing capacity and is capable of the biotransformation of xenobiotics. It could modify xenobiotics half-lives and their potential biological effect (inactivate drugs or increase or alleviate toxicity) in the human host.

as diversity and richness (Zimmer *et al.*, 2012). At the species level, *Faecalibacterium prausnitzii* (main SFCA was distinctly more prevalent in vegans than in vegetarians (Koeth *et al.*, 2013). *Bacteroides* spp., *Bifidobacterium* spp., *Escherichia coli* and *Enterobacteriaceae* spp. were significantly higher in omnivores than in vegans and vegetarians (Medawar *et al.*, 2019). There are also clear changes at functional level (genes, proteins and metabolites) (De Angelis *et al.*, 2020; do Rosario, Fernandes and Trindade, 2016).

High animal protein intake (tested in urban populations) modifies the gut microbiome and is highly associated with a gut microbiome dominated by *Bacteroides* called enterotype *Bacteroides* (Wu *et al.*, 2011). In short term intervention in humans, a diet based on TASF was shown to increase the abundance of bile-tolerant microorganisms (*Alistipes*, *Bilophila* and *Bacteroides*) and to decrease the levels of *Firmicutes* that metabolize dietary plant polysaccharides (*Roseburia*, *Eubacterium rectale* and *Ruminococcus bromii* – short chain fatty acid producing bacteria) (David *et al.*, 2014). Long term adherence to diets based on TASF have been shown to increase pro-inflammatory species, including those related to *Ruminococcus gnavus* and *Collinsella* spp. (van Soest *et al.*, 2020).

Protein origin seems to have different influences on the gut microbiome (Lang *et al.*, 2018; Zhu *et al.*, 2015). Rats fed with meat proteins (red meat: beef and pork or white meat: chicken and fish) had a similar overall structure of faecal bacterial communities separated from rats fed with non-meat proteins (casein and soy). But the beneficial genus *Lactobacillus* was higher in the white meat than in the red meat or non-meat protein groups (Zhu *et al.*, 2015). In both mice and humans, beef consumption increased the relative abundance of *Proteobacteria* and *Firmicutes* and decreases in *Bacteroidetes* (Zhang, Li and Tang, 2019; Zhu *et al.*, 2015). Overall, in human and animal studies, consumption of dairy products (milk, yogurt, kefir) has a positive impact on the gut microbiome by increasing the bacterial diversity and the abundance of beneficial genera *Lactobacillus* and *Bifidobacterium* (Aslam *et al.*, 2020). Consumption of dairy products during childhood determines the acquisition of methanogenic archaea as *Methanobrevibacter smithii* (van de Pol *et al.*, 2017). *M. smithii* seems to play an important role in human physiology. Its depletion has been associated with both obesity and severe acute malnutrition in children (Million *et al.*, 2012, 2016).

TASF preparation could have an impact on the gut microbiome. In humans, fried meat intake lowered microbial community richness (Gao *et al.*, 2021; Partula *et al.*, 2019) and decreased *Lachnospiraceae* and *Flavonifractor* abundances while increasing *Dialister*, *Dorea*, and *Veillonella* abundances. Those changes were associated with increased intestinal endotoxin and systemic inflammation but some of the effects might be also related to saturated fats (Gao *et al.*, 2021). Processed meat has been shown to be inversely correlated with *Roseburia*, a short chain fatty acid butyrate producing bacteria (Yu *et al.*, 2021). In a mice study, raw versus cooked meat had no discernible effect on the gut bacterial population (Carmody *et al.*, 2019). Fermented TASF (sausages, cheese, yogurt, kefir) are source of foodborne microorganisms, usually lactic acid bacteria, that can be found in the gut microbiome, that are usually associated with positive health outcomes (David *et al.*, 2014; Firmesse *et al.*, 2007, 2008; Pasolli *et al.*, 2020). The most frequently detected are starter cultures for fermented foods, as *Streptococcus thermophilus* and *Lactococcus lactis*. Traditionally prepared TASF (i.e. dried raw meat in Inuit) might also be a source of environmental microorganisms (Hauptmann *et al.*, 2020). In addition of being a source of bacteria, fermented products can also modulate the resident microbiome by other mechanisms. For example, the consumption of cheese was negatively associated with Akkermansia muciniphila abundance (Partula *et al.*, 2019). In patients with Irritable Bowel Disease (IBD) consumption of fermented milk (compared to non-fermented milk) led to a decrease in *Bilophila wadsworthia* (a bacteria associated with inter-abdominal infections and inflammation) and an increase in butyrate-producing bacteria and short chain fatty acid (Veiga *et al.*, 2014).

Differences on the gut microbiome observed between diverse TASF might be due to the fact that each TASF varies for protein accessibility, amino acid composition in branched-chain amino acids, taurine, choline, carnitine and other elements associated as fats, fibres and polyphenols, which can favour some species depending of their metabolic potential. Casein and whey have a high content of the branched-chain amino acids (valine, leucine, and isoleucine). Branched-chain amino acids supplemented mice had higher abundance of *Akkermansia* and *Bifidobacterium* in the gut (Yang *et al.*, 2016). (Yu *et al.*, 2016). In addition to the amino acid composition, different protein sources vary in other macronutrients as fats and fibres. Red and processed meats are rich in saturated fatty acids (SFAs) (Lang *et al.*, 2018). Processing and cooking also influence nutrient accessibility and presence of products resulting, for example, from fermentation or cooking processes.

Finally, TASF could contain exogenous components as residues of veterinary drugs used in livestock production and food additives. Antibiotics, at therapeutic doses, have a strong impact on the microbiome with consequences on health. Effects of antimicrobial drugs at residual level deserve further studies. Food additives as potassium sorbate and sodium nitrite commonly used in processed meat, have been shown to disturb the gut microbiome in animal models (reduced diversity, increase of Proteobacteria) (Cao *et al.*, 2020a). More data are needed to determine the impact on health.

4.2 Microbial metabolism of terrestrial animal source food and health

Type and quantity of TASF consumed influence microbiome composition but also the microbial metabolites produced with potential consequences on human health (O'Keefe, 2016; Singh *et al.*, 2017). Importantly, the overall quality of the diet might compensate or exacerbate some of the effects described in this section.

Protein metabolism

TASF are a major source of proteins. Undigested dietary proteins can reach the large intestine and are broken down by proteolytic bacteria and subsequently used as a source of amino acids for bacteria to make their own proteins or are fermented, by proteolytic fermentation, as an energy source. Bacterial metabolism of dietary proteins produces several types of metabolites. Similar to fibre fermentation, protein fermentation produces beneficial short chain fatty acid, but in lower quantity. Branch-chained fatty acids (BCFA) are reliable markers of proteolytic fermentation as they are produced exclusively through the fermentation of branched-chain amino acids. Little is known about the effects of BCFAs on host physiology. Fermentation of aromatic amino acids by the gut microbiome is also particularly important biologically as this generates a wide range of bioactive end products such as phenol and p-cresol (Tyrosine), or indole and skatole (Tryptophan). Derived from p-cresol and indole, microbial-derived uremic toxins, p-cresol sulfate, indoxyl sulfate and indole 3-acetic acid are associated with kidney diseases (Chen *et al.*, 2019). Indole and its derivative produced by microbes from tryptophane, may have both negative and positive impact: enhance neurodevelopmental or psychiatric diseases but might be protective of multiple sclerosis (Diether and Willing, 2019). Proteins fermentation by the gut microbiome releases potentially toxic nitrogenous and sulfur metabolites such as ammonia, amines, nitrates, nitrites and hydrogen sulfide (Diether and Willing, 2019; Madsen *et al.*, 2017).

TASF and inflammation

Several studies in animals and in humans have showed an association between diets rich in TASF and pro-inflammatory bacteria in the gut (David *et al.*, 2014; Devkota *et al.*, 2012; Gao *et al.*, 2021; van Soest *et al.*, 2020). In a large participant prospective study, high total protein intake, especially animal protein (fish and meat, not eggs and dairy products), was associated with a significantly increased risk of IBD (Bisanz *et al.*, 2019). In mice, the interactions between dietary protein of animal origin and gut microbiota increase sensitivity to intestinal inflammation (like colitis) by promoting pro-inflammatory response of monocytes (Kostovcikova *et al.*, 2019). Some studies reported that animal fats might be associated with pro-inflammatory change in the gut microbiome in animals and humans (Caesar *et al.*, 2015; Wan *et al.*, 2019). On the contrary, in rat model, processed meat when it is enriched with prebiotic inulin, decreased pro-inflammatory bacterial populations (Fernández *et al.*, 2019). In human high intake of fermented food (mix of dairy and plant products) has been shown to reduce inflammation via the modulation of the gut microbiome (Wastyk *et al.*, 2021; Marco *et al.*, 2021). Yoghurt supplemented in *Bifidobacterium* probiotic could help in maintaining a normal microbiota composition during the ingestion of a meat-based diet (Odamaki *et al.*, 2016). High intake of cheese and yogurt have been shown to decrease the risk of cardiovascular disease, Type 2 Diabetes and cancer (meta-analysis) (Barengolts *et al.*, 2019; Gille *et al.*, 2018; Zhang *et al.*, 2019b, 2019c) which might be partially explained by a reduction of low grade inflammation usually associated with several NCDs.

TASF and cancer

Data suggest that several substances present in red and processed meat could have a role in carcinogenesis, some of the effects being mediated by the gut microbiome. Heterocyclic amines (HCAs) are generated from amino acids in red meat formed during cooking under high temperatures and preservation processes. Some HCAs can be taken up by bacteria and converted by the enzyme β-Glucuronidase in activated mutagenic intermediates (Zhang *et al.*, 2019a). Red meat is rich in heme. In the mice model, heme rich diet has been shown to induce mucin degrading bacteria leading to impaired intestinal barrier function and induced cell hyperproliferation (Ijssennagger *et al.*, 2015). Data also suggest that the microbiota could play a role in the heme-induced promotion of colorectal carcinogenesis by contributing to heme-induced lipoperoxidation (Martin *et al.*, 2015). The bacteria *Fusobacterium nucleatum* have been strongly associated with colorectal cancer. Diets rich in red and processed meat were associated with *F. nucleatum* positive tumors but not with *F. nucleatum* negative tumors (Liu *et al.*, 2018). *F. nucleatum* has the ability to produce hydrogen sulfide (from cysteine) (Basic *et al.*, 2017). Hydrogen sulfide could induce carcinogenesis in the colon as it can damage the epithelium, induce chronic inflammation, and influence epithelial proliferation/differentiation (Abu-Ghazaleh, Chua and Gopalan, 2021). It is involved in the pathogenesis of ulcerative colitis, a risk factor for colorectal cancer. *Bilophila wadsworthia* could also produce hydrogen sulfide from taurine (Peck *et al.*, 2019). This bacteria was positively correlated with intake of dietary fat and meat (David *et al.*, 2014). Diets high in certain animal proteins and fats could also promote colorectal cancer by selecting for bacteria capable of converting primary host bile acids to toxic, tumor-promoting secondary bile acids as deoxycholic acid (Ridlon, Wolf and Gaskins, 2016). p-cresol could also induce DNA damage and alter cell cycle (Al Hinai *et al.*, 2019).

A human study compared diet and faecal microbiota in African-Americans, a population with a high incidence of colorectal cancer to rural South Africans, a population with a low incidence of colorectal cancer. Higher levels of proteolytic fermentation products were observed in rural South Africans. However, this was observed alongside increased carbohydrate fermentation and a lower incidence of colorectal polyps (O'Keefe *et al.*, 2015). When metabolic networks are examined, branched-chain amino acids fermentation appear to be increased in the African diet. Data that high fibre intake may alter protein fermentation pathways and provide protective effects against inflammation and disruption of cell cycles (Diether and Willing, 2019; O'Keefe *et al.*, 2015). In human clinical trials, maize starch consumption also prevented pro-mutagenic effect of red meat and correlate with change in gut microbiome (Le Leu *et al.*, 2015). Polyphenol from cranberries attenuated the impact of the diet based on TASF on microbiota composition, bile acids and short chain fatty acid (Rodríguez-Morató *et al.*, 2018). There is also experimental evidence that *Lactobacillus* probiotics could directly bind to heterocyclic amines and therefore potentially protect the host from the induction of DNA damage (Vernooij *et al.*, 2019; Zsivkovits *et al.*, 2003).

TASF, trimethylamine N-oxide and health

Trimethylamine N-oxide (TMAO) is a metabolite that has attracted attention as recent meta-analysis on humans shows that higher circulating TMAO concentration increases the risk or aggravation of several NCDs such as cardiovascular events (Farhangi, Vajdi and Asghari-Jafarabadi, 2020; Tang *et al.*, 2021), diabetes (Zhuang *et al.*, 2019) , chronic kidney disease (Zeng *et al.*, 2021), liver steatosis (Flores-Guerrero *et al.*, 2021; León-Mimila *et al.*, 2021), obesity (Dehghan *et al.*, 2020) and all cause of mortality (Farhangi, 2020). TMAO production results from the fermentation by the gut microbiota of dietary nutrients such as choline, phosphatidylcholine and L- carnitine (mostly present in protein rich food from animal origin) which are transformed to trimethylamine and converted into TMAO by hepatic enzymes.

In humans, ingestion of phosphatidylcholine produced a post-prandial peak in circulating TMAO levels, which was not observed after depletion of intestinal microbiota by broad-spectrum antibiotics (Tang *et al.*, 2013). The capacity to produce trimethylamine is present in several taxa of bacteria (Clostridia, Proteus, Shigella, E. coli and Aerobacter). In humans, high animal proteins diet increase production of TMAO (Crimarco *et al.*, 2020b; Ijssennagger *et al.*, 2015; Mitchell *et al.*, 2019; Park *et al.*, 2019). Long-term (all >1 year) vegans/vegetarians had lower circulating TMAO than omnivores and a markedly reduced capacity to produce TMAO from oral carnitine (contained for example in red meat) (Koeth *et al.*, 2018; Wu *et al.*, 2016; Zhang *et al.*, 2018). Bacteria responsible for TMAO production are enriched in an omnivore microbiome, and frequent exposure to L-carnitine or phosphatidylcholine induces the gut microbiota's capacity to produce TMAO (Koeth *et al.*, 2013, 2018; Wu *et al.*, 2019, 2020; Zhang *et al.*, 2018). The animal protein sources impact on plasma TMAO differently, red meat (carnitine) increase TMAO (Wang *et al.*, 2019; Zhu *et al.*, 2020) when white meat, eggs, dairy products (Burton *et al.*, 2020a) or phosphatidylcholine (Cho *et al.*,

2020) are not correlated with higher TMAO. Adherence to the Paleolithic diet (with high meat and egg consumption but no dairy product) increased TMAO compared to control and it was inversely associated with whole grain intake (low in paleolithic diet) (Genoni *et al.*, 2020). Discontinuation of dietary red meat reduces plasma TMAO within 4 to 8 weeks (Crimarco *et al.*, 2020b; Wang *et al.*, 2019). TMAO postprandial response is lower after consumption of fermented dairy products than non-fermented dairy products. However, no effect of the daily consumption of dairy products was found on TMAO level (Burton *et al.*, 2020b). In a recent cross-sectional study in Hispanics/Latinos in the United States of America, TMAO was associated with a higher risk of cardiovascular disease. Fish, red meat, and egg intakes were major dietary factors associated with serum TMAO. Red meat-TMAO association was dependent on microbial TMA production from dietary carnitine, whereas the fish-TMAO association is independent of gut microbiota (Mei *et al.*, 2021). Few studies suggest that TMA (directly produced by bacterial metabolism) might have negative impact on health more than TMAO (Jaworska *et al.*, 2019). Fibre intake might modulate serum TMAO, higher intake being inversely correlated with TMAO (Genoni *et al.*, 2020; Leal-Witt *et al.*, 2018; Li *et al.*, 2017).

Studies in animal models gave mechanistic insights on how diet-induced TMAO production by microbiome might be involved in diverse health conditions (exacerbation of hepatic steatosis (Ji *et al.*, 2020), atherosclerotic development (Gregory *et al.*, 2015) and thrombosis (Zhu *et al.*, 2016a)). In addition, those data suggested a causal role of the microbiome in disease. More data are needed to confirm TMAO effects in humans.

4.3 Terrestrial animal source and microbiome over the life course

Most studies have been made on adults, but some data suggest that the impact of TASF on gut microbiome might be different depending of age. The first 1000 days of life (from conception to two years of age) are critical for the child development and for the establishment of the gut microbiome. In one cohort, intake of red and processed meat during pregnancy was associated with high beneficial Bifidobacterium content in child microbiome (Lundgren *et al.*, 2018). In another cohort, maternal intake of animal protein but not the total protein, contributed to change in maternal and child gut microbiome. Maternal dietary patterns were associated with distinct maternal microbiome and different outcomes on child BMI. Infants from mothers with higher intake of animal protein and saturated fat, had increased BMI by the age of 18 months compared to infants from mothers with diet enriched in plant-based products (García-Mantrana *et al.*, 2020).

Few studies have looked at the introduction of TASF as complementary food. In breastfed infants, introduction of meat as complementary food modifies differently the gut microbiome, when compared to cereal food (Krebs *et al.*, 2013). *Enterobacteriaceae* were more abundant in the meat group and relative abundance of *Bifidobacteriaceae* was stable compared to cereal groups (Qasem *et al.*, 2017). In formula fed infants, introduction of meat induced more changes than dairy products (Tang *et al.*, 2019) which can be expected as most formula are based on cow's milk.

Two independent studies on children from the United States of America and Europe cohorts showed that an unbalanced TASF consumption, defined in the study as high daily meat consumption associated with low milk/yoghurt, in the first year of life was associated with asthma. In both studies there were correlations with changes in gut microbiome composition and function (Hose *et al.*, 2021; Lee-Sarwar *et al.*, 2019). The deleterious effect of the unbalanced TASF consumption was reduced by the increased duration of breastfeeding but enhanced by prolonged formula feeding (Hose *et al.*, 2021).

On the contrary to early life, two studies showed that in older adults, dietary interventions with increased animal protein consumption had low impact on microbiome and on the level of protein fermentation products (Dahl *et al.*, 2020; Mitchell *et al.*, 2020).

In conclusion, numerous studies both in animal models and on human cohorts and randomized controlled trials showed that diverse TASF have an impact on the gut microbiome. Data support the potential mediating role of the microbiome between TASF and human health. Red and processed meat as well as animal fats could induce deleterious effects on health via the production of detrimental microbial metabolites (e.g. TMAO, hydrogen sulfide). Fermented dairy products are associated with positive changes. Impact of TASF on gut microbiome might be modulated by the overall diet quality. More data on humans are needed to confirm the implication of the gut microbiome in the TASF-health interconnections.

5 Terrestrial animal source and sustainable healthy diets

Another critical emerging topic where evidence is building is TASF in the context of planetary health. As noted in the Introduction of this document, the topic will be handled in Component Documents 2 and 3 of the Assessment. Here we summarize some threads of research emerging under the broader category of TASF intake and sustainable healthy diets (described in the Introduction of this Section).

Livestock are essential parts of agroecosystems and they contribute to the agroecological transitions of our food systems. Based on the ten elements of agroecology defined by FAO (2018) and approved by member states, livestock are shown to contribute not only through enhancing diversity, synergies and recycling on farm and in pastoral systems, but also to cultural and food traditions as well as circular economy and overall efficiency and resilience of food systems. For example, they generate a variety of products adapted to local cultural values and food traditions. Specific markets for such products – some of which may become more popular with consumers as incomes rise – provide an opportunity to add value and improve livelihoods, and to conserve animal genetic resources by keeping them in profitable use.

Achieving balance between human nutrition, food consumption and sustainability has led to the current critical discussion of changing dietary patterns to align with planetary health (Ridoutt, Baird and Hendrie, 2021; Springmann *et al.*, 2018; Van Mierlo, Rohmer and Gerdessen, 2017; Willett *et al.*, 2019). These changes suggest limiting TASF consumption with a view towards reducing greenhouse gas emissions and other environmental impacts from livestock production. Nevertheless, to address sustainability, consideration should be granted to regional variation in resources, background health and nutrition (Capper, 2013). Others argue that the proposed changes in diets to align with planetary health may not meet all human nutrition requirements, particularly for women and children, and some foods in the healthy reference diet of the EAT-Lancet Commission may not be available or accessible in certain contexts (Adesogan *et al.*, 2020; Capper and Bauman, 2013; Chen, Chaudhary and Mathys, 2019; Hirvonen *et al.*, 2020; Perignon *et al.*, 2017). Livestock play a crucial role in enhancing food security and nutrition of the public at large and the rural and urban poor, in particular providing access to TASF such as meat, milk and eggs that are nutrient dense. In addition, if managed sustainably, they can contribute to important ecosystem functions such as nutrient cycling, soil carbon sequestration and the conversation of agricultural landscapes (FAO, 2018c).

Another emerging theme related to TASF and sustainable healthy diets is the important role of biodiversity to public health and nutrition. Livestock include a diverse range of species and breeds raised in a variety of production systems (FAO, 2018c).The reduction in the diversity of breeds has so far been greatest in HICs, as widely used, high-output varieties have come to dominate. All human health depends on ecosystem services that are made possible by biodiversity. In this way, biodiversity can be considered as the foundation for human health and thus, biodiversity conservation, the sustainable use of biodiversity and the equitable sharing of its benefits is a global responsibility at all levels and across all sectors (FAO, 2012). Efforts are underway to blend disciplines such as environmental science, agricultural science, genetics and human nutrition for the application of metrics across different sectors and creation of novel metrics for measuring TASF impacts on the environment. Dietary diversity, for example, could be reframed and evaluated with indicators of biodiversity and metrics from the field of ecology. Research analyzing 24-hour recalls from seven LMIC countries examined the relationships between biodiversity indicators (species richness, Simpson's index of diversity and functional diversity) and human diet diversity (Lachat et al., 2018). The study found the species richness defined as the number of different species consumed per day positively correlates with nutrient adequacy and diet diversity among women and children in rural areas. FAO published a food composition database(INFOODS1) for biodiversity that reports the value of nutrients and bioactive for foods with information available below the species level, including: genus, species, subspecies, and variety/cultivar/breed (Charrondiere et al., 2017).

Efforts are underway to develop metrics measuring the impacts of TASF and other foods by nutrient density and may present different picture regarding diets recommended for planetary health. Evidence for TASF in sustainable food systems from LMIC are also emerging to provide a fuller analysis of this topic to achieve nutrition needs while safeguarding human health, livestock biodiversity, and the environment.

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1 Glossary

Agrifood systems	Framework that covers the journey of food from farm to table - including when it is grown, fished, harvested, processed, packaged, transported, distributed, traded, bought, prepared, eaten and disposed of. It also encompasses non-food products that constitute livelihoods and all of the people as well as the activities, investments and choices that play a part in getting us these food and agricultural products;
Agrifood systems, sustainable	System delivering food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised, i.e. productive and prosperous, equitable and inclusive, empowering and respectful, resilient, regenerative, and healthy and nutritious system;
Agroecology	Integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems, seeking to optimize the interactions between plants, animals, humans and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system;
Amino acid	Organic compounds that form protein;
Anaemia	Condition in which the number of red blood cells or the haemoglobin concentration within them is lower than normal, decreasing the capacity of the blood to carry oxygen to the body’s tissues;
Animal welfare	Physical and mental state of an animal in relation to the conditions in which it lives and dies;
Antimicrobial resistance	Ability of microorganisms to persist or grow in the presence of drugs designed to inhibit or kill them;
Balanced diet	Food intake that provides an adequate amount and variety of food to meet a person's energy, macro- and micronutrient needs for a healthy and active life;
Bioavailability	Proportion of nutrient intake that is absorbed and metabolized;
Biotechnology	Technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for a specific use;
Compound, antinutritional	Substance that naturally occurs in plant and animal source foods and interferes with the absorption and/or metabolism of nutrients, also called antinutritional factor or antinutrient;
Compound, bioactive	Substance that modulates metabolic functions leading to beneficial outcomes, also called bioactive factor;
Compound, biochemical	Substance found in living organisms and made of carbon, hydrogen and oxygen (e.g. carbohydrates, lipids, proteins);
Dietary pattern	Combination of foods that are consumed over a period of time;
Dietary pattern, healthy/appropriate	Combination of food consumed over time meeting but not exceeding energy and nutrient requirements for growth and development and health maintenance across the life course;

Digestible Indispensable Amino Acid Score	Metric used to rate protein quality, i.e. the percentage of digestible indispensable amino acids compared with a reference protein;
Disability-adjusted life years	Standard metric commonly used to compare the impacts of diseases on population health, expressed as the number of years lost due to ill-health, disability or early death, one DALY being equivalent to one year of healthy life that is lost;
Disease, food-borne	Any illness that results from the consumption of contaminated food (e.g. with toxins, zoonotic pathogens, bacteria, chemicals);
Disease, vector-borne	Any illness caused by an infectious pathogen (parasites, bacteria or virus) transmitted to humans by vectors (e.g. mosquitoes, ticks, flies);
Disease, zoonotic	Infectious diseases that can be spread between animals and humans; can be spread by food, water, fomites, or vectors; also called zoonoses;
Experimental trial	Study of effects of an intervention (e.g. risk factor, medical treatment) on people who are assigned to different groups, the control group receiving no specific intervention or a placebo; also called or intervention trial;
Factor, antioxidant	Compound that prevents or delays cell and DNA damage rising from free radicals or oxidation;
Fat globule (in milk)	Structure composed of lipids and proteins secreted from milk producing cells and enabling milk as an emulsion;
Fatality rate	Proportion of deaths from a certain disease out of the total number of people diagnosed with the disease for a particular periode, also called lethality;
Fatty acid	Primary component of lipids, classified in different ways (e.g. length, saturation);
Food balance sheet	Comprehensive picture of the pattern of a country's food supply during a specified reference period;
Food control system	Integration of a mandatory regulatory approach with preventive and educational strategies that protect the whole food chain, through enforcement by national or local authorities to provide consumer protection and ensure that all foods during production, handling, storage, processing and distribution are safe, wholesome and fit for human consumption;
Food group	Set of foods that share similar nutritional properties or biological characteristics;
Food hazard	Biological, chemical or physical agent in food with the potential to cause adverse heatlh effects;
Food insecurity	Lack of regular access to enough safe and nutritious food for normal growth and development and an active and healthy life;
Food matrix	Physical domain where nutrients and non-nutrients of food interact providing different performance from those displayed by the components in isolation or free state;
Food quality	Attributes of food that influence its value and that make it acceptable or desirable for the consumer;
Food safety	Assurance that food will not cause adverse health effects to the consumer when it is prepared and/or eaten according to its intended use;

Food security	Conditions in which all people, at all times, have the physical and economic access to sufficient, safe, and nutritious foods to meet their dietary needs and food preferences for an active and healthy life, including six dimensions: availability, access (economic, social and physical), utilization (nutritional uptake), stability, agency (capacity to act independently) and sustainability;
Food value chain	All the stakeholders and activities involved in the coordinated production and value-adding activities that are needed to make food products;
Food, fortified	Food with added micronutrient fortificants or powders, generally with the aim of improving its nutritional composition;
Food, processed	Substance intended for human consumption which has been altered by either mechanical or chemical operation;
Food-based dietary guidelines	National advice and principles on healthy diets and lifestyles, which are rooted on sound evidence, and respond to a country's public health and nutrition priorities, food production and consumption patterns, sociocultural influences, food composition data, and accessibility, among other factors;
Genetically Modified Organism	Organisms in which the genetic material has been altered in a way that does not occur naturally, in order to induce or remove a trait;
Hazard ratio	Ratio of the probability of the occurrence of a hazard (such as death) between an exposed and a non-exposed group of people to an event (such as resistance of a pathogen to antibiotics, consumption of terrestrial animal source food); a higher risk being above 1;
Healthy diet	Set of foods in adequate quantity and quality that achieves optimal growth and development of all individuals and support functioning and physical, mental and social wellbeing at all life stages and physiological needs; healthy diets are safe, diverse, balanced and based on nutritious food;
Healthy diet, sustainable	Diet that promotes all dimensions of individuals' health and wellbeing, has low environmental pressure and impact, is accessible, affordable, safe and equitablem, and is culturally acceptable;
Healthy population	Absence of disease in a population based on clinical signs and symptoms and function, normally assessed by routine laboratory methods and physical evaluation;
Height-for-age Z score	Height of a child in relation to a standardized median height of children of the same age and sex; when a child has low height-for-age Z (< -2 standard deviations from the median of the WHO Child Growth Standards), it is stunted;
Incubation period	Period between the infection of an individual by a pathogen and the manifestation of the symptoms;
Indigenous peoples	No single definition but a consensus on the following criteria: priority in time, with respect to occupation and use of a specific territory; the voluntary perpetuation of cultural distinctiveness, which may include aspects of language, social organization, religion and spiritual values, modes of production, laws and institutions; self-identification, as well as recognition by other groups, or by State authorities, as a distinct collectivity; and an experience of subjugation, marginalization, dispossession, exclusion or discrimination, whether or not these conditions persist;

Informal market	Informal markets have specific characteristics such as: absence of specialization; very low capital investment; interlinkage between production and consumption; absence of bank accounts and the non-payment of all or some taxation; predominance of households and micro-enterprises with varying and limited purchasing power; importance of virtually free labour in the form of apprentice help or family members who are fed but receive no or little pay; relationships with the rural sector that often enable the provision of raw materials at lower cost;
Insects	Animals belonging to zoological class Insecta or Hexapoda with segmented bodies, six jointed legs and external skeletons (exoskeletons); grubs are insects in the larval phase of their life cycle;
Intrauterine growth retardation	Impaired growth and development of the foetus and/or its organs during gestation;
Iron-heme protein	Protein that contains iron as part of a heme group (e.g. hemoglobin), heme protein is for human health as it transports oxygen in the blood;
Lactase deficiency	Inability to digest large amounts of lactose, also called lactase non-persistence;
Lactose intolerance	Condition generally caused by lack of lactase enzyme resulting in the inability to digest lactose; symptoms may include abdominal pain, bloating and diarrhea;
Lactose malabsorption	Failure to digest and/or absorb lactose in the small intestines;
Large-for-gestational age	Newborn with weight above the ninetieth percentile for the gestational age in comparison with average infant population of the same sex and gestational age;
Life course	Succession of life stages that encapsulate both biological and social determinants of health: infants and young children (below 5), school age children and adolescents (5 to 18), adults, older adults (older than 65);
Life cycle	Succession of life stages that refers to the biological developmental phases of an organism;
Life cycle assessment	Compilation and evaluation of inputs, outputs, and potential environmental impacts of a product system across the course of its life cycle;
Life span	Succession of life stages that refers to the temporal aspects of an individual from conception to death;
Low birthweight	Weight at birth below 2 500 gram;
Malnutrition	Abnormal physiological condition caused by inadequate, unbalanced or excessive intake of macronutirents and/or micronutrients;
Meat, from wild animals	Meat derived from hunting of wild animals and wildlife farming, also called bushmeat, wild meat or game meat;
Meat, poultry	Meat derived from domesticated avian species including chicken, duck, Muscovy duck, goose, guinea fowl, turkey, quail and pigeon;
Meat, processed	Meat products (including offals) that have undergone treatment such as salting, curing, smoking, marinating, drying, cooking;

Meat, red	Meat which is dark brown in colour after it has been cooked and is derived from the following mammalian ruminant and monogastric livestock species: cattle, buffalo, goat, sheep, pig, dromedary, Bactrian camel, horse, donkey;
Meat, white	Meat which is pale in colour before and after cooking and is derived from rabbits and avian livestock species;
Meta-analysis	Statistical analysis of combined data from a number of independent studies of the same subject, in order to determine overall trends;
Metabolite	Molecule used or produced during metabolism; for example, glycine and L-arginine are precursor amino acids of the biosynthesis of creatine, which is the final metabolite.
Microbiome	Microbial community (that includes bacteria, archaea, protozoa, fungi and viruses) and its activity (genome, proteins, metabolites) in a given environment;
Micronutrient deficiency	Lack of essential vitamins and/or minerals that the human body requires in small amounts, also called hidden hunger;
Monogastrics	Animals with one-compartmented stomach (e.g. avian species, pig, rabbit, horse);
Morbidity	Symptom arising from a disease or condition and usually presented as a prevalence calculated by dividing the number of affected individuals by the total number of individuals within a specific population (e.g. acute diarrhea, upper respiratory illness);
Mortality	Deaths caused by a disease, injury or disability; may be communicated as an absolute number or as a rate, by dividing the number of deaths in a given time for a given population by the total population;
Non communicable disease	Illness that results of a combination of genetic, physiological, environmental and behavioural factors, also known as chronic disease (e.g. cardiovascular diseases (heart attacks or strokes), cancers, chronic respiratory diseases (such as chronic obstructive pulmonary disease and asthma) and diabetes);
Nutrient	Substance that is required by the body for optinormal growth, development and maintenance of good health;
Nutrient density	Relative amount of nutrients per calories, food volume or serving size;
Nutrient profile	Classification or rank of foods according to their nutritional composition for reasons related to preventing disease and promoting health;
Nutrient requirement	Recommendations to consumers on nutrient intakes, amount of nutrients needed to maintain health in an otherwise healthy individual or group of people; nutrient requirements are periodically updated based on new evidence;
Nutrient, essential	Food component required in the diet that cannot be synthesized by the human body;
Nutrient, macronutrient	Energy-containing components of food needed in substantial quantities, typically above 10 gram per day (e.g. carboydrates, proteins and fats);
Nutrient, micronutrient	Food component required by the body in small amounts, usually below 2 gram per day (e.g. vitamins and minerals);

Nutrient, non-essential	Food component required by the human body that can be synthesized by the human body under normal conditions and are thus not required in the diet;
Obesity	Body weight that is pathologically above normal, as a result of an excessive accumulation of fat in adipose tissue to the extent that health may be impaired;
Offal	Organs from mammalian and avian species such as liver, kidney, heart, lungs, intestines, blood;
Omics	Scientific discipline or field of research that analyzes complete genetic or molecular profiles in humans and other organisms;
One Health	Integrated approach that recognizes the fundamental interconnection between the health of animals, people, plants and the environment;
Overweight	Body weight above normal for height, generally as a result of an excessive accumulation of fat and a manifestation of expending fewer calories than are consumed
PCR method	Polymerase chain reaction is a method used to amplify specific segments of DNA into numerous copies and one of its application is to identify infectious agents;
Plant source food	Food derived from plants (e.g. vegetables, fruits, legumes, seeds, nuts);
Protein quality	Determined by assessing the proteins's essential amino acid composition, digestibility and bioavailability of amino acids and whether the protein meets the requirements of essential amino acids and the physiological needs of the organism.
Public health	Science that promotes and protects the health of people and communities generally by applying a population-based approach to disease prevention; subfields include epidemiology, biostatistics, health policy, global health, environmental health, among others;
Residues	Traces of substances in agricultural commodities, animal feed or food resulting for example, from the use of pesticide or veterinary drugs;
Review, narrative	Analysis that describes the evidence on a topic but is not systematic and does not follow a specific method;
Review, systematic	Analysis focusing on a clearly formulated question that uses systematic and reproducible methods to identify, select and critically appraise all relevant research;
Risk	A measure of the probability and severity of adverse effects; human health risk is the probability that a given exposure or series of exposures will damage the wellbeing of individuals;
Risk analysis	Process consisting of three components: risk assessment, risk management and risk communication;
Risk assessment	Human health risk assessment is a process intended to estimate the risk to a given target organism, system or (sub)population, including the identification of attendant uncertainties, following exposure to a particular agent, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system;

Ruminants	Hoofed herbivorous grazing or browsing mammals that are able to acquire nutrients from plant-based food by fermenting it in a specialized stomach prior to digestion, principally through microbial actions (e.g. cattle, buffalo, goat, sheep);
Shelf-life	Shelf-life of food is the time, under defined storage conditions, during which food remains safe, retains desired sensory, chemical, physical and biological characteristics and complies with any label declaration;
Small-for-gestational age	Newborn with weight below the tenth percentile for the gestational age in comparison with standardized median weight of the same sex and gestational age;
Study, case control	Observational study that compares people with an existing health issue to people without that issue;
Study, cohort	Observational study that compares the effect of an intervention on a group of people with shared characteristics (cohort), who have been exposed to the intervention with the effect on a group of people who have not been exposed;
Study, cross-sectional	Observational study that analyses numerous characteristics and variables at once (at a single point of time)
Study, observational	Study of the effects of an intervention on people who were already exposed to this intervention before the study;
Stunting	Low height-for-age Z score < -2 standard deviations according to WHO Child Growth Standards; associated with both physical and cognitive delays in growth and development and an elevated risk of death;
Surveillance	Systematic ongoing collection, collation and analysis of data and the timely dissemination of information to those who need to know so that action can be taken;
Terrestrial animal source food	Food derived from terrestrial animals;
Traceability	Tracability of food is the ability to follow the movement of a food through specified stage(s) of production, processing and distribution;
Wasting	Low weight-for-height Z score < -2 standard deviations according to WHO Child Growth Standards; generally arises from recent and severe weight loss often associated with infectious disease and acute starvation;
Weight-for-age Z score	Weight of a child in relation to standardized median weight of children of the same age and sex; when a child has low weight-for-its age (<-2 standard deviation from the median of the WHO Child Growth Standards), it is underweight;
Weight-for-length/height Z score	Weight of a child in relation to the average length/height of children of the same age and sex; when a child has low weight-for-its length/height (<-2 standard deviation from the median of the WHO Child Growth Standards) it is wasted; child overweight is weight-for-height greater than 2 standard deviation above WHO Child Growth Standards median; obesity is weight-for-height greater than 3 standard deviation above the WHO Child Growth Standards median;

Annex Tables Section B

Table B1 Recommended nutrient intake by life cycle phase: vitamins

Life cycle phase	Water-soluble vitamins									Fat-soluble vitamins			
	Vitamin C mg/day)	Thiamine (mg/day)	Riboflavin (mg/day)	Niacin (a) (mg NE/day)	Vitamin B6 (mg/day)	Pantothenate (mg/day)	Biotin (μg/day)	Vitamin B12 (μg/day)	Folate (b) (μg RE/day)	Vitamin A (c,d) (μg RE/day)	Vitamin D (μg/day)	Vitamin E (e) (mg α-TE/day)	Vitamin K (μg/day)
Infants 7-12 months	30	0.3	0.4	4	0.3	1.8	6	0.7	80	400	5	2.7 (f)	10
Children 1-3 years	30	0.5	0.5	6	0.5	2	8	0.9	150	400	5	5.0 (f)	15
Children 4-6 years	30	0.6	0.6	8	0.6	3	12	1.2	200	450	5	5.0 (f)	20
Children 7-9 years	35	0.9	0.9	12	1	4	20	1.8	300	500	5	7.0 (f)	25
Adolescents females 10–18 years	40	1.1	1	16	1.2	5	25	2.4	400	600	5	7.5	35-55
Adolescents males 10–18 years	40	1.2	1.3	16	1.3	5	25	2.4	400	600	5	10	35-55
Adults females 19-50 years (premenopausal)	45	1.1	1.1	14	1.3	5	30	2.4	400	500	5	7.5	55
Adults females 51-65 years (menopausal)	45	1.1	1.1	14	1.5	5	30	2.4	400	500	10	7.5	55
Adults males 19-65 year	45	1.2	1.3	16	1.3 (19-50 yrs) 1.7 (50+yrs)	5	30	2.4	400	600	5 (19-50 yrs) 10 (51-65 yrs)	10	65
Older females 65+ years	45	1.1	1.1	14	1.5	5		2.4	400	600	15	7.5	55
Older males 65+ years	45	1.2	1.3	16	1.7	5		2.4	400	600	15	10	65
Pregnant women	55	1.4	1.4	18	1.9	6	30	2.6	600	800	5	(g)	55
Lactating women	70	1.5	1.6	17	2	7	35	2.8	500	850	5	(g)	55

Note: Recommended nutrient intake (RNI) is the daily intake which meets the nutrient requirements of almost all (97.5 percent) apparently healthy individuals in an age- and sex-specific population.
(a) NE = Niacin equivalents; (b) DFE = Dietary folate equivalents; mg of DFE provided = [mg of food folate + (1.7 ¥ mg of synthetic folic acid)];
(c) Vitamin A values are "recommended safe intakes" instead of RNIs;
(d) Recommended safe intakes as mg retinol equivalent (RE)/day; conversion factors are as follows: 1mg retinol = 1 RE; 1mg b-carotene = 0.167mg RE; 1mg other provitamin A carotenoids = 0.084mg RE; (e) Data were not sufficiently robust to formulate recommendations. The figures in the table therefore represent the best estimate of requirements.
(f) Preformed niacin; (g) See Chapter 5 for details from FAO and WHO 2004;
Source: Adapted from WHO and FAO, 2004.

Table B2 Recommended nutrient intake by life cycle phase: minerals

Life cycle phase	Calcium (mg/day)	Selenium (µg/day)	Magnesium (mg/day)	Zinc (mg/day)			Iron (mg/day)				Iodine (µg/day)
				50% High bioavailability	30% Moderate bioavailability	15% Low bioavailability	15% Bioavailability	12% Bioavailability	10% Bioavailability	5% Bioavailability	
Infants, 7-12 months	400	10	54	0.8 (d)	4.1	8.4	6.2 (a)	7.7 (a)	9.3 (a)	18.6 (a)	90 (b)
Children, 1-3 years	500	17	60	2.4	4.1	8.3	3.9	4.8	5.8	11.6	90 (b)
Children, 4-6 years	600	22	76	2.9	4.8	9.6	4.2	5.3	6.3	12.6	90 (b)
Children, 7-9 years	700	21	100	3.3	5.6	11.2	5.9	7.4	8.9	17.8	120 (6-12 yrs)
Adolescents females 10-18 years	1300 (10-18 yrs)	26 (10-18 yrs)	220 (10-18 yrs)	4.3 (10-18 yrs)	7.2 (10-18 yrs)	14.4 (10-18 yrs)	9.3 (11-14 yrs) (c)	11.7 (11–14 yrs) (c)	14.0 (11–14 yrs) (c)	28.0 (11–14 yrs) (c)	150 (13–18 yrs)
							21.8 (11–14 yrs)	27.7 (11–14 yrs)	32.7 (11–14 yrs)	65.4 (11–14 yrs)	nd
							20.7 (15–17 yrs)	25.8 (15–17 yrs)	31.0 (15–17 yrs)	62.0 (15–17 yrs)	nd
Adolescents males 10-18 years	1300	32	230	5.1	8.6	17.1	9.7 (11–14 yrs)	12.2 (11–14 yrs)	14.6 (11–14 yrs)	29.2 (11–14 yrs)	150 (13–18 yrs)
							12.5 (15–17 yrs)	15.7 (15–17 yrs)	18.8 (15–17 yrs)	37.6 (15–17 yrs)	nd
Adults females 19-50 years (premenopausal)	1000	26	220	3	4.9	9.8	19.6	24.5	29.4	58.8	150
Adults females 51-65 years (menopausal)	1300	26	220	3	4.9	9.8	7.5	9.4	11.3	22.6	150
Adults males 19-65 years	1000	34	260	4.2	7	14	9.1	11.4	13.7	27.4	150
Older females 65+ years	1300	25	190	3	4.9	9.8	7.5	9.4	11.3	22.6	150
Older males 65+ years	1300	33	224	4.2	7	14	9.1	11.4	13.7	27.4	150
Pregnant women first trimester	(d)	(d)	220	3.4	5.5	11	e	e	e	e	200
Pregnant women second trimester	(d)	28	220	4.2	7	14	e	e	e	e	200
Pregnant women third trimester	1200	30	220	6	10	20	e	e	e	e	200
Lactating women 0-3 months	1000	35	270	5.8	9.5	19	10	12.5	15	30	200
Lactating women 3-6 months	1000	35	270	5.3	8.8	17.5	10	12.5	15	30	200
Lactating women 7-12 months	1000	42	270	4.3	7.2	14.4	10	12.5	15	30	200

Note: Recommended nutrient intake (RNI) is the daily intake which meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population; nd: no data available. (a) *Bioavailability of dietary iron during this period varies greatly. (b) Recommendation for the age group 0–4.9 years. (c) Pre-menarche. (d) Not specified.*
(e) It is recommended that iron supplements in tablet form be given to all pregnant women because of the difficulties in correctly assessing iron status in pregnancy. In non-anaemic pregnant women, daily supplements of 100mg of iron (e.g. as ferrous sulphate) given during the second half of pregnancy are adequate. In anaemic women higher doses are usually required.
Source: Adapted from WHO and FAO, 2004.

Table B3 Nutrient composition of poultry eggs

Nutrient	Chicken		Duck	Chicken egg yolk		Chicken egg white		Geese	Quail	Turkey
	avg	range	avg	avg	range	avg	range	avg	avg	avg
Energy (kcal/kJ)	135/566	127-143/533-599	185/776	318/1331	313-322/1311-1350	50/207	47-52/197-216	185/775	158/663	171/716
Carbohydrates (g)	0.5	0.3-0.7	1.5	1.9	0.2-3.6	0.6	0.4-0.7	1.4	0.4	1.2
Lactose (g)	-	-	nd	0.04	0-0.07	0.04	0-0.07	nd	nd	nd
Protein (g)	12.6	nd	12.8	15.8	15.6-15.9	11.1	10.9-11.2	14.0	13.0	13.7
Fat (g)	8.5	8.5-9.5	13.8	27.4	26.5-28.2	0.1	0-0.2	13.0	11.1	11.9

Note: Nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - nutrient not contained.
Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B4 Vitamin content of poultry eggs

Vitamin	Chicken		Duck	Chicken egg yolk		Chicken egg white		Geese	Quail	Turkey
	avg	range	avg	avg	range	avg	range	avg	avg	avg
Vitamin A (µg) RAE*	145	130-160	194	415	381-449	-	-	187	156	166
Vitamin E (alphatocopherol) (mg)	1.4	1.1-1.7	1.3	5.1	2.6-7.9	-	-	1.3	1.1	nd
Vitamin D (µg)	1.7	1.4-2.0	1.7	11.2	5.4-17.0	-	-	1.7	1.4	nd
Vitamin K (phylloquinone) (µg)	0.3	nd	0.4	0.7	nd	-	-	0.4	0.3	nd
Vitamin C (mg)	-	-	-	-	-	-	-	-	-	-
Thiamin (mg)	0.06	0.04-0.07	0.16	0.18	0.17-0.19	-	-	0.15	0.13	0.11
Riboflavin (mg)	0.44	0.46-0.43	0.40	0.46	0.40-0.53	0.42	0.41-0.44	0.38	0.79	0.47
Niacin (mg)	0.04	0-0.08	0.20	0.01	0-0.02	0.05	0-0.11	0.19	0.15	0.02
Pantothenic acid (mg)	1.52	1.50-1.53	1.86	4.10	2.99-5.20	0.21	0.19-0.22	1.76	1.76	1.89
Vitamin B6 (mg)	0.09	0.01-0.17	0.25	0.26	0.16-0.35	-	0-0.01	0.24	0.15	0.13
Folate DFE** (µg)	79	47-110	80	133	120-146	7	4-7	76	66	71
Vitamin B12 (µg)	1.15	0.89-1.40	5.40	2.98	1.95-4.00	0.05	0-0.09	5.10	1.58	1.69

*Note: *Vitamin A content expressed in retinol equivalents (RAE); **Dietary folate equivalent; nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - Vitamin not contained;*
Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B5 Amino acid composition of milk from mammalian livestock species and humans

Amino acid (in g)	Human		Buffalo	Cattle		Yak	Goat		Sheep	Reindeer	Donkey
	avg	range	avg	avg	range	avg	avg	range	avg	avg	avg
Alanine	0.04	nd	0.03	0.11	nd	0.03	0.12	nd	0.27	0.03	0.03
Arginine	0.04	nd	0.03	0.09	nd	-	0.12	nd	0.20	0.03	0.05
Asparagine	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Aspartic acid	0.08	nd	0.07	0.27	nd	0.07	0.21	nd	0.33	0.06	0.09
Cystine	0.02	nd	0.08	0.02	nd	0.01	0.05	nd	0.04	0.00	0.00
Glutamic acid	0.17	nd	0.21	0.69	nd	0.16	0.63	nd	1.02	0.20	0.22
Glutamine	nd	nd	nd	nd	nd	0.17	nd	nd	nd	nd	nd
Glycine	0.03	nd	0.02	0.07	nd	0.03	0.50	nd	0.04	0.02	0.01
Histidine	0.02	nd	0.03	0.10	nd	nd	0.09	nd	0.17	0.03	0.02
Isoleucine	0.06	nd	0.05	0.18	0.16-0.20	0.04	0.21	-	0.34	0.04	0.05
Leucine	0.10	nd	0.09	0.31	0.29-0.33	0.12	0.31	nd	0.59	0.09	0.08
Lysine	0.07	nd	0.08	0.28	0.26-0.31	0.07	0.29	-	0.51	0.08	0.07
Methionine	0.02	nd	0.02	0.08	nd	0.03	0.08	nd	0.16	0.02	0.02
Phenylalanine	0.05	nd	0.05	0.17	nd	0.05	0.16	nd	0.28	0.04	0.04
Proline	0.08	nd	12.00	0.32	0.31-0.33	0.03	0.37	-	0.58	0.09	0.09
Serine	0.04	nd	0.05	0.19	nd	0.04	0.18	nd	0.49	0.05	6.13
Threonine	0.05	nd	0.04	0.14	0.13-0.15	0.04	0.16	nd	0.27	0.04	0.04
Tryptophan	0.03	0.02-0.05	0.00	0.04	nd	0.02	0.04	-	0.08	0.01	nd
Tyrosine	0.05	nd	0.05	0.15	nd	0.03	0.18	-	0.28	0.05	0.04
Valine	0.06	nd	0.06	0.22	0.20-0.23	0.06	0.24	-	0.45	0.05	0.07

Note: Nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - amino acid not contained.
Source: Australian Food Composition Database, 2021; Balthazar et al., 2017; FoodData Central USDA, 2021; Frida, 2021; Medhammar et al., 2012; Tabla de Composición de Alimentos Colombianos, 2021.

Table B6 Fat and fatty acid composition of milk from ruminant and monogastric livestock species and humans

Fat/Fatty acid (in g)	Human		Livestock species																			
			Buffalo		Cattle	Yak		Goat	Sheep		Bactrian camel		Donkey		Dromedary	Llama		Horse		Reindeer	
	avg	range	avg	range	avg	range	avg	avg	range	avg	avg	range	avg	range	avg	range	avg	avg	range	avg	range
SFA	1.99	1.98-2.01	5.80	4.20-8.80	2.84	1.86-5.00	5.81	2.58	2.50-2.60	4.60	2.23	1.84-2.50	0.3	0.24-0.38	2.08	1.50-2.60	2.90	0.55	0.32-0.75	11.20	nd
SFA 4:0	-	-	0.29	0.23-0.38	0.07	0.06-0.12	nd	0.13	0.13-0.14	0.20	nd	nd	-	0.02-0.04	-	nd	0.09	0	0	0.95	0.50-1.30
SFA 6:0	-	-	0.16	0.11-0.27	0.07	0.05-0.09	nd	0.10	0.09-0.10	0.15	nd	nd	0.01	0.00-0.01	0.01	nd	0.11	0	0	0.32	0.10-0.40
SFA 8:0	-	-	0.11	0.07-0.18	0.04	0.03-0.08	nd	-	0-0.10	0.14	nd	nd	0.06	0.05-0.08	0.01	0.00-0.08	0.10	0.03	0.01-0.05	0.08	0.03-0.12
SFA 10:0	0.06	0.05-0.06	0.31	0.11-1.2	0.08	0.07-0.10	0.06	0.26	0.26-0.28	0.40	nd	nd	0.09	0.07-0.11	0.01	0.00-0.01	0.11	0.07	0.03-0.10	0.1	0.06-0.15
SFA 12:0	0.24	0.22-0.25	0.20	0.14-0.33	0.10	0.08-0.10	0.09	0.13	0.12-0.13	0.24	0.02	0.02	0.04	0.04	0.03	0.03	0.07	0.07	0.04-0.16	0.15	0.09-0.21
SFA 14:0	0.31	0.3-0.32	0.92	0.68-1.2	0.35	0.30-0.40	0.42	0.34	0.32-0.33	0.66	0.29	0.23-0.34	0.03	0.02-0.03	0.33	0.13-0.48	0.48	0.08	0.06-0.11	1.70	1.10-2.50
SFA 16:0	0.96	0.92-1.01	2.5	2.06-3.50	0.96	0.83-1.08	1.89	0.95	0-91-0.99	1.62	1.04	0.78-1.90	0.06	0.04-0.07	0.88	0.61-1.15	1.30	0.26	0.15-0.31	5.20	3.70-6.90
SFA 18:0	0.31	0.29-0.33	0.92	0.55-1.20	0.37	0.37-0.40	0.96	0.44	0.48-0.44	0.9	0.78	0.72-0.86	0.01	0.00-0.01	0.78	0.72-0.86	0.43	0.01	0.08-0.02	2.10	1.30-2.70
MUFA	1.56	1.43-1.66	2.10	1.30-2.70	1.25	0.78-2.5	1.18	1.08	1.00-1.15	1.72	1.3	0.89-1.60	0.08	0.06-0.01	2.20	1.7-2.5	1.20	0.43	0.21-0.64	2.70	1.90-3.10
MUFA 16:1	0.12	0.11-0.13	0.15	0.07-0.25	0.06	0.05-0.06	0.01	0.09	0.09	0.13	0.17	0.10-0.21	nd	nd	0.29	0.17-0.36	0.29	0.07	0.06-0.09	nd	nd
MUFA 18:1	1.38	1.30-1.48	1.80	1.10-2.20	0.77	0.70-0.81	1.10	1.02	0.97-1.07	1.56	1.10	0.76-1.40	0.05	0.04-0.06	nd	nd	nd	0.23	0.06-0.39	2.40	1.7-2.9
MUFA 20:1	0.02	0.01-0.04	nd	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	0.01	-	0.00-0.01	nd	nd
MUFA 22:1	-	-	nd	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
PUFA	0.49	0.48-0.50	0.45	0.27-0.45	0.16	0.09-0.30	0.15	0.14	0.10- 0.16	0.31	0.15	0.12-0.17	0.08	0.06-0.10	0.28	0.23-0.32	0.15	0.56	0.30-1.02	0.50	0.20-0.80
PUFA 18:2	0.38	0.37-0.39	0.1	0.07-0.10	0.09	0.07-0,12	0.09	0.11	0.11-0.12	0.18	nd	nd	nd	nd	0.11	0.97-0.12	0.06	0.12	0.06-0.20	nd	nd
PUFA 18:3	0.04	0.05-0.03	0.05	0.01-0.10	0.08	0.00-075	0.06	0.04	0.04	0.13	0.06	0.05-0.06	nd	nd	0.08	0.05-0.12	nd	0.18	0.12-0.25	nd	nd
PUFA 18:4	-	-	nd	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
PUFA 20:4	0.02	0.02-0.03	nd	nd	-	-	nd	-	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
PUFA 2:5 n-3 (EPA)	-	-	nd	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
PUFA 22:5 n-3 (DPA)	0.01	-	nd	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
PUFA 22:6 n-3 (DHA)	0.01	-	-	nd	-	-	nd	-	-	nd	nd	nd	nd	nd	nd	nd	nd	0.10	nd	nd	nd
Fatty acids, total trans	-	0.1	0.52	0.39-0.07	0.12	0.11-0.13	0.02	-	-	nd	0.02	0.02-0.07	nd	nd	nd	nd	0.18	nd	nd	0.46	0.44-0.48
Cholesterol (mg)	14	14-15	nd	nd	12	10-14	nd	13	11-15	27	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Choline (mg)	nd	nd	nd	nd	14	nd	nd	16	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Note: Nutrient values are expressed per 100 gram edible portion on fresh weight basis; SFA = saturated fatty acids; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid; slaughter weight and degree of maturity at slaughter weight influences fat composition; nd = no value in common data sources; - fatty acid not contained.

Source: Australian Food Composition Database, 2021; Balthazar et al.*, 2017; FoodData Central USDA, 2021; Frida, 2021; Medhammar* et al.*, 2012; Tabla de Composición de Alimentos Colombianos, 2021.*

Table B7 Mineral composition of milk from livestock species and humans

Mineral		Calcium (mg)	Magnesium (mg)	Phosphorus (mg)	Potassium (mg)	Sodium (mg)	Iron (mg)	Zinc (mg)	Copper (mg)	Manganese (mg)	Selenium (µg)	Iodine (µg)
Human	avg	33	3	15	53	16	0.03	0.2	0.1	0.03	1.0	4.3
	range	32-34	3	14-15	50-58	15-18	0-0.07	0.2-0.3	0-0.1	0.03	1.0-1.9	3.1-7
Buffalo	avg	191	12	185	112	47	0.17	0.5	-	nd	nd	4.0
	range	147-220	2-16	102-293	nd		nd	nd	nd	nd	nd	nd
Cattle	avg	114	11	91	143	43	0.07	0.5	0	-	2.0	10.7
	range	113-120	10-12	84-95	132-153	43-49	0.20	0.4-0.8	0-0.3	-	1.3-3.7	10.7-22.9
Mithan	avg	88	nd	147	nd	nd	nd	nd	nd	nd	nd	nd
Yak	avg	129	nd	nd	nd	nd	0.57	0.9	0.4	nd	nd	nd
	range	119-134	nd	nd	nd	nd	0.15-0.98	0.7-1.1	nd	nd	nd	nd
Goat	avg	129.33	14	105	195	50	0.06	0.3	0.1	0.02	1.0	nd
	range	120-134	14	100-111	180-204	50	0.10	0.3-0.4	0-0.1	0.02	1.0	nd
Sheep	avg	193	18	158	137	44	0.10	0.5	0.1	0.02	2.0	nd
	range	195-200	17-23	139-142	136-140	32-46	0.10	0.5-0.7	0.1	6.15-8.15	0.7-2.7	nd
Bactrian camel	avg	154	8.1	132	186	66	nd	0.7	nd	nd	nd	nd
	range	152-155	nd	117-146	181-191	61-72	nd	nd	nd	nd	nd	nd
Dromedary	avg	114	13	86	151	66	0.21	0.6	0.2	106.00	nd	nd
	range	105-120	12-14	83-90	124-173	59-73	0.17-0.26	0.4-0.6	0.1-0.2	60-180	nd	nd
Llama	avg	195	19	270	156	48	nd	1.1	nd	nd	nd	nd
	range	170-220	nd	nd	nd	46-50	nd	nd	nd	nd	nd	nd
Reindeer	avg	320	19	270	156	48	nd	1.1	nd	nd	nd	nd
	range	nd	nd	nd	nd	46-50	nd	nd	nd	nd	nd	nd
Donkey	avg	91	4	61	50	22	nd	nd	nd	nd	nd	nd
	range	68-115	nd	49-73	nd	nd	nd	nd	nd	nd	nd	nd
Horse	avg	95	7	58	51	16	0.10	0.2	0.1	nd	nd	nd
	range	76-124	4.0-12.0	43-83	25-87	13-20	0.03-0.15	0.2-0.3	0.1	nd	nd	nd

Note: Nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - mineral not contained.

Source: Australian Food Composition Database, 2021; Balthazar et al.*, 2017; FoodData Central USDA, 2021; Frida, 2021; Medhammar* et al.*, 2012; Tabla de Composición de Alimentos Colombianos, 2021.*

Table B8 Vitamin composition in dairy products

Product	Vitamin A RAE* (µg)	Vitamin E (alphatocopherol) (mg)	Vitamin D (µg)	Vitamin K (phylloquinone) (µg)	Vitamin C (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Pantothenic acid (mg)	Vitamin B6 (mg)	Folate DFE** (µg)	Vitamin B12 (µg)
Buttermilk	47	0.1	1.3	0.3	-	0.05	0.17	0.09	0.38	0.04	5	0.46
Yogurt	37	0	-	0.2	0.3	0.03	0.19	0.04	0.38	0.03	17	0.44
Milk powder	350	0.9	0.6	nd	41.0	0.20	1.60	0.00	nd	0.19	117	0.70
Cream	120	0.1	1.1	1.7	0.8	0.02	0.19	0.09	0.44	0.04	2	0.14
Sour cream	154	0.6	-	1.5	0.5	0.01	0.14	0	0.30	-	32	0.16
Ice cream	111	0.3	0.2	0.3	3.0	0.04	0.24	0.14	0.72	0.05	11	0.39
Butter	758	2.2	0.2	7.0	-	-	0.04	0.57	0.06	-	5	-
Ghee	860	2.0	1.2	nd	-	-	0.01	-	nd	-	-	-

*Note: * Vitamin A content expressed in retinol equivalents (RAE) ** Dietary folate equivalent; Average values provided for vitamin content; nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - vitamin not contained; cheeses have been excluded due to the large diversity.*
Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B9 Mineral composition in dairy products

Mineral	Buttermilk	Butter	Cream	Ice cream	Milk powder	Sour cream	Yogurt
Calcium (mg)	115	21	91	119	850	92	152
Magnesium (mg)	10	2	9	14	80	7.5	16
Phosphorus (mg)	85	20	92	104	810	74	126
Potassium (mg)	135	23.5	136	212	1300	75	197
Sodium (mg)	105	709.5	72	72	310	25	60
Iron (mg)	0.03	0.01	0.05	0.57	0.00	0.04	0.03
Zinc (mg)	0.4	0.1	0.3	0.5	2.3	0.3	0.6
Copper (mg)	0.03	-	0.01	0.04	nd	0.01	0.01
Manganese (mg)	-	-	0.01	0.08	nd	-	-
Selenium (µg)	4	1	5	2	12	2	2
Iodine (µg)	nd	8.8	nd	nd	120.0	15.3	25.0

Note: Nutrient values expressed per 100 gram edible portion on fresh weight basis; nd= no value in common data sources; - mineral not contained; cheeses have been excluded due to the large diversity.

Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B10 Vitamin composition of milk from ruminant and monogastric livestock species and humans

Vitamin	Human	Livestock species									
		Buffalo	Cow	Goat	Sheep	Bactrian camel	Donkey	Dromedary		Mare	
	avg	avg	avg	avg	avg	avg	avg	avg	range	avg	range
Vitamin A (µg) RAE*	62	69	43	34	44	97	nd	nd	nd	nd	nd
Vitamin E (alphatocopherol) (mg)	0.1	0.2	0.1	0.1	nd	0.2	nd	nd	nd	nd	nd
Vitamin D (µg)	0.1	nd	0.06	0.1	nd	1.6	nd	nd	nd	nd	nd
Vitamin K (phylloquinone) (µg)	0.3	nd	0.3	0.2	nd	nd	nd	nd	nd	nd	nd
Vitamin C (mg)	4.7	2.5	0.8	1.2	4.2	3	nd	6.7	2.5-18.4	4.3	1.7-8.1
Thiamine (mg)	0.01	0.05	0.01	0.04	0.07	0.01	0.06	nd	nd	0.03	0.02-0.04
Riboflavin (mg)	0.04	0.11	0.18	0.14	0.36	0.12	0.03	0.06	nd	0.02	0.01-0.03
Niacin (mg)	0.19	0.17	0.11	0.28	0.42	nd	0.09	nd	nd	0.07	nd
Pantothenic acid (mg)	0.24	0.15	0.37	0.31	0.41	nd	nd	nd	nd	nd	nd
Vitamin B6 (mg)	0.01	0.33	0.05	0.05	0.06	0.05	nd	nd	nd	nd	nd
Folate DFE** (µg)	5	1	8	1	7	nd	nd	nd	nd	nd	nd
Vitamin B12 (µg)	0.10	0.50	0.50	0.10	0.70	nd	nd	nd	nd	nd	nd

*Note: * Vitamin A content expressed in retinol equivalents (RAE); ** Dietary folate equivalent; nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - Vitamin not contained.*

Source: Australian Food Composition Database, 2021; Balthazar et al., 2017; FoodData Central USDA, 2021; Frida, 2021; Medhammar et al., 2012; Tabla de Composición de Alimentos Colombianos, 2021.

Table B11 Amino acid composition of meat from ruminant and monogastric livestock species

Amino acid (in g)	Cattle		Buffalo		Sheep											
	avg	avg	avg	Goat	Pig	Horse	Rabbit	Deer	Chicken	Turkey	Quail	Pheasant	Duck	Goose	Pigeon	Guinea fowl
	1.00	nd	nd	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg
Alanine (g)	1.15	1.28	nd	0.54	0.53	1.23	1.25	1.43	0.96	1.22	1.34	1.42	1.11	1.44	1.08	1.13
Arginine (g)	1.31	2.03	nd	1.03	0.60	1.40	1.30	1.65	1.00	1.28	1.38	1.43	1.17	1.45	1.11	1.24
Aspartic Acid (g)	0.23	0.32	nd	0.58	nd	2.10	1.49	2.13	1.59	1.81	1.81	2.28	1.70	2.23	1.46	1.84
Cystine (g)	2.12	2.96	nd	0.25	0.10	0.30	0.26	0.26	0.11	0.21	0.38	0.31	0.25	0.35	0.31	0.26
Glutamic acid (g)	1.24	0.79	nd	0.92	1.41	3.12	3.21	3.34	2.44	3.07	2.82	3.48	2.78	3.56	2.27	3.09
Glycine (g)	0.44	0.68	nd	1.01	0.42	1.03	1.08	1.18	0.86	0.97	1.44	1.04	0.93	1.27	1.16	1.01
Histidine (g)	0.58	1.02	nd	0.29	0.38	0.82	0.72	1.14	0.53	0.61	0.83	0.94	0.50	0.60	0.66	0.64
Isoleucine (g)	1.20	1.76	nd	0.63	0.44	1.01	1.09	0.91	0.57	0.65	1.19	1.32	0.96	1.17	0.96	1.09
Leucine (g)	1.16	1.61	nd	1.08	0.76	1.70	1.66	1.95	1.22	1.57	1.87	2.00	1.52	1.92	1.50	1.55
Lysine (g)	0.43	0.51	nd	0.99	0.82	1.82	1.79	2.01	1.31	1.87	1.90	2.16	1.53	1.95	1.53	1.75
Methionine (g)	0.64	0.82	nd	0.33	0.25	0.47	0.55	0.566	0.40	0.59	0.69	0.69	0.49	0.62	0.55	0.57
Phenylalanine (g)	0.92	0.78	nd	0.48	0.38	0.88	0.81	0.94	0.58	0.73	0.94	0.92	0.77	0.954	0.76	0.82
Proline (g)	0.57	0.88	nd	0.64	0.37	0.99	0.89	1.18	0.67	1.22	0.80	0.86	0.84	1.12	0.64	0.85
Serine (g)	0.47	0.98	nd	0.29	0.39	0.82	0.95	0.97	0.72	0.90	1.06	1.01	0.79	0.98	0.85	0.71
Threonine (g)	0.17	0.25	nd	0.61	0.41	0.96	1.04	1.08	0.69	0.82	1.09	1.18	0.87	0.97	0.53	0.87
Tryptophan (g)	0.38	0.82	nd	0.20	0.11	0.265	0.27	nd	0.12	0.24	0.30	0.33	0.24	0.32	0.27	0.24
Tyrosine (g)	0.92	1.08	nd	0.79	0.37	0.67	0.75	0.81	0.49	0.67	1.01	0.77	0.68	0.87	0.81	0.70
Valine (g)																

Note: Nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - amino acid not contained.
Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B12 Fat and fatty-acid composition of meat from livestock species

Fat/Fatty acid (in g)	Cattle	Buffalo	Sheep	Goat	Pig	Horse	Rabbit	Deer	Chicken	Turkey	Quail	Pheasant	Duck	Goose	Pigeon	Guinea fowl
	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg
SFA (g)	18.74	0.46	27.175	12.5	22	1.44	1.22	0.95	4.73	0.46	2.31	1.24	2.02	2.79	4.40	0.64
SFA 4:0 (g)	nd	nd	nd	nd	-	nd	nd	-	nd	-	nd	nd	nd	nd	nd	nd
SFA 6:0 (g)	nd	nd	nd	nd	-	nd	nd	-	nd	-	nd	nd	nd	nd	nd	nd
SFA 8:0 (g)	nd	nd	nd	nd	-	nd	nd	-	nd	-	nd	nd	nd	nd	nd	nd
SFA 10:0 (g)	nd	nd	nd	nd	0.05	nd	nd	-	nd	0	nd	-	nd	-	nd	-
SFA 12:0 (g)	nd	nd	nd	nd	0.05	0.01	nd	-	nd	0	nd	0.05	nd	0.03	nd	0.01
SFA 14:0 (g)	nd	0.01	nd	nd	0.83	0.17	nd	0.02	nd	0.01	nd	0.03	nd	0.03	nd	0.02
SFA 15:0 (g)	nd	nd	nd	nd	0.04	nd	nd	nd	nd	0	nd	nd	nd	nd	nd	nd
SFA 16:0 (g)	nd	0.25	nd	nd	13.6	1.08	nd	0.41	nd	0.29	nd	0.75	nd	1.47	nd	0.42
SFA 18:0 (g)	nd	0.19	nd	nd	7.07	0.16	nd	0.51	nd	0.14	nd	0.36	nd	0.92	nd	0.18
SFA 20:0 (g)	nd	nd	nd	nd	0.12	nd	nd	nd	nd	0	nd	nd	nd	nd	nd	nd
SFA 4:0 (g)	-	nd	nd	-	-	nd	-	-	nd	-	-	nd	-	nd	-	nd
SFA 6:0 (g)	-	nd	nd	-	-	nd	-	-	nd	-	-	nd	-	nd	-	nd
SFA 8:0 (g)	-	nd	nd	-	-	nd	-	-	nd	-	-	nd	-	nd	-	nd
SFA 10:0 (g)	-	nd	nd	-	0.05	nd	-	-	-	0	-	-	-	-	-	-
SFA 12:0 (g)	-	nd	nd	-	0.05	0.01	0.01	-	-	0	0.02	0.05	0.02	0.03	-	0.01
SFA 14:0 (g)	1.65	0.01	1.99	0.06	0.83	0.17	0.10	0.02	0.15	0.01	0.02	0.03	0.03	0.03	0.08	0.02
SFA 16:0 (g)	10.18	0.25	11.88	5.18	13.6	1.08	0.9	0.41	3.53	0.29	1.57	0.75	1.20	1.47	3.22	0.42
SFA 18:0 (g)	6.05	0.19	11.93	5.97	7.07	0.16	0.205	0.51	0.98	0.14	0.63	0.36	0.62	0.92	1.09	0.18
MUFA (g)	18.43	0.42	22.41	8.31	28.00	1.61	1.05	0.67	9.30	0.48	2.9	1.17	2.73	1.85	8.40	0.68
MUFA 14:1 (g)	nd	nd	nd	nd	0.02	nd	nd	nd	nd	0	nd	nd	nd	nd	nd	nd
MUFA 16:1 (g)	nd	0.03	nd	nd	1.28	0.31	nd	0.03	nd	0.04	nd	0.2	nd	0.27	nd	0.09
MUFA 18:1 (g)	nd	0.37	nd	nd	26.30	1.3	nd	0.63	nd	0.42	nd	0.96	nd	1.58	nd	0.57
MUFA 20:1 (g)	nd	nd	nd	nd	0.48	nd	nd	-	nd	0.01	nd	-	nd	-	nd	0.01
MUFA 22:1 (g)	nd	nd	nd	nd	nd	nd	nd	-	nd	0	nd	-	nd	-	nd	-
MUFA 16:1 (g)	1.58	0.03	0.74	0.53	1.28	0.31	0.12	0.03	0.86	0.04	0.42	0.20	0.19	0.27	1.56	0.09
MUFA 18:1 (g)	15.94	0.37	21.16	7.52	26.30	1.30	0.89	0.63	8.36	0.42	2.44	0.96	1.93	1.58	6.78	0.57
MUFA 20:1 (g)	0.07	nd	nd	-	0.48	nd	0.01	-	-	0.01	0.02	-	0.01	-	0.03	0.01
MUFA 22:1 (g)	-	nd	nd	-	-	nd	-	-	-	-	-	-	-	-	-	-
PUFA (g)	1.08	0.27	3.18	0.58	13.20	0.65	0.805	0.47	4.55	0.41	1.87	0.62	0.76	0.90	2.30	0.59
PUFA 18:2 (g)	1.55	0.16	1.63	0.38	11.80	0.29	0.61	0.31	4.11	0.34	1.58	0.54	0.65	0.80	1.93	0.40
PUFA 18:3 (g)	0.24	0.04	1.25	0.14	0.59	0.36	0.13	0.07	0.24	0.017	0.095	0.08	0.06	0.1	0	0.02

Fat/Fatty acid (in g)																
	Cattle	Buffalo	Sheep	Goat	Pig	Horse	Rabbit	Deer	Chicken	Turkey	Quail	Pheasant	Duck	Goose	Pigeon	Guinea fowl
	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg
PUFA 18:4 (g)	-	nd	nd	0.06	-	nd	nd	-	nd	-	nd	nd	-	nd	nd	nd
PUFA 20:4 (g)	-	0.07	-	-	0.18	nd	0.07	0.1	0.1	0.03	0.11	-	0.04	-	0.11	0.07
PUFA 2:5 n-3 (EPA) (g)	-	nd	nd	nd	-	nd	nd	-	-	-	0.01	-	-	-	0.01	0.01
PUFA 22:5 n-3 (DPA) (g)	-	nd	0.14	0.08	0.05	nd	0.02	-	-	0	0.01	-	-	-	0.05	0.02
PUFA 22:6 n-3 (DHA) (g)	-	nd	0	0	0.02	nd	0	-	-	0	0.02	-	0	-	0.02	0.03
Fatty acids, total trans (g)	3.02	nd	5.16	4.12	0.60	nd	0.01	nd	nd	0	0.06	nd	0.03	nd	0.11	nd
Cholesterol (mg)	135	46	70	93	72	52	62	85	143	67	85	66	94	84	87	63
Choline (mg)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Note: Nutrient values are expressed per 100 gram edible portion on fresh weight basis; SFA = saturated fatty acids; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid; slaughter weight and degree of maturity at slaughter weight influences fat composition; nd = no value in common data sources; - fatty acid not contained.
Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B13 Mineral composition of meat from ruminant and monogastric livestock species

	Mineral	Calcium (mg)	Magnesium (mg)	Phosphorus (mg)	Potassium (mg)	Sodium (mg)	Iron (mg)	Zinc (mg)	Copper (mg)	Manganese (mg)	Selenium (µg)	Iodine (µg)
Cattle	avg	246	13	206	219	41	3.48	2.26	0.03	0.01	10.4	2.2
	range	6-485	9-17	87-324	180-277	25-57	1.30-5.67	0.94-3.58	0-0.056	0-0.012	0-20.7	nd
Buffalo	avg	12	32	197	297	53	1.61	1.93	0.15	nd	9.0	nd
Goat	avg	13	7	129	255	64	2.41	2.60	0.14	0.02	7.2	11
	range	nd	nd	78-180	125-255	45-82	2.00-2.83	1.20-4.00	0.041-0.256	0-0.04	5.6-8.8	nd
Sheep	avg	8	7	72	111	28	0.59	0.76	-	-	5.0	0
	range	5-10	6-8	56-88	91-130	22-33	0.41-0.77	0.54-0.99	nd	nd	0-10	nd
Deer	avg	5	23	202	318	51	3.40	2.09	0.25	0.04	9.7	nd
Horse	avg	6	24	221	360	53	3.82	2.90	0.14	0.02	10.1	nd
Pig	avg	14	6	84	333	47	0.26	0.60	0.07	0	9	nd
Rabbit	avg	11	23	212	350	23	1.28	1.58	0.11	0.01	24.4	nd
	range	9-13	19-26	210-213	300-370	41-53	1.00-1.57	1.57-1.60	0.07-0.15	0-0.03	23.7-25	nd
Chicken	avg	187	12	132	104	40	1.22	1.90	0.07	0.02	15.7	nd
Duck	avg	9	19	186.5	270.5	82.5	2.10	1.95	0.25	0.1	19.45	-
	range	7-11	nd	170-203	270-271	74-91	1.80-2.40	1.90-2.00	0.25-0.25	0-0.02	13.9-19.5	-
Goose	avg	13	24	312	420	87	2.57	2.34	0.31	0.02	16.8	nd
Guinea fowl	avg	11	24	169	220	69	0.77	1.20	0.04	0.02	17.5	nd
Pheasant	avg	13	20	230	262	37	1.15	0.97	0.07	0.02	16.2	nd
Pigeon	avg	13	21.5	234	218	59.5	3.45	2.45	0.59	0.02	13.4	1.3
	range	nd	18-25	161-307	199-237	51-68	2.4-4.51	2.20-2.70	nd	nd	13.3-13.5	nd
Quail	avg	10	25	259	369	48	2.91	1.72	0.35	0.01	16.2	nd
	range	6-13	24-25	210-307	237-369	45-51	1.30-4.51	0.74-2.70	0.1-0.59	0-0.02	15-17.4	nd
Turkey	avg	11	27	190	235	118	0.86	1.84	0.08	0.01	22.6	nd

Note: Nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - mineral not contained.

Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B14 Vitamin composition of meat from ruminant and monogastric livestock species

Vitamin		Vitamin A RAE* (µg)	Vitamin E (alphatocopherol) (mg)	Vitamin D (µg)	Vitamin K (phylloquinone) (µg)	Vitamin C (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Pantothenic acid (mg)	Vitamin B6 (mg)	Folate DFE ** (µg)	Vitamin B12 (µg)
Cattle	avg	-	0.7	1.0	nd	-	0.04	0.08	2.27	0.27	0.30	5	2.7
	range	-	nd	nd	nd	nd	0-0.07	0.05-0.11	2.00-2.55	0.279-0.28	0.29-0.30	5-10	2.6-2.9
Buffalo	avg	-	nd	nd	nd	-	0.04	0.2	5.97	0.16	0.53	8	1.7
Sheep	avg	42	0.9	0.7	nd	-	-	0.07	3.50	0.45	0.10	2	1.5
	range	34-64	0.7-1.1	nd	nd	nd	nd	nd	2.00-5.00	0.43-0.46	nd	0-4	0.1-2.9
Goat	avg	33	3.7	2.0	nd	-	0.07	0.26	2.62	0.14	0.02	13	1.3
	range	0-66	nd	nd	nd	nd	0.11-0.03	0.03-0.49	1.50-3.75	nd	Nd	5-20	1.1-1.5
Deer	avg	-	0.2	nd	1.1	-	0.22	0.48	6.37	nd	0.37	4	6.3
Horse	avg	-	nd	nd	nd	1.0	0.13	0.1	4.60	nd	0.38	nd	3
Pig	avg	26	0.4	1.7	-	-	0.16	0.09	2.63	0.43	0.14	-	0.7
Rabbit	avg	5	0.9	1.6	nd	-	0.08	0.11	7.38	0.67	0.38	8	6.2
	range	0-10	nd	nd	nd	nd	0.1-0.06	0.06-0.15	7.27-7.50	0.53-0.80	0.25-0.50	nd	5.3-7.2
Chicken	avg	45	nd	nd	nd	2.0	0.1	0.14	5.25	nd	0.28	5	0.3
Duck	avg	21	0.6	0.2	2.8	2.9	0.34	0.33	4.90	1.50	0.22	12.5	0.6
	range	18-24	0.4-0.7	0.1-0.2	nd	0-5.8	0.32-0.36	0.2-0.45	4.5-5.30	1.40-1.60	0.10-0.34	0-25	0.4-0.7
Goose	avg	12	nd	nd	nd	7.2	0.13	0.38	4.28	1.97	0.64	31	0.5
Guinea fowl	avg	12	nd	nd	nd	1.7	0.07	0.11	8.78	0.94	0.47	6	0.4
Pheasant	avg	50	nd	nd	nd	6.0	0.08	0.15	6.76	0.96	0.74	6	0.8
Pigeon	avg	51	0.3	0.6	nd	6.1	0.25	0.25	6.45	0.79	0.47	7	0.4
	range	28-73	nd	nd	nd	nd	0.21-0.28	0.22-0.29	6.05-6.86	nd	0.41-0.53	6-7	0.4-0.5
Quail	avg	19	0.8	0.6	nd	7.2	0.19	0.39	7.40	1.14	0.60	4	0.8
	range	17-20	nd	nd	nd	nd	0.1-0.28	0.29-0.51	6.60-8.20	0.78-1.50	0.53-0.68	0-7	0.5-1.2
Turkey	avg	9	0.1	0.2	-	-	0.05	0.19	8.10	0.84	0.65	7	1.2

*Note: * Vitamin A content expressed in retinol equivalents (RAE); ** Dietary folate equivalent; nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - vitamin not contained.*

Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B15 Amino acid composition of selected offals from ruminant and monogastric livestock species

Amino acid (in g)	Large ruminant	Small ruminant	Monogastric				
	Cattle liver	Sheep kidney	Pig liver	Pig kidney	Chicken liver	Turkey liver	Goose liver
Alanine (g)	1.16	0.85	1.28	1.04	0.99	0.99	0.95
Arginine (g)	1.24	0.91	1.32	1.01	1.09	1.09	1.00
Aspartic Acid (g)	1.93	1.36	1.94	1.55	1.59	1.59	1.56
Cystine (g)	0.38	0.18	0.40	0.36	0.27	0.27	0.22
Glutamic acid (g)	2.61	1.71	2.78	1.96	2.09	2.09	2.12
Glycine (g)	1.16	0.915	1.24	1.04	0.85	0.85	0.95
Histidine (g)	0.63	0.40	0.58	0.40	0.51	0.51	0.44
Isoleucine (g)	0.96	0.63	1.08	0.88	0.81	0.81	0.87
Leucine (g)	1.91	1.18	1.91	1.48	1.51	1.51	1.48
Lysine (g)	1.61	1.02	1.65	1.18	1.33	1.33	1.24
Methionine (g)	0.54	0.32	0.53	0.35	0.43	0.43	0.39
Phenylalanine (g)	1.08	0.73	1.05	0.78	0.82	0.82	0.82
Proline (g)	0.96	0.81	1.15	1.02	0.73	0.73	0.81
Serine (g)	0.91	0.73	1.16	0.87	0.74	0.74	0.71
Threonine (g)	0.87	0.74	0.91	0.68	0.73	0.73	0.73
Tryptophan (g)	0.26	0.21	0.30	0.21	0.18	0.18	0.23
Tyrosine (g)	0.80	0.55	0.73	0.59	0.65	0.65	0.58
Valine (g)	1.26	0.92	1.32	0.95	0.10	1.00	1.03

Note: Nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - amino acid not contained.

Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021..

Table B16 Fat and fatty acid composition of selected offals from ruminant and monogastric livestock species

Fat/Fatty acid (in g)	Large ruminant		Small ruminant	Monogastric				
	Cattle liver	Cattle kidney	Sheep kidney	Pig liver	Pig kidneys	Chicken liver	Turkey liver	Goose liver
SFA (g)	1.23	0.87	1.00	1.17	1.04	1.45	1.66	1.59
SFA 4:0 (g)	-	-	nd	-	-	-	-	nd
SFA 6:0 (g)	-	-	nd	-	-	-	-	nd
SFA 8:0 (g)	-	-	nd	-	-	-	-	nd
SFA 10:0 (g)	-	-	nd	-	-	-	-	-
SFA 12:0 (g)	-	-	0.01	-	0.01	0	0	0
SFA 14:0 (g)	0.02	0.02	0.03	0.02	0.04	0.01	0.012	0.01
SFA 16:0 (g)	0.31	0.39	0.42	0.44	0.58	0.88	0.89	0.80
SFA 18:0 (g)	0.86	0.37	0.52	0.7	0.41	0.66	0.66	0.76
MUFA (g)	0.48	0.59	0.63	0.52	1.07	1.16	0.82	0.81
MUFA 16:1 (g)	0.04	0.04	0.04	0.03	0.09	0.11	0.11	0.06
MUFA 18:1 (g)	0.42	0.54	0.55	0.46	0.97	1.13	1.13	0.74
MUFA 20:1 (g)	0.01	0.01	-	-	0.02	0.02	0.02	0.01
MUFA 22:1 (g)	-	-	0.01	-	-	-	-	-
PUFA (g)	0.47	0.55	0.55	0.87	0.26	1.01	1.68	0.26
PUFA 18:2 (g)	0.30	0.29	0.21	0.35	0.17	0.44	0.48	0.18
PUFA 18:3 (g)	0.02	0.01	0.07	0.03	0.01	0.01	0.01	0.01
PUFA 18:4 (g)	-	-	nd	-	-	-	-	nd
PUFA 20:4 (g)	0.14	0.23	0.14	0.44	0.08	0.32	0.33	0.07
PUFA 2:5 n-3 (EPA) (g)	-	-	0.05	-	-	nd	-	-
PUFA 22:5 n-3 (DPA) (g)	-	-	0.04	0.03	-	-	-	-
PUFA 22:6 n-3 (DHA) (g)	-	-	0.03	0.02	-	-	-	-
Fatty acids, total trans (g)	0.17	0.1	nd	nd	nd	0.07	0.07	nd
Cholesterol (mg)	275	411	337	301	319	345	345	515
Choline (mg)	333	nd	nd	nd	nd	nd	nd	nd

Note: Nutrient values are expressed per 100 gram edible portion on fresh weight basis; SFA = saturated fatty acids; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid; slaughter weight and degree of maturity at slaughter weight influences fat composition; nd = no value in common data sources; - fatty acid not contained.

Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021..

Table B17 Mineral composition of selected offals from ruminant and monogastric livestock species

Mineral		Calcium (mg)	Magnesium (mg)	Phosphorus (mg)	Potassium (mg)	Sodium (mg)	Iron (mg)	Zinc (mg)	Copper (mg)	Manganese (mg)	Selenium (µg)	Iodine (µg)
Large ruminant	Cattle liver	5	18	387	313	69	4.90	4.0	9.80	0.30	39.7	nd
	Cattle kidneys	13	17	257	262	182	4.60	1.92	0.40	0.10	141.0	nd
Small ruminant	Sheep kidneys	13	17	246	277	156	6.38	2.24	0.40	0.10	127.0	nd
Monogastric	Pig liver	9	18	288	273	87	23.30	5.76	0.68	0.30	52.7	nd
	Pig kidneys	9	17	204	229	121	4.89	2.80	0.60	0.12	190.0	nd
	Chicken liver	6	19	299	230	69	5.20	3.10	0.40	0.30	54.6	1.4
	Turkey liver	20	19	297	230	71	8.94	3.40	0.50	0.26	54.6	nd
	Goose liver	43	24	261	230	140	30.50	3.10	7.52	-	68.1	nd

Note: Nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - mineral not contained.
Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Table B18 Vitamin composition of selected offals from ruminant and monogastric livestock species

Vitamins		Vitamin A (µg) RAE*	Vitamin E (alphatocopherol) (mg)	Vitamin D (µg)	Vitamin K (phylloquinone) (µg)	Vitamin C (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Pantothenic acid (mg)	Vitamin B6 (mg)	Folate DFE** (µg)	Vitamin B12 (µg)
Large ruminant	Cattle liver	4970	0.4	1.2	3.1	1.3	0.19	2.76	13.20	7.17	1.08	290	59.30
Small ruminant	Cattle kidney	419	0.2	1.1	0	9.4	0.36	2.84	8.03	3.97	0.665	98	27.50
Monogastric	Sheep kidney	95	nd	nd	nd	11.0	0.62	2.24	7.51	4.22	0.22	28	52.40
	Pig liver	6500	nd	nd	nd	25.3	0.28	3.00	15.30	6.65	0.69	212	26.00
	Pig kidney	59	nd	nd	nd	13.3	0.34	1.70	8.21	3.13	0.44	42	8.49
	Chicken liver	7650	0.6	-	-	18.0	0.31	1.78	9.73	5.62	0.85	1019	16.60
	Turkey liver	8060	0.7	-	-	17.90	0.31	1.78	9.73	6.23	0.85	677	19.70
	Goose liver	9310	nd	nd	nd	4.50	0.56	0.89	6.50	6.18	0.76	738	54.00

*Note: * Vitamin A content expressed in retinol equivalents (RAE); ** Dietary folate equivalent; nutrient values expressed per 100 gram edible portion on fresh weight basis; nd = no value in common data sources; - vitamin not contained.*
Source: Australian Food Composition Database, 2021; FoodData Central USDA, 2021.

Annex Tables Section C

Table C1 Contribution of selected food to recommended nutrient intake of vitamin A

Life cycle phase	Vitamin A (a,b) (µg RE/day)	Beef (%)	Chicken egg (%)	Cow milk (%)	Insects (%)	Yoghurt (%)	Tuna (%)	Carrot (%)	Dark green leafy vegetables (%)	Pulses (%)	Tomato (%)	Whole grains (%)
Infant (7-12 months)	400	0	18	5	0	5	82	104	35	0	9	0
Children (1-3 years)	400	0	18	5	0	5	82	104	35	0	9	0
Children (4-6 years)	450	0	16	5	0	4	73	93	31	0	8	0
Children (7-9 years)	500	0	15	4	0	4	66	84	28	0	8	0
Adolescent females (10–18 years)	600	0	24	7	0	6	109	139	47	0	13	0
Adolescent males (10–18 years)	600	0	24	7	0	6	109	139	13	0	13	0
Adult females (19-50 years) (premenopausal)	500	0	29	9	0	7	131	167	2	0	15	0
Adult females (51-65 years) (menopausal)	500	0	29	9	0	7	131	167	0	0	15	0
Adult males (19-65 years)	600	0	24	7	0	6	109	139	0	0	13	0
Older females (65+ years)	600	0	24	7	0	6	109	139	0	0	13	0
Older males (65+ years)	600	0	24	7	0	6	109	139	0	0	13	0
Pregnant women	800	0	18	5	0	5	82	104	0	0	9	0
Lactating women	850	0	17	5	0	4	77	98	0	0	9	0

Note: For infants and children the seving was 50g while for the other life phase groups the serving was 100g.
(a) Vitamin A values are "recommended safe intakes" instead of RNIs.
(b) Recommended safe intakes as mg retinol equivalent (RE)/day; conversion factors are as follows: 1mg retinol = 1 RE; 1mg b-carotene = 0.167mg RE; 1mg other provitamin A carotenoids = 0.084mg RE.
Source: Adapted from WHO and FAO, 2004; USDA, 2021; Weru, Chege and Kinyuru, 2021.

Table C2 Contribution of selected food to recommended nutrient intake of vitamin B12

Life cycle phase	Vitamin B12 (µg/day)	Beef (%)	Chicken egg (%)	Cow milk (%)	Insects (%)	Yoghurt (%)	Tuna (%)	Carrot (%)	Dark green leafy vegetables (%)	Pulses (%)	Tomato (%)	Whole grains (%)
Infant (7-12 months)	0.7	195	82	33	nd	31	674	0	0	0	0	0
Children (1-3 years)	0.9	152	64	26	nd	24	524	0	0	0	0	0
Children (4-6 years)	1.2	114	48	19	nd	18	393	0	0	0	0	0
Children (7-9 years)	1.8	76	32	13	nd	12	262	0	0	0	0	0
Adolescent females (10–18 years)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Adolescent males, (10–18 years)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Adult females, (19-50 years) (premenopausal)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Adult females, (51-65 years) (menopausal)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Adult males (19-65 years)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Older females (65+ years)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Older males (65+ years)	2.4	114	48	19	nd	18	393	0	0	0	0	0
Pregnant women	2.6	105	44	18	nd	17	363	0	0	0	0	0
Lactating women	2.8	98	41	17	nd	16	337	0	0	0	0	0

Note: For infants and children the seving was 50g while for the other life cycle phase groups the serving was 100g; nd: no data available.
Recommended nutrient intake (RNI) is the daily intake which meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population.
Source: Adapted from WHO and FAO, 2004; USDA, 2021; Weru, Chege and Kinyuru, 2021.

Table C3 Contribution of selected food recommended nutrient intake of iron

Life cycle phase	Iron (mg/day) 15% bioavailability	Iron (mg/day) 10% bioavailability	Beef (%)	Chicken egg (%)	Cow milk (%)	Insects (%)	Yoghurt (%)	Tuna (%)	Carrot (%)	Dark green leafy vegetables (%)	Pulses (%)	Tomato (%)	Whole grains (%)
Infants (7-12 months) (a)	6.2	9.3	28	15	1	433	0	8	2	9	33	3	19
Children (1-3 years)	3.9	5.8	45	23	1	688	0	13	3	14	54	4	31
Children (4-6 years)	4.2	6.3	41	22	1	639	0	12	2	13	49	4	28
Children (7-9 years)	5.9	8.9	29	15	1	455	0	9	2	9	35	3	20
Adolescents females (11-14 years) (b)	9.3	14.0	37	20	1	289	0	11	2	12	45	3	25
Adolescents females (11-14 years)	21.8	32.7	16	8	0	123	0	5	1	5	19	1	11
Adolescents females (15-17 years)	20.7	31.0	17	9	0	130	0	5	1	5	20	2	11
Adolescents males (11-14 years)	9.7	14.6	36	19	1	277	0	11	2	11	43	3	24
Adolescents males (15-17 years)	12.5	18.8	28	15	1	215	0	8	2	9	33	3	19
Adult females (19-50 years) (premenopausal)	19.6	29.4	18	9	0	137	0	5	1	6	21	2	12
Adult females (51-65 years) (menopausal)	7.5	11.3	46	24	1	358	0	14	3	15	55	4	32
Adult males (19-65 years)	9.1	13.7	38	20	1	295	0	11	2	12	45	3	26
Older females (65+ years)	7.5	11.3	46	24	1	358	0	14	3	15	55	4	32
Older males (65+ years)	9.1	13.7	38	20	1	295	0	11	2	12	45	3	26
Pregnant women	c	c	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Lactating women (0-3 months)	10.0	15.0	35	18	1	269	0	10	2	11	42	3	24
Lactating women (3-6 months)	10.0	15.0	35	18	1	269	0	10	2	11	42	3	24
Lactatting women (7-12 months)	10.0	15.0	35	18	1	269	0	10	2	11	42	3	24

Note: Bioavailability of TASF = 15%; Bioavailability of PSF = 10%; For infants and children the seving was 50g while for the othr life cycle phase groups the serving was 100g; nd: no data available.

Recommended nutrient intake (RNI) is the daily intake which meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population.

(a) Bioavailability of dietary iron during this period varies greatly.

(b) Pre-menarche.

(c) It is recommended that iron supplements in tablet form be given to all pregnant women because of the difficulties in correctly assessing iron status in pregnancy. In non-anaemic pregnant women, daily supplements of 100mg of iron (e.g. as ferrous sulphate) given during the second half of pregnancy are adequate. In anaemic women higher doses are usually required.

Source: Adapted from WHO and FAO, 2004; USDA, 2021; Weru, Chege and Kinyuru, 2021.

Table C4 Contribution of selected food to recommended nutrient intake of zinc

Life cycle phase	High bioavailability	Moderate bioavailability	Low bioavailability	Beef (%)	Chicken egg (%)	Cow milk (%)	Insects (%)	Yoghurt (%)	Tuna (%)	Carrot (%)	Dark green leafy vegetables (%)	Pulses (%)	Tomato (%)	Whole grains (%)
Infants (7-12 months) (a)	1	4	8	141	76	30	990	37	38	1	2	22	1	14
Infants (7-12 months) (b)	3			45	24	10	317	12	12	1	2	22	1	0
Children (1-3 years)	2	4	8	47	25	10	330	12	13	1	2	22	1	14
Children (4-6 years)	3	5	10	39	21	8	273	10	10	1	2	19	1	12
Children (7-9 years)	3	6	11	34	18	7	240	9	9	1	2	17	1	10
Adolescents females (10-18 years)	4	7	14	53	28	11	368	14	14	2	3	26	1	16
Adolescents males (10-18 years)	5	9	17	44	24	9	311	12	12	1	2	22	1	14
Adults females (19-50 years) (premenopausal)	3	5	10	75	40	16	528	20	20	2	4	38	1	24
Adults females (51-65 years) (menopausal)	3	5	10	75	40	16	528	20	20	2	4	38	1	24
Adults males (19-65 years)	4	7	14	54	29	11	377	14	14	2	3	26	1	17
Older females (65+ years)	3	5	10	75	40	16	528	20	20	2	4	38	1	24
Older males (65+ years)	4	7	14	54	29	11	377	14	14	2	3	26	1	17
Pregnant women first trimester	3	6	11	66	36	14	466	17	18	2	3	34	1	21
Pregnant women second trimester	4	7	14	54	29	11	377	14	14	2	3	26	1	17
Pregnant women third trimester	6	10	20	38	20	8	264	10	10	1	2	18	1	12
Lactating women (0-3 months)	6	10	19	39	21	8	273	10	10	1	2	19	1	12
Lactating women (3-6 months)	5	9	18	43	23	9	299	11	11	1	2	21	1	13
Lactating women (7-12 months)	4	7	14	53	28	11	368	14	14	2	3	26	1	16

Note: TASF: high bioavailability; PSF: low bioavailability; For infants and children the seving was 50g while for the other life cycle phase groups the serving was 100g. Recommended nutrient intake (RNI) is the daily intake which meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population.
(a) Breastfed.
(b) Bioavailability of dietary iron during this period varies greatly.
Source: Adapted from WHO and FAO, 2004; USDA, 2021; Weru, Chege and Kinyuru, 2021.

Table C5 Contribution of selected food to recommended nutrient intake of calcium

Life cycle phase	Calcium (mg/day)	Beef (%)	Chicken egg (%)	Cow milk (%)	Insects (%)	Yoghurt (%)	Tuna (%)	Carrot (%)	Dark green leafy vegetables (%)	Pulses (%)	Tomato (%)	Whole grains (%)
Infants, 7-12 months	400	31	6	14	9	19	1	4	15	15	1	7
Children, 1-3 years	500	25	5	11	7	15	1	3	12	12	1	5
Children, 4-6 years	600	20	4	9	6	13	1	3	10	10	0	4
Children, 7-9 years	700	18	4	8	5	11	1	2	8	9	0	4
Adolescents females, 10-18 years	1300	19	4	9	5	12	1	3	9	9	0	4
Adolescents males, 10-18 years	1300	19	4	9	5	12	1	3	9	9	0	4
Adults females, 19-50 years (premenopausal)	1000	25	5	11	7	15	1	3	12	12	1	5
Adults females, 51-65 years (menopausal)	1300	19	4	9	5	12	1	3	9	9	0	4
Adults males, 19-65 years	1000	25	5	11	7	15	1	3	12	12	1	5
Older females, 65+ years	1300	19	4	9	5	12	1	3	9	9	0	4
Older males, 65+ years	1300	19	4	9	5	12	1	3	9	9	0	4
Pregnant first trimester	a	a	a	a	a	a	a	a	a	a	a	a
Pregnant second trimester	a	a	a	a	a	a	a	a	a	a	a	a
Pregnant third trimester	1200	20	4	9	6	13	1	3	10	10	0	4
Lactating women, 0-3 months	1000	25	5	11	7	15	1	3	12	12	1	5
Lactating women, 3-6 months	1000	25	5	11	7	15	1	3	12	12	1	5
Lactating women, 7-12 months	1000	25	5	11	7	15	1	3	12	12	1	5

Note: For infants and children the seving was 50g while for the other life cycle phase groups the serving was 100g. Recommended nutrient intake (RNI) is the daily intake which meets the nutrient requirements of almost all (97.5%) apparently healthy individuals in an age- and sex-specific population.

(a) Not specified.

Source: Adapted from WHO and FAO, 2004; USDA, 2021; Weru, Chege and Kinyuru, 2021.

Table C6 Evidence for health effects of terrestrial animal source food by life cycle phase

Food	**Comparator**	**Specific findings**	**Sample size**	**Country of study**	**Study design**[1]	**Reference**
Women during pregnancy and lactation, including foetus and breastfeeding child through 6 months						
Milk, dairy products	Lower or no intake of milk and dairy products	For mothers with higher intakes of milk and dairy products during pregnancy: 1. Increased birth weight 2. Increased infant length 3. Reduced risks for small-for-gestational age 4. Reduced risks for low birth weight 5. Increased risk for large-for-gestational age 6. No effect of milk and dairy on standard ultrasound measures of the foetal size	111 184 pregnant women	Canada, China, Denmark, India, Malawi, Netherlands, New Zealand, Spain, Sweden, United Kingdom, United States of America	Systematic review and meta-analysis (14 studies: 1 quasi randomized trial; 4 retrospective cohort; 9 prospective cohort)	Pérez-Roncero et al., 2020
	Various (lower intakes of milk; fortified milk; varying fat levels of dairy; total and median dairy intake)	1. Maternal milk intake during pregnancy is positively associated with infant birth weight and length. 2. No conclusion drawn on related to preterm deliveries, spontaneous abortion, and lactation due to limited evidence.	>237 555 women	China, Denmark, India, Iran, Italy, Malawi, Netherlands, Portugal, Spain, Sweden, United States of America	Systematic review (17 studies: 3 intervention; 6 prospective cohort; 3 retrospective cohort and 2 case-control)	Achón et al., 2019
	0-1 glass of milk per day	1. For mothers who consumed ≥3 glasses of milk per day: 2. Greater foetal weight gain in third trimester of pregnancy 3. Higher birth weight by 88g 4. Larger foetal head circumference by 2.3cm 5. No associations found between milk consumption and femur length. 6. Maternal protein intake from milk was associated with offspring birth weight.	3 405 pregnant women	Netherlands	Observational (Prospective Cohort Study)	Heppe et al., 2011
	<150ml/day of milk	1. For mothers who consumed ≥150ml of milk per day: • Higher z-scores for birth weight (by 0.32 z-scores) • Higher z-scores for birth length (by 0.34 z-scores) • For offspring of mothers who consumed ≥ 150ml of milk per day, at 20 years of follow-up: • Higher z-scores for height (by 0.19 z-scores) • Higher levels of insulin-like growth factor-1 (IGF-1) • Higher levels of insulin	809 pregnant women	Denmark	Observational (Prospective Cohort Study)	Hrolfsdottir et al., 2013

[1] including number of embedded studies if systematic review;

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
	Intake of milk, gram per day	1. Positive association between intake of milk products during the first trimester of pregnancy and infant BW. 2. Positive association between percent intake of protein from milk products and infant BW. 3. Positive association between intake of milk products during the third trimester of pregnancy and GWG. 4. Positive association between percent intake of protein from milk products during the third trimester of pregnancy and GWG. 5. No associations between % intake of vitamin B12 from milk products and infant BW nor GW.	2036 live births	India	Observational (Prospective Cohort Study)	Mukhopadhyay et al., 2018
	Intake of milk, gram per day	1. Positive association between maternal dairy intake in first trimester and head circumference of offspring. 2. Increased dairy intakes between first and second and first trimester was associated with lower maternal weight gain during pregnancy.	98 pregnant women	Portugal	Observational (Prospective Cohort Study)	Abreu et al., 2017
	Parallel group design: 1. Milk with folic acid supplement 2. Folic acid supplement alone 3. Milk alone 4. Control	1. Increased serum folate (vitamin B9) concentrations at 16 and 32 weeks of pregnancy and cord blood at birth.	4 052 pregnant women	China	Parallel randomised trial	Li et al., 2014
Infants and young children						
Non-specific	Various (cereal-based foods, no intervention)	1. Significant increases in change in height-for-age Z score or length-for-age Z score in intervention groups compared to controls associated with TASF consumption (3 studies). 2. Significant increases in change in weight-for-age Z score associated with TASF consumption (3 studies). 3. Yogurt associated with significant reduction in duration and incidence of diarrhoea and upper respiratory infections. 4. Eggs during associated with increase in diarrhoeal morbidity compared to control. 5. Meat- and dairy-based diets:	3 036 children	China, the Democratic Republic of Congo, Ecuador, Guatemala, Pakistan, United States of America and Zambia	Systematic review (6 studies: all randomized controlled or quasi-randomized controlled trials)	Eaton et al., 2019

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
		1. Associated with increases in length-for-age Z scores. 2. No significant associations with weight-for-age Z scores.				
Non-specific	Various (usual diet, fortified and non-fortified cereals)	1. Reduced stunting associated with TASF consumption (2 studies) 2. Non-significant asociations with anaemia, height/weight, and head circumference.	Average sample size per region: Latin America and the Caribbean=1 367; Sub-Saharan Africa=6 749; South Asia=5 343; East Asia and the Pacific=2 904	Bangladesh, Cambodia, China, Ecuador, Indonesia, Jamaica, Kenya, Mexico, Myanmar, Nepal, Peru, Senegal, Uganda	Systematic review (21 studies: 7 randomized controlled trials; 14 observational—longitudinal cohort and cross-sectional studies)	Shapiro et al., 2019
Milk, dairy products	Intake of milk, ml per day	1. Increases in child height by 0.4cm per year compared for increases in 245ml of milk consumed daily. 2. Increased growth from milk consumption for children with stunted growth. 3. Greater effect of milk on height compared to other dairy products.	Range: 36 to 757 participants	China, India, Indonesia, Kenya, North Vietnam, United States of America, Europe	Systematic review and meta-analysis (12 studies: 7 randomised controlled trials; 5 non- randomised controlled trials)	de Beer, 2012
Meat	Various, fortified cereal, low meat, no intervention	1. Meat consumption associated with reduced risk of iron deficiency among breastfeeding infants who had low iron intake or were at risk of inadequate iron stores during the first year of life. 2. Limited evidence for meat's impact on infant zinc status during the complementary feeding.	1792 children (studies on meat only)	Australia, Austria, Canada, Colombia, Denmark, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, New Zealand, Portugal, Spain, Sweden, United Kingdom, United States of America	Systematic review (15 studies specifically on meat consumption: 8 randomised controlled trials; 7 prospective cohort studies)	Obbagy et al., 2019

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Milk, dairy products	Parallel design: 1. FVF group (3.5g fat/dl; 100% vegetable fat from palm-, coconut- and soybean oil) 2. LF milk (1g cow's milk fat/dl) 3. SF (3.5g cow's milk fat/dl) 4. PVF (3.5g fat/dl; 50% vegetable fat from rapeseed oil, 50% milk fat)	1. Higher amounts of plasma LA in (4) FVF group compared to LF and SF milk groups. 2. Higher amounts of plasma ALA in group PVF compared to SF milk for triglycerides and cholesterolesters. 3. Higher amounts of plasma ALA in group PVF milk compared to LF milk for phospholipids and cholesterolesters. 4. Similar amounts of plasma AA and plasma DHA in phospholipids and cholesterolesters across milk groups. 5. Lower plasma trans fatty acids in cholesterolesters for PVF and FVF milk groups compared to SF. 6. Higher plasma concentrations of of α-tocopherol in FVF group compared to other groups.	37 1-year-old children	Sweden	Parallel randomized trial	Svahn et al., 2002
Eggs	No intervention	1. Increased length-for-age by 0.63 for children in egg intervention group. 2. Stunting reduced by 47 percent from egg intervention. 3. Increased plasma concentrations of DHA and choline.	163 children	Ecuador	Randomized controlled trial	Iannotti et al., 2017a, 2017b
Eggs	No intervention	1. No significant effect of eggs on growth. 2. No significant effect of eggs on developmental outcomes.	660 children	Malawi	Randomized controlled trial	Prado et al., 2020; Stewart et al., 2019
Meat	Fortified cereal	1. No significant differences in linear growth velocity between meat group and comparator. 2. No significant differences in anemia meat group and comparator.	532 infants	Democratic Republic of Congo, Guatemala, Pakistan, and Zambia	Randomized controlled trial	Krebs et al., 2012
Insects, insect product	No intervention (usual diet)	1. At 18 months old: 2. No difference in stunting prevalence at between the intervention (caterpillar cereal) and control groups 3. Increased haemoglobin levels in the intervention group compared to control 4. Significantly lower anaemia prevalence in intervention group compared to control group 5. No difference in estimates of iron stores between the intervention and control groups	175 infants	Democratic Republic of Congo	Cluster-randomised trial	Bauserman et al., 2015
Honey	Intervention group: honey as much as 45g	1. For children receiving 45g of honey per day (15g, 3x1 doses) for 2 months:	60 children	Indonesia	Quasi-experimental design	Harmiyati et al., 2017

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
	per day for 2 months with drinking dose 3x1 Control group: formula milk, as much as 8 boxes of milk (60cc per day 3x1 doses) for 2 months	2. Significantly higher weight, height, weight-for-height z-score, weight-for-age z-score and height-for-age z-score compared to control				
School age children and adolescents						
Milk, dairy products	Lowest level of dairy intake or each 1 serving/day increment in dairy consumption	6. For children in the highest group of milk consumption: 7. 38% reduced risk for overweight/obesity compared to the lowest intake group of dairy consumption 8. Reduced body fat by 0.65% for every unit increase in daily serving of dairy 9. 13% reduced risk of obesity/overweight for every unit increase in daily serving of dairy	46 011 children and adolescents	Australia, China, Sweden, United Kingdom, United States of America	Systematic review and meta-analysis (10 cohort studies)	Lu et al., 2016
Milk, dairy products	Evidence associations between dairy intake and adipositas in pre-schoolers, school-age children and adolescents	1. No significant association between dairy intake and adiposity. 2. Inverse association between dairy intake and adiposity in adolescents.	N/A	Australia, Canada, Hong Kong, Iran, Italy, New Zealand, Portugal, Sweden, United Kingdom, United States of America	Systematic review and meta-analysis (36 studies for systematic review; 22 studies for meta-analysis).	Dror, 2014
Milk, dairy products	Various (specifics not reported)	1. Significant relationship between dairy consumption and bone mineral content and bone mineral density (BMD) (8 studies). 2. Average of 8% increase in BMD after 16 months of dairy consumption (8 studies). 3. No significant relationships between dairy consumption and body size and composition (significant relationships for body size only found in 2 out of 14 trials measuring body size; significant relationships found only in 1 out of 11 trials measuring body composition).	N/A	Chile, China, Finland, Germany, Iran, New Zealand, United States of America, United Kingdom	Systematic review (15 randomised controlled trials)	Kouvelioti, Josse and Klentrou, 2017
Eggs	No egg consumption	1. Positive correlation between egg intake and radius and tibia cortical bone mineral content (Ct.BMC), total bone area, cortical area, cortical thickness, periosteal circumference, and polar strength strain.	294 children (9-13-year old)	United States of America	Cross-sectional	Coheley et al., 2018
Meat	Various, 3 studies with no food as control; fortified cereal, milk	1. One intervention with a non-feeding control arm and found beef consumption to improve cognitive abilities compared to the control.	N/A	Democratic Republic of Congo, Guatemala, Kenya,	Systematic review (8 studies)	An et al., 2019

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
	snack; meal without beef; wheat and soy biscuits	2. Inconsistent results on cognition for studies comparing beef consumption to other food-specific comparators.		Pakistan, United States of America, Zambia		
	Control group with no food; variations of githeri stew (maize, beans, and greens): meat with githeri stew milk with githeri stew, githeri stew alone	1. Children in the meat group performed better in terms of Increased cognitive function in meat group compared to milk or control groups. 2. Increased vitamin B12 plasma concentrations in the meat and milk groups compared to control. 3. Significantly increased arm muscle area and mid-upper arm circumference over time for meat and milk groups compared to the githeri only and control groups. 4. Significantly greater decrease in probability of morbidity outcome (PMO) for total and severe illnesses, malaria, poor appetite, reduced activity, fever and chills in meat group and githeri only group. 5. For eat group, significant declines in PMO for gastroenteritis (diarrhoea) and typhoid compared with the control group, for jaundice compared with the githeri only group, and for skin infection compared with the milk group. 6. Greatest declines in PMO for upper respiratory infection for milk group.	911 school children	Kenya	Randomized controlled trial	Gewa et al., 2009; Hulett et al., 2014; McLean et al., 2007; Neumann et al., 2007, 2013; Whaley et al., 2003
Adults						
Milk, dairy products	Increases of 200g/day of dairy consumption; increases of 200–244g/day of milk consumption; increases of per 10-50g/day of cheese consumption	1. No association between dairy consumption and all-cause mortality.	Ranges: 24 466 participants reporting 5 092 mortality cases to 938 817 participants reporting 126 759 mortality cases.	N/A	Meta-review (8 meta-analyses)	Cavero-Redondo et al., 2019
Milk, dairy products	Increases of 200ml/day of milk	1. For every 200ml/day increase in milk consumption: • Lower risk of cardiovascular disease, stroke, hypertension, colorectal cancer, metabolic syndrome, obesity, diabetes, Alzheimer's disease, and osteoporosis • Increased risk of prostate cancer, Parkinson's	N/A	N/A	Meta-review (41 meta-analyses)	Zhang et al., 2021

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
		disease, and acne				
Milk, dairy products	Increases of 200g/day of high-fat milk consumption; increases of 90g/day of cheese	1. Increase of 200g/d intake of high-fat milk intake positively associated with coronary heart disease. 2. Increase of 90 g/d of cheese associated with reduced the risk of coronary heart disease.	N/A	Denmark, Finland, Greece, Iran, Netherlands, Spain, Sweden, United Kingdom, United States of America of America	Systematic review and meta-analysis (13 cohort studies)	Jakobsen et al., 2021
Milk, dairy products	Increases of 200g/day of dairy consumption; increases of 30g/day of cheese (when servings are not reported); dose-response	1. Decreased risk of hypertension with increased consumption of dairy, low-fat dairy, milk, and fermented dairy. 2. Increased risk of hypertension for women and Americans with increased consumption of dairy. 3. Non-linear relationship between total dairy products and milk consumption and risk of hypertension. 4. Linear association between low-fat dairy intake and hypertension.	N/A	N/A	Systematic review and meta-analysis (16 studies)	Heidari et al., 2021
Milk, dairy products	Lower or no intake of dairy products	1. Dairy intakes for each 200g/d increase reduced risk of type 2 diabetes. 2. Yogurt intakes at 80 g/d versus no intake associated with reduced risk of type 2 diabetes.	79 832 individuals and 43 118 cases with type 2 diabetes	N/A	Systematic review and meta-analysis (22 cohort studies)	Gijsbers et al., 2016
Milk, dairy products	One serving increment per day different dairy products.	1. Yogurt found to be protective against type 2 diabetes. 2. Total dairy consumption was not associated with risk of type 2 diabetes. 3. Neither low-fat nor high-fat dairy intake was appreciably associated with risk of T2D.	41 436 men in the Health Professionals Follow-Up Study; 67 138 women in the Nurses' Health Study; 85 884 women in the Nurses' Health Study II	United States of America	Meta-analysis (3 cohort studies)	Chen et al., 2014
Milk, dairy products	Increment in dairy consumption of one serving/d.	1. Higher dairy consumption significantly associated with reduced risk of metabolic syndrome.	N/A	N/A	Systematic review and meta-analysis (15 cross-sectional studies; 1 case-control study; 7 prospective cohort studies)	Chen et al., 2015
Milk, dairy products	Low dairy consumption <400g/day	1. High and modest dairy consumption (>600 and 400–600 g/day, respectively) significantly reduced the	1 566 940 participants (cohort studies);	China, Finland, France, Iran, Japan, Netherlands,	Systematic review and meta-analysis (22 prospective cohort	Zang et al., 2015

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
		risk of breast cancer compared with low dairy consumption. 2. Linear relationship between dairy consumption and breast cancer risk. 3. Yogurt and low-fat dairy associated with reduced the risk of breast cancer. 4. Reduced risk of breast cancer for participants in the United States of America of America and Asia, and in participants followed for 10 years, in association with dairy consumption.	33 372 participants (case-control studies).	Norway, United Kingdom, United States of America	studies;5 case-control studies)	
Milk, dairy products	Lowest category of intake ranging from 0-<407, <2.5-<30, and 0 to <32 g/day for nonfermented milk, solid cheese, and fermented milk, respectively	1. Reduced risk of colorectal cancer in men consuming highest intake of nonfermented milk (average of 525g/day) 2. No association found between consumption of nonfermented milk and rectal cancer in men nor nonfermented milk and colon or rectal cancer in women. 3. No protective association was found between consumption of solid cheese or fermented milk and colorectal cancer.	over 900 000 subjects and over 5 200 colorectal cancer cases	Finland, France, Norway, Switzerland, Sweden, United Kingdom, United States of America	Systematic review and meta-analysis (15 prospective cohort studies)	Ralston et al., 2014
Milk, dairy products	Lowest consumption or for each increment in dose of exposure of dairy	1. Compared to comparator: • Non-significant, reduced risk of osteoporotic fractures for highest intake of dairy. • Reduced risk of hip fractures for highest intake of dairy. • Reduced risk of vertebral fractures. • 1.7–3% lower hip bone mass density in young and postmenopausal women with poor intake of milk in their youth.	N/A	France, Sweden, Switzerland, United States of America	Systematic review and meta-analysis (13 studies, with 9 used for meta-analysis)	Matía-Martín et al., 2019
Milk, dairy products	Lowest intake of dairy; increment of 1 glass per day of milk	1. Higher consumption of yogurt associated with reduced risk of hip fractures. 2. Higher consumption of milk associated with reduced risk of hip fractures in the United States of America of America, but not in Scandinavian countries.	9 564 hip fracture events among 363,383 participants	Scandinavian countries; United States of America	Systematic review and meta-analysis (9 articles)	Hidayat et al., 2020
Milk, dairy products	No dairy intake or less frequent dairy intake	1. Total dairy intake associated with the reduced risk of endometriosis. 2. Decreased risk of endometriosis when intake of dairy products was over 21 servings/week.	N/A	Belgium, Italy, Iran, United States of America	Systematic review and meta-analysis (5 case-control studies)	Qi et al., 2021

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
		3. Possible reduced risk of endometriosis with high cheese intake.				
Milk, dairy products	Consumption of nuts, legumes, or whole grains; consumption of red and processed meat Total dairy consumption (quintiles—lowest quintile: mean of 0.8 servings per day)	1. Lower risk of mortality associated with consumption of nuts, legumes, or whole grains instead of dairy foods. 2. Consumption of red and processed meat instead of dairy was associated with higher mortality.	168 153 women and 49 602 men without cardiovascular disease	United States of America	Prospective cohort study (3 cohort studies)	Ding et al., 2019
Eggs	Various, usual diet, no eggs, egg substitutes, lower eggs, choline supplements, lean animal protein, bagels, oatmeal	1. No significant effect of egg consumption on systolic nor diastolic blood pressure.	748 participants	Australia, Colombia, Mexico, Thailand, United States of America	Systematic review and meta-analysis (15 randomised controlled trials)	Kolahdouz-Mohammadi et al., 2020
Eggs	Various, lower egg consumption	1. No significant association between egg consumption and coronary heart disease nor stroke. 2. Increased risk of coronary heart disease for persons with diabetes in association with egg consumption.	N/A	Japan, United States of America	Meta-analysis (8 articles:17 reports)	Rong et al., 2013
Eggs	Low egg consumption (less than one egg per week)	1. For high egg consumption (more than seven eggs per week), no significant increases in risk for all-cause mortality, mortality from cardiovascular disease, ischemic heart disease, or stroke compared to low egg consumption. 2. Small reduction in stroke risk associated with egg consumption.	28 024 participants without cardiovascular disease at baseline	China	Meta-analysis (Guangzhou Biobank Cohort Study)	Xu et al., 2019
Meat, red and white meat from chicken / poultry, sheep, pig, cattle, goat, fish, seafood, buffalo, kangaroo, camel, deer or rabbit, processed meat	Various (vegetarian, vegan, low meat, alternative protein sources, usual diet, etc.)	1. Positive association between animal flesh intake (85-300g/day) and iron status (5 studies).	N/A	Australia, Austria, Belgium, Canada, Czech Republic, Demark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland,	Systematic review (49 studies: 41 observational; 8 experimental)	Jackson et al., 2016

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
				United Kingdom, United States of America		
Meat, animal husbandry, not direct consumption	Various	1. Interventions trials targeting poultry production showed a positive effect on anaemia among women. 2. Observation studies demonstrated the chicken ownership increased risk for anaemia in young children, potentially arising from increased risk of enteric pathogen exposures.	N/A	Afghanistan, Bangladesh, Burkina Faso, Cambodia, Chad, China, Equatorial Guinea, Ghana, Haiti, Kazakhstan, Kenya, Nepal, Philippines, Thailand	Systematic review (23 articles)	Lambrecht, Wilson and Jones, 2019
Meat, processed and unprocessed red meat	0g of meat/week	1. Higher intakes of processed red meats (≥150g/week versus 0g/week) associated with increased risk of total mortality. 2. Non-significant findings for unprocessed red meat and poultry on the negative health outcomes.	134 297 individuals	21 low-, middle- and high-income countries	Cohort study	Iqbal et al., 2021
Meat, processed and unprocessed red meat	Alternative proteins: plant protein sources (nuts, legumes, and soy); dairy; fish, eggs, poultry Total red meat, processed red meat, and unprocessed red meat consumption (quintiles).	1. Increased risk of cardiovascular disease for one additional daily serving of total red meat, unprocessed red meat, and processed meat. 2. Lower risk of cardiovascular disease for the intake of one serving per day of combined plant protein sources (nuts, legumes, and soy), compared to total red meat, unprocessed red meat, and processed red meat. 3. Substitutions of whole grains and dairy products for total red meat and eggs for processed red meat were associated with lower cardiovascular disease risk.	43 272 men without cardiovascular disease or cancer at baseline	United States of America	Prospective cohort study	Al-Shaar et al., 2020
Meat, processed and unprocessed red meat	Total red meat, processed red meat, and unprocessed red meat consumption (quintiles).	1. For every increase in 100g/d of unprocessed meat and 50g/d of processed meats, there was an increased risk of type 2 diabetes.	37 083 men in the Health Professionals Follow-Up Study (1986–2006); 79 570 women in the Nurses' Health Study I (1980–2008); and 87 504 women in the Nurses' Health Study II	United States of America	Meta-analysis (3 prospective cohort studies)	Papadimitriou et al., 2021

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Meat, red and processed	Evaluation of epidemiological data regarding the association between red and processed meat consumption and cancer	• Classification of processed meat consumption as "carcinogenic to humans" (Group 1) on the basis of sufficient evidence for colorectal cancer • Positive association with the consumption of processed meat was found for stomach cancer • Classification of red meat consumption as "probably carcinogenic to humans" (Group 2A) • Positive association between consumption of red meat and colorectal cancer and the strong mechanistic evidence • Consumption of red meat was also positively associated with pancreatic and with prostate cancer	More than 800 epidemiological studies	Many countries, from several continents, with diverse ethnicities and diets	Monograph critical review	Bouvard et al., 2015
Meat, processed and unprocessed	Increments of daily servings of unprocessed red meats (430.9g/d) and processed meats (421.8g/d).	1. Positive association between increased daily servings of unprocessed red meats (430.9 g/d) and processed meats (421.8g/d) with four-year weight gain.	120 877 women and men	United States of America	Prospective cohort study	Mozaffarian et al., 2011
Meat, processed and unprocessed	Total meat consumption (in quartiles)	1. Total meat consumption, processed meat consumption, and unprocessed meat consumption in the highest quartile was significantly associated with a higher risk of gestational diabetes.	3 298 healthy women	Spain	Prospective cohort study	Marí-Sanchis et al., 2018
Meat, red meat	Less that 0.5 servings (35g)/day of total red meat intake	1. No significant differences in changes for levels of glucose, insulin, Homeostatic Model Assessment of Insulin Resistance, or c-reactive protein.	N/A	N/A	Meta-analysis (24 articles from randomised controlled trials)	O'Connor et al., 2021
Meat, processed	High vegetables and fruit with low processed meat intakes	1. Low co-consumption of fruit and vegetables with high levels of processed meat increased risk of all-cause and 15 cancers compared to high vegetables and fruit with low processed meat intakes.	26 218 adults	Canada	Prospective cohort study	Maximova et al., 2020
Meat, red meat	Alternative protein sources: high-quality plant protein sources (legumes, soy, nuts); chicken/poultry/fish; fish only; poultry only; mixed animal protein sources (including dairy); carbohydrates (low-quality refined grains and simple	1. No differences between red meat and the combined category for all alternative diets for changes in blood concentrations of total, low-density lipoprotein, or high-density lipoprotein cholesterol, apolipoproteins A1 and B, or blood pressure. 2. Lesser decreases in triglycerides for red meat compared to alternative protein sources. 3. Lesser decreases in total cholesterol and low-density lipoprotein compared to high-quality plant protein sources.	1 803 participants	N/A	Meta-analysis (36 randomised controlled trials)	Guasch-Ferré et al., 2019

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
	sugars, such as white bread, pasta, rice, cookies/biscuits); or usual diet	4. Greater decreases in low-density lipoprotein compared to fish.				
Meat, poultry	Lowest category of poultry intake (quintile; never consumed) Increments of one serving per week	1. Reduced, but non-significant total risk of stroke for highest category of poultry intake. 2. No association between increments of one serving per week of poultry and risk of stroke. 3. For studies in the United States of America and for women, reduced total risk of stroke for highest category of poultry intake. 4. Lower risk of stroke at consumption of ~1 serving of poultry per week.	354 718 participants	China, Iran, Japan, United States of America	Systematic review and meta-analysis (7 cohort studies)	Mohammadi et al., 2018
Insect, insect products	Outcomes of interventional studies: effects of the consumption of bee products on CVD risk factors	1. Possible association between natural honey consumption and improved lipid profile as well as anthropometry. 2. Possible association between propolis supplementation and improved lipid profile and glycemic markers. Inconclusive findings on bee products and cardiovascular risk.	N/A	Brazil, Chile, Iran, Japan, Slovenia, Taiwan, Province of China, Turkey	Systematic review (23 interventional studies)	Hadi, Rafie and Arab, 2021
Insect, insect products	Control: Sucrose intake (70g/day)	1. For intervention group receiving 70g/d of honey: 1 Decrease in total cholesterol, triacylglycerol, and LDL cholesterol, whereas these parameters increased in the control group. 2 Increase in HDL cholesterol, whereas these parameters increased in the control group.	60 healthy subjects.	Iran	Randomized controlled trial	Rasad et al., 2018
Insect, insect products	Trial 1: Sucrose intake providing 1.2g of carbohydrate per kg of body weight per day. Trial 2: Clover honey providing 1.2g of carbohydrate per kg of body weight per day.	1. In both trials, no effects on serum concentrations of insulin, total cholesterol, low density lipoprotein-cholesterol, or high density lipoprotein-cholesterol. 2. Significantly reduced intake of carbohydrates, sugars, and saturated fats in honey trial. 3. Increases in serum triglycerides for both trials. 4. Transient increase in body weight for honey trial.	37 healthy adults	United States of America	Randomized crossover trial	Al-Tamimi et al., 2020
Insect, insect products	Breakfast meals without cricket powder	1. 25g/day whole cricket powder found not to be toxic. 2. Increase in probiotic bacterium, Bifidobacterium animalis by 5.7-fold for intervention group.	20 adults	United States of America	Randomized controlled trial	Stull et al., 2018

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
		3. Cricket powder associated with Tumour Necrosis Factor-alpha (TNF-α)–biomarker of systemic inflammation.				
Older adults						
Milk, dairy products	Various, lower quantities of milk/dairy; total dairy intake	1. No firm onclusion between milk/dairy consumption and cognitive impairment. 2. Consumption of milk at midlife may be negatively associated with verbal memory performance. 3. High intakes of dairy desserts and ice cream associated with cognitive decline in old women. 4. Inverse relation between dairy intake and development of Alzheimer disease among older individuals (1 study). 5. Possible reduced risk of frailty with high consumption of low-fat milk and yogurt. 6. Possible reduced risk of sarcopenia associated with consumption of dairy products.	N/A	France, Japan, Mexico, Spain, United States of America	Systematic narrative review (6 studies: 5 observational prospective cohort studies and 1 randomised controlled trial)	Cuesta-Triana et al., 2019
Milk, dairy products	Various	1. Data from 2 long Japanese cohorts indicate that milk and dairy intake could prevent dementia and Alzheimer's. 2. No definite conclusions on milk and dairy as preventative against dementia and Alzheimer's.	N/A	Australia, Congo,France, Japan, Korea Netherlands, Sweden, Switzerland, United Kingdom, United States of America	Systematic review (2 ecological surveys, 1 complex document, 28 cross-sectional studies and 7 cohort surveys; 2 randomised control trials)	Bermejo-Pareja et al., 2021
Milk, dairy products	Less than four cups per week of milk intake.	1. Almost daily intake of milk compared to less than four cups per week during midlife reduced the odds of Alzheimer’s. 2. Low milk intake during midlife associated with vascular dementia.	1 174 subjects	Japan	Longitudinal cohort study	Yamada et al., 2003
Milk, dairy products	Total milk consumption (quartiles)	1. Milk and dairy intake are associated with reduced risk of dementia.	1 081 subjects	Japan	Prospective cohort study	Ozawa et al., 2014

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Eggs Meat (lean red meat)	Various	1. Consistent and robust findings for beneficial effects of lean red meat consumption and dairy foods on muscle mass or lean tissue mass. 2. Inconclusive evdence for eggs on muscle mass or lean tissue mass.	N/A	Australia, Finland, France, Ghana, India, Japan, Korea, Mexico, Russia, Spain, South Africa, United Kingdom, United States of America	Systematic review (19 observational studies; 9 intervention studies)	Granic et al., 2020
Milk, dairy products	Usual diet [700(247)mg/day calcium and 58(14)g/day protein (0.9g/kg body weight)]	1. For groups receiving additional dairy products with usual diet [(166) mg/day calcium and 12 (6)g/day protein achieving a total intake of 1142 (353)mg calcium/day and 69 (15)g/day protein (1.1g/kg body weight)]: 3 Reduced risks of all fractures by 33 percent compared to control 4 Reduced risks of hip fractures by 46 percent for hip fractures 5 Reduced risks of falls by 11 percent. No differences in mortality risk	7 195 participants	Australia	Cluster randomised controlled trial	Iuliano et al., 2021
Meat, lean red meat	Control: progressive resistance training with [1 serving pasta or rice/d]	1. For groups receiving ~160g cooked lean red meat in addition to progressive resistance training: 6 Greater protein intake 7 Greater gains in total body and leg lean tissue mass and muscle strength	100 women	Australia	Cluster randomised controlled trial	Daly et al., 2014
Meat, lean red meat	Control: ~225g of cooked pasta or rice with resistance training Intervention: two 80g servings of cooked lean red meat with resistance training	1. No significant differences were found in changes for total body and leg lean mass. 2. The intervention did not significantly affect changes in thigh muscle cross-sectional area, leg and back muscle strength, executive and cognitive functioning, systolic blood pressure, and physical function. 3. Individuals assigned to the lean red meat group had greater improvements in arm lean mass, gait speed, muscle density, and appendicular lean mass. 4. Greater improvements for indicators of memory and learning in control group.	154 subjects	Australia	Randomized controlled trial	Formica et al., 2020
Meat	Control: 25g of meat protein Intervention: 25g of isoflavone soy protein	1. Non-significant differences in indicators of bone or cardiovascular health. 2. Non-significant differences in calcim intake or calcium retention	13 post-menopausal women	United States of America	Controlled feeding study	Roughead et al., 2005

Food	Comparator	Specific findings	Sample size	Country of study	Study design[1]	Reference
Meat	Control: Lacto-ovo-vegetarian diet (0.6g protein per kg of body weight per day) with resistance training; Intervention: Beef-containing diet (0.6g protein per kg of body weight per day) with resistance training)	1. No significant difference between groups in body composition, resting energy expenditure, and concentrations of muscle creatine, phosphocreatine, and total creatine.	21 men	United States of America	Randomized controlled trial	Haub et al., 2002
Milk, dairy products	No comparator	1. Consumption of fermented milk containing Lactobacillus casei Shirota increased percentage of stool types per week and reduced diarrhoea. 2. No significant impact on bowel movement.	135 participants	The Netherlands	Intervention study (non-randomized)	van den Nieuwboer et al., 2015
Meat, red meat, poultry	Total meat consumption g/day (in quartiles)	1. Increased risk of cognitive impairment in highest quartile of red meat consumption. 2. Non-significant, but negative association between poultry intake in the highest quartile (median intake: 37.18g/day) and cognitive impairment. 3. Organ meat consumption in the highest quartile found to be protective against cognitive impairment. 4. Fresh red meat and preserved/processed meat in the highest quartile were respectively associated with a 15% increased likelihood of cognitive impairment.	16 948 participants	Singapore	Prospective cohort study	Jiang et al., 2020

Note: BW = birth weight; GWG = gestational weight gain; LA = linoleic acid; ALA = α-linoleic acid; AA = arachidonic acid; DHA = docosahexaenoic acid; FVF = Full vegetable fat milk; SF = Standard fat milk; PVF = Partially vegetable fat milk; N/A = not available;

Table C7 Examples of micronutrient related recommendations from Food-based Dietary Guidelines

Country	Document name	Recommendation	Link
Afghanistan	National Food-Based Dietary Guidelines for Afghans - A manual	Animal source foods are a good source of iron, zinc, calcium, B vitamins and protein	http://www.fao.org/3/i5283e/i5283e.pdf
Australia	The Australian guide to healthy eating	During pregnancy, three to four serves a day of animal source foods are recommended to provide additional iron and zinc	https://www.nhmrc.gov.au/file/10001/download?token=gUZekSqQ
Kenya	National Guidelines for Healthy Diets and Physical Activity	Meat is a more complete source of micronutrients than plants for: vitamin A, iron, zinc and vitamins B1, B2, B12	http://nak.or.ke/wp-content/uploads/2017/12/NATIONAL-GUIDELINES-FOR-HEALTHY-DIETS-AND-PHYSICAL-ACTIVITY-2017-NEW-EDIT.pdf
Lesotho	Lesotho Food and Nutrition Policy	The high prevalence of anaemia among under-five children in Lesotho is related to low intake of iron-rich foods (like meat, fish, dried beans, and green leafy vegetables) combined with lower intakes of dietary enhancers of iron absorption (like Vitamin C) and higher intakes of iron absorption inhibitors (like cereal bran and grain in general)	https://extranet.who.int/ncdccs/Data/LSO_B11_Lesotho Food and Nutrition Policy FINAL.doc
New Zealand	Eating and Activity Guidelines for New Zealand Adults	Red meat is an excellent source of key nutrients like iron (in an easily absorbed form) as well as zinc. Low iron levels are a problem for some New Zealanders, particularly young women.	https://extranet.who.int/ncdccs/Data/NZL_B14_eating-activity-guidelines-for-new-zealand-adults-oct15_0.pdf
Nigeria	Food-based dietary guidelines for Nigeria – a guide to healthy eating	Foods such as liver, milk, butter and local cheese (wara) have good amounts of vitamin A	http://www.fao.org/3/as841e/as841e.pdf
Sierra Leone	Food-based dietary guidelines for healthy eating	Meat, bush meat and poultry are particularly rich sources of haem-based iron	http://www.fao.org/3/I9679EN/i9679en.pdf

1 **Table C8 Examples of sustainability related recommendations from Food-based Dietary Guidelines**

Country	Document name	Recommendation	Link
Canada	Canada's food guide	Reduce animal source food intake to lower environmental impact	https://food-guide.canada.ca/sites/default/files/artifact-pdf/CDG-EN-2018.pdf
Denmark	The official dietary guidelines – good for health and climate	To reduce the effect on the environment, eat a more plant-based diet and less meat	https://backend.orbit.dtu.dk/ws/portalfiles/portal/213297896/20_Lassen_Final_Rapport_R_d_om_b_redygtig_kost_002_.pdf
Italy	Dietary Guidelines for Healthy Eating– Revision 2018	Select poultry or legumes over red meat to reduce environmental impact	https://www.crea.gov.it/web/alimenti-e-nutrizione/-/cel-guida-per-una-sana-alimentazione-2018
Netherlands	Food based dietary guidelines for the Netherlands	To limit environmental impact, reduce consumption of meat to a maximum of 500 gram per week, consume 2-3 portions of dairy products per day, more is not necessary and eat fish (only) once a week.	https://www.voedingscentrum.nl/Assets/Uploads/voedingscentrum/Documents/Professionals/Schijf%20van%20Vijf/Richtlijnen%20Schijf%20van%20Vijf.pdf
Norway	National action plan for better diet (2017–2021)	It is pointed out in the Public Health Report that a plant-based diet as well as increased intake of fish and less meat, will help to reach both health policy and climate policy goals	https://extranet.who.int/ncdccs/Data/NOR_B14_handlingsplan_kosthold_2017-2021.pdf
South Africa	Food-based dietary guidelines for South Africa	The delicate balance between adequate, over- and underconsumption of animal sources of food remains a very complicated aspect of ensuring healthy and nutritionally adequate, yet environmentally sustainable, diets.	http://www.fao.org/3/as842e/as842e.pdf
Sweden	Find your way to eat greener, not too much and be active!	Limit consumption of dairy, as cattle used to produce these products have an environmental impact	https://www.livsmedelsverket.se/globalassets/publikationsdatabas/andra-sprak/kostraden/kostrad-eng.pdf?AspxAutoDetectCookieSupport=1
Uruguay	Dietary guidelines for the Uruguayan population: for a healthy, shared and enjoyable diet	Combining foods of plant origin with foods of animal origin contributes to a balanced diet. It also contributes to the promotion of a more sustainable food system	http://www.fao.org/3/as861e/as861e.pdf

2 **Table C9 Examples of life cycle phase related recommendations from Food-based Dietary Guidelines**

Country	Document name	Recommendation	Link
Afghanistan	National Food-Based Dietary Guidelines for Afghans – A manual	Pregnant women should take extra servings of meat, fish, eggs or dairy products every day	http://www.fao.org/3/i5283e/i5283e.pdf
Finland	Finnish nutrition recommendations 2014	Infants above 6 months of age should be fed high protein milk products and a moderate amount of poultry and some red meat	https://www.ruokavirasto.fi/en/themes/healthy-diet/nutrition-and-food-recommendations/
Iceland	Manual for the kindergarten kitchen	Limit consumption of processed meats for infants and young children	http://www.fao.org/nutrition/education/food-dietary-guidelines/regions/countries/celand/en/
Lesotho	Lesotho Food and Nutrition Policy	The high prevalence of anaemia among under-five children in Lesotho is related to low intake of iron-rich foods (like meat, fish, dried beans, and green leafy vegetables) combined with lower intakes of dietary enhancers of iron absorption (like Vitamin C) and higher intakes of iron absorption inhibitors (like cereal bran and grain in general)	https://extranet.who.int/ncdccs/Data/LSO_B11_Lesotho Food and Nutrition Policy FINAL .doc
Nigeria	Food-based dietary guidelines for Nigeria – a guide to healthy eating	Pregnant mothers should eat more iron rich foods such as snails	http://www.fao.org/3/as841e/as841e.pdf
Sierra Leone	Food-based dietary guidelines for healthy eating	Animal source food should be allocated to family members with special needs, such as young children aged six months to five years old and pregnant and lactating women	http://www.fao.org/3/I9679EN/i9679en.pdf
Turkey	Dietary guidelines for Turkey	Young children should consume eggs daily	http://www.fao.org/3/as697e/as697e.pdf

Table C10 Number of policy documents available in common databases and analyzed by year

Year	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
2000	1	-	-	-	-	1
2001	1	-	-	-	-	1
2002	2	-	-	-	-	2
2003	2	-	-	-	-	2
2004	2	-	-	-	-	2
2005	1	-	-	-	-	1
2006	5	-	-	-	-	5
2007	4	-	-	-	-	4
2008	6	-	-	-	-	6
2009	5	-	-	-	-	5
2010	8	-	-	-	-	8
2011	3	-	-	-	-	3
2012	16	-	-	-	-	16
2013	16	-	-	-	-	16
2014	13	-	-	-	-	13
2015	12	2	0	2	0	16
2016	11	10	11	3	3	38
2017	5	39	2	1	3	50
2018	7	3	5	2	7	24
2019	4	16	3	2	3	28
2020	4	1	2	1	0	8
2021	1	0	0	0	0	1

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.html); the most recent FBDG from each country was analyzed; - not in the scope of this analysis.

Table C11 Number of quantitative and qualitative recommendations in policy documents available in common databases and analyzed

Recommendations	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
Qualitative	543	130	12	12	16	713
Quantitative	327	34	3	1	0	365

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.html).

Table C12 Number of policy documents extracted from common databases and analyzed by region

Region	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
Africa	7	16	5	5	12	45
Asia and the Pacific	18	13	3	2	3	39
Europe	34	16	0	1	0	51
Latin America and the Caribbean	29	9	2	1	1	42
Near East	9	2	1	0	0	12
North America	2	1	0	0	0	3

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.html).

Table C13 Number of recommendations in policy documents available in common databases and analyzed by food group

Food group	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
Animal source food	162	63	17	7	8	261
Eggs	191	13	0	0	0	204
Meat from wild animals	6	0	0	1	1	8
Insects	6	1	0	0	0	7
Meat	366	46	1	5	2	420
Milk and dairy products	281	44	4	1	1	331
Offal	53	2	0	0	0	55
Poultry	133	7	2	1	0	143
Red meat	48	10	0	0	0	58
White meat	5	2	0	0	0	7

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.htm).

Table C14 Number of recommendations in policy documents available in common databases and analyzed by category

Category	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
Animal welfare	1	0	0	0	0	1
Micronutrients	703	10	15	13	16	761
Non-communicable diseases	148	154	8	0	0	310
Sustainability	9	3	0	0	0	12

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.html).

Table C15 Number of recommendations in policy documents available in common databases and analyzed by life cycle phase

Life cycle phase	FBDG	NCD	GINA	FAOLEX	FAPDA	Total
Adolescents, 10-19 years	64	5	0	1	0	70
Women, reproductive age from 15-49 years	23	3	0	1	0	27
Women, pregnant	23	0	4	0	1	28
Women, lactating	11	0	0	0	0	11
Older, general	30	1	0	0	0	31
Older, women	2	0	0	0	0	2
Older, men	2	0	0	0	0	2
General	607	143	10	11	12	783
Adolescents, 10-19 years	64	5	0	1	0	70
Women, reproductive age from 15-49 years	23	3	0	1	0	27

Note: Common databases: FBDG (Food-based dietary guidelines, https://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en); NCD (Noncommunicable Disease Document Repository, https://extranet.who.int/ncdccs/documents); GINA (Global database on the Implementation of Nutrition Action, https://extranet.who.int/nutrition/gina/en/home); FAOLEX (https://www.fao.org/faolex); FAPDA (Food And Agriculture Policy Decision Analysis Tool, http://fapda.apps.fao.org/fapda/#main.html).

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