



The influence of livestock-derived foods on nutrition during the first 1,000 days of life



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The influence of livestock-derived foods on nutrition during the first 1,000 days of life

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Executive summary

This report synthesizes the best current evidence on the influence of livestock-derived foods (LDF), such as meat, milk and eggs, on the nutrition of mothers and infants in low- and middle-income countries (LMIC), especially in Africa and Asia. It focuses on the needs of pregnant and lactating mothers and their infants during their first 1,000 days of life, from conception to around two years.

The study was driven by concern for still unacceptably high levels of child undernutrition (globally, almost 30% of children under 5 are stunted or wasted in 2017); an appreciation of the potential nutritional benefits that LDF can provide, especially in areas where livestock production and keeping is high; and concerns about the enormous, demand-driven growth and intensification of the livestock sector in LMIC and any associated human health, animal welfare and environmental risks.

Chapter 1 sets out a framework to understand the ways that LDF positively or negatively influence nutrition, and the key synergies and trade-offs involved. Chapter 2 provides up-to-date information on the absolute and relative contributions of meat, milk and eggs to human diets and the prevalence of undernutrition in developing regions. While this is not all specific to the first 1,000 days of life, it provides a deeper understanding of the dietary context. Chapter 3 presents empirical evidence about the impact of interventions that provide meat, milk and eggs on the nutrition of children as well as pregnant and lactating women. Chapter 4 summarizes available evidence on how interventions based on providing animal stock or improving the productivity of livestock have an impact on human nutrition. Chapter 5 looks at livestock products as sources of food-borne disease (FBD) and the impacts of LDF-related diseases on human health and nutrition. Chapter 6 provides an overview of the sustainability dimensions of different livestock production systems and diets, including environmental sustainability and social and economic well-being.

The livestock sector is a fast-changing domain where enormous potential for innovation – such as lab-grown and artificial meat, insects as food, plant-based LDF replacements – and consumer attitudes to animal welfare, health or the environment are transforming LDF production and consumption, especially in high-income countries. These potential high-impact game-changers, while already starting to influence high-income countries, are not examined in this report as they are not expected to have a significant impact for some time on the nutrition of mothers and infants in LMIC.

Chapter 1 illustrates how the quantity and quality of nutrients in milk, meat and eggs makes LDF an important component of healthy diets, particularly for pregnant and breastfeeding women and young children in LMIC. It also shows the need for targeted promotion of LDF consumption that benefits under-nourished people and avoids over-consumption in others. It also indicates the pathways through which LDF production can impact nutrition, and some important trade-offs.

Chapter 2 focuses on consumption patterns. In the absence of comprehensive information on LDF consumption in the first 1,000 days of a child's life, summarized information is presented from the Food and Agriculture Organization of the United Nations (FAO) and other sources on per capita consumption in LMIC, particularly in Africa and Asia. The data shows that consumption of LDF is rapidly increasing in most LMIC regions; but is still much lower than in higher income regions. Moreover, significant regional variations in livestock systems and LDF consumption indicate

that livestock and nutritional interventions must be tailored to local contexts, such as dairy-based interventions in southern Asia, where milk and milk products are central to people's diets. Surveys reporting on levels of meat, milk and egg consumption in the first 1,000 days confirm that mothers and infants from low-income households typically only consume these products occasionally. The picture is further complicated as some infants under six months old are routinely given cow or goat milk, despite an evidence-based global consensus recommending the exclusive breastfeeding of infants until they reach six months of age.

Chapter 3 features a systematic literature review on the potential effects of LDF on nutritional outcomes during the first 1,000 days. This was challenged by the scarcity of articles documenting intervention studies that assessed the effects of LDF supplementation on nutritional outcomes: a common feature of systematic literature reviews focusing on LMIC. The 14 studies that met the inclusion and quality criteria of the study indicate that consumption of LDF can improve growth, cognition and other nutrition outcomes in children. Milk was particularly associated with better linear growth, meat with better cognition. Furthermore, malnourished children benefitted more from LDF consumption than healthy children. Given the demonstrable nutritional benefits shown of providing LDF to malnourished children in the first 1,000 days of life, further rigorous studies are needed to understand the types and quantities of LDF suitable for different regions and circumstances, and the best means to enable access to them for poor communities and households.

Chapter 4 considers the evidence from major scientific reviews and other research papers that evaluated the impacts of livestock interventions on nutrition (for example, interventions providing poultry to women). These indicate that livestock interventions do improve small-scale food production and increase incomes and household expenditure. They can thus improve nutrient consumption and diets in poor households and may improve nutritional outcomes, particularly in poor children and women. These studies also indicate that some interventions can have a negative impact on nutrition by, for example, diverting food from households to markets. The literature is also consistent on two things: 1) agricultural interventions, including livestock, are more successful at improving nutrition when they target women and/or include a nutritional educational component and, 2) when they are integrated into larger interventions that address various determinants of undernutrition. While the number of such studies is increasing rapidly, more research, and of higher quality, is needed to understand fully the potential of livestock interventions to reduce undernutrition among poor households.

Chapter 5 focuses on foodborne diseases which most constrain the use of LDF to achieve better nutrition in the first 1,000 days. FBD have recently been shown to impose a human health burden comparable to malaria, HIV/AIDs and tuberculosis. Children under-5 bear a disproportionate amount of the FBD burden and pregnant women are particularly vulnerable to FBD. Other hazards associated with these foods include the presence of toxins, including aflatoxins, which can contaminate milk and are associated with stunting; allergens, especially eggs and milk; and faecal bacteria causing enteric dysfunction. Raising or processing livestock can increase exposure to 'zoonotic' diseases transmitted from animals to people, play major roles in the emergence of new human diseases, including pandemics such as avian influenza, and can contribute to the rise of antibiotic-resistant pathogens. Approaches to increase and intensify the production of LDF should be accompanied by ways to enhance livestock food safety and disease control and improve health security.

Finally, chapter 6 discusses LDF and sustainable diets. There is a broad evidence-based consensus that diets low in LDF and high in fruits, vegetables and legumes offer the greatest twin benefits to human nutrition and environmental sustainability. For LMIC however, this consensus has several important caveats and the general arguments need to be 'unpacked' to address LMIC realities. First, while high LDF diets are, on average, less environmentally sustainable than diets with low LDF levels, more typical 'LMIC' diets that incorporate some LDF, especially milk and eggs, can use less land for food production than their plant-based alternatives. The type of land used for production is also often different. Rather than competing with crops for land, much of this meat and milk is produced using non-human-edible feed resources and on marginal rangelands that would otherwise be unproductive.

Evidence shows that medium levels of livestock grazing are better for the health, productivity and biodiversity of rangelands than having no livestock at all. When managed well, these lands can also sequester large amounts of carbon

in their soils. Second, diets considered environmentally sustainable in high-income countries in the global north often contain more meat, milk and eggs than are actually consumed by the poor in LMIC, demonstrating significant inequalities in LDF access between richer and poorer countries. Arguments suited to high-income countries with widely available energy-rich foods and over-consumption problems should be adjusted to address LMIC needs.

Third, typical diet sustainability assessments suffer from two main weaknesses: most are relevant only to specific contexts, and assess only the environmental aspect of sustainability, often ignoring the social, economic and health dimensions. Assessments of the environmental dimension typically restrict themselves to just one element of environmental sustainability—such as the level of greenhouse gases emitted or how much land is used to produce the foods. It is important to assess all the dimensions to have a full and accurate picture.

Fourth, the proportion of global LDF production needed to meet the nutritional needs of all the world's undernourished infants in their first 1,000 days and pregnant/lactating mothers is so small that this amount could easily be protected through equitable redistribution, even in the face of environmentally-motivated overall reductions in the production of LDF.

Recommendations

The roles of LDF in nutrition are complex and can be markedly different between high- and low-income countries and between different populations within these countries; one person's problem can be another's solution. The many health and environmental concerns around LDF production and consumption in high-income countries and wealthier segments of society are of legitimate concern, but the overconsumption of the rich should not be a reason for wholesale restrictions on all populations that limit nutritional options for the poor.

This study and the evidence reviewed suggests that LDF offer significant potential 'now' to contribute to better health and nutrition in low- and middle-income countries. The potential benefit is especially high for target groups like pregnant and lactating mothers and their infants from low-income households susceptible to undernutrition. To be fully realized, the nutritional 'wins' require that the environmental and health externalities and trade-offs are well understood and managed.

While each chapter contains its own specific conclusions and recommendations, this section highlights four cross-cutting recommendations across the broader issue.

Recommendation 1: Increase the availability and accessibility of safe LDF in LMIC populations with low intakes

Notwithstanding trends in high-income countries to question and reduce LDF intake, LMIC countries should extend interventions to improve the availability, accessibility and affordability of LDF to people whose intake of these high-quality protein and micronutrients is low. Such an 'equity first' approach should identify and prioritize people whose nutrition status would most greatly benefit from LDF – either because they have the greatest need, offer the strongest future potential for improving nutritional status, have little dietary choice or have the least access. This is particularly important for pregnant and lactating women and children whose physiology demand nutrient-dense foods. Such efforts to increase LDF availability and consumption in LMIC should be matched by interventions to improve food safety and reduce the risk of FBD. Strategies to increase LDF availability should be coupled with interventions to promote healthy diets, avoid over-consumption of LDF, and monitor consumption levels in different segments of society.

Recommendation 2. Base global LDF strategies on full sustainability assessments and recognize the particular needs of mothers and infants

Balancing the perceived needs of the planet – for fewer livestock and lower LDF consumption – with the immediate nutrition needs – and the healthy futures – of women and infants in LMIC requires a fuller understanding and accurate figures about LDF production and sustainability in LMIC. Livestock production should follow all the sustainability dimensions – economic, environmental, health and social – and sustainability assessments should measure all the dimensions, capturing the multiple contributions of livestock to sustainable livelihoods as well as sustainable nutrition. Recognizing the equity arguments underpinning these issues and considering that global nutrient requirements in the first 1,000 days of life are a small proportion of total food production, production of LDF for young children and their mothers should be safeguarded and prioritized even as the world may seek to reduce overall LDF production and consumption as part of global environmental or sustainability commitments.

Recommendation 3. Better align nutrition, health, livestock and sustainability policies at national level

Nationally, the livestock, nutrition and health sectors need to come together and apply a ‘One Health’ approach to effectively align livestock and LDF strategies and interventions with wider dietary and nutrition policies that encourage healthy eating habits, ensure food security, and safeguard the particular nutritional needs of vulnerable groups such as women and children. These evidence-based policies and guidance should also take into account sustainability considerations around the environment and natural resource use. Internationally, these same concerns should be brought into broader development discussions such as those in the 2030 Agenda for Sustainable Development and be taken up by development agencies as they support policy development and implementation in these areas.

Additionally, the conclusions and recommendations in this report require that livestock interventions are designed and implemented in a more ‘nutrition-sensitive’ way— for example targeting mothers and infants, promoting healthy dietary practices, monitoring potential side-effects or assessing nutritional impacts. This would be a significant shift for a sector typically more focused on overcoming animal productivity yield gaps through, for example, improved animal, health, genetics and feeds. It should prioritize outcomes that lead to safer and ‘more nutritious’ as well as ‘more’ milk, meat and eggs, in the hands and mouths of specific population groups who need them most.

Recommendation 4. Expand the evidence base through high quality action research

Although LDF are known to be a rich source of high-quality protein and essential micronutrients, there is a worrying lack of scientific evidence on the effect of LDF intake in nutritional outcomes in the first 1,000 days of life. While studies can be complicated, they need not be and the significant potential of LDF to improve nutrition during the first 1,000 days is a strong case for greater investment in such research. Emergency supplementation interventions could also be designed in a way that allows for rigorous impact assessment. Larger research studies with robust designs are needed to demonstrate if an effect exists for different LDF in children’s growth and development and the dose-response relationship.

Beyond more rigorous studies of the nutritional effects of LDF, there is an urgent need to generate evidence on the most effective ways to deliver such interventions. For primary or secondary school children, school meal programs seem a suitable delivery platform to promote LDF consumption, with most studies considering milk as a food of choice. However, for younger children and women, the evidence identified was too limited to draw any recommendations and the delivery of interventions in these groups presents substantial challenges, according to the studies reviewed. Investments are needed to fill evidence gaps, strengthen evaluation rigour and extend promising and successful approaches. Eggs were particularly underrepresented in the research reviewed and their widespread availability and lower preservation requirements make them a product with great nutrition potential that requires more attention.

Scientific evidence on the more complex question of the impact of livestock interventions on nutritional outcomes in the first 1,000 days is also very scarce. Broader scope studies that have assessed the effect of livestock interventions on nutrition seem to suggest that such interventions can improve nutrient consumption and diets and may improve nutritional outcomes in children and women, especially in farming households. However, the evidence is limited and weak, again mostly explained by the complexity of the pathways that link livestock interventions and nutrition. Development projects—often implemented at large scale and with long-term monitoring processes—with a focus on or including livestock interventions could be used as platforms to increase the evidence base around the impact of such interventions on nutrition.

Introduction

Poor nutrition, a persistent, if declining, problem

Good nutrition (i.e. an adequate and well-balanced diet) during the 1,000 days between conception and a child's second birthday is crucial to ensuring optimal health, physical growth and brain development. Good nutrition is also required by women who are pregnant or breast feeding, when physiological requirements for nutrients increase in terms of both quality and quantity. However, while progress has been made in tackling poor nutrition in the first 1,000 days of life, undernutrition remains unacceptably high and overnutrition is trending upwards worldwide. UNICEF estimated that among children under five in 2014, 159 million were stunted (around one in four), 50 million were wasted and 41 million were overweight (UNICEF 2015). While overall numbers of stunted and wasted childrenⁱ are declining, nutritional progress is uneven across low- and middle-income countries (LMIC¹). Moreover, micronutrient deficiencies, especially of iron, vitamin A, iodine and zinc, are common among children and pregnant women in these countries (Black et al. 2013).

i Stunted children are short for their age; wasted children are thin for their height; overweight children are heavy for their height.

Major initiatives tackling poor nutrition

Over the past decades, many research programs, initiatives and guidelines promoting good nutrition for mothers and newborns have emerged. For example, the first and second International Conference on Nutrition, the 2008 and 2013 Lancet Series on Maternal and Child Nutrition, and the Copenhagen Consensus have set out the benefits of tackling nutrition and cost-effective options to do so. The World Health Organization (WHO) global strategy for infant and young child feeding recommends breastfeeding, food fortification and nutritional supplementation as key priorities to its member states. The Food and Agriculture Organization of the United Nations (FAO) has launched training programs in a range of LMIC to demonstrate how families with infants and young children can improve their dietary practices. FAO has also recommended the use of appropriate complementary foodsⁱⁱ and that families should eat together in these resource-poor settings.

ii Complementary feeding starts when breast milk alone is no longer sufficient to meet the nutritional requirements of infants and, therefore, other foods and liquids are needed, along with breast milk, in the transition from exclusive breastfeeding to family foods. It typically covers the period from 6–24 months of age, even though breastfeeding may continue up to two years of age and beyond.

Since the Millennium Development Goals (MDGs) were launched in 2000, efforts toward achieving MDG 1, eradicating extreme hunger and poverty, and MDG 4, reducing child mortality, have placed significant focus on improving maternal, newborn and child nutrition. In particular, a multitude of studies have tried to assess the impacts

1. <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>

of nutrition-specific or nutrition-sensitive interventionsⁱⁱⁱ made during the first 1,000 days of life, that is, between conception and a child's second birthday, due to the importance of this period on a child's growth. Building on this body of work will be crucial in achieving the ambitions of the recently launched United Nations Sustainable Development Goals (SDGs), particularly SDG 2, to end all forms of malnutrition by 2030, while ensuring food production systems are sustainable and agricultural productivity of small-scale producers is doubled.

ⁱⁱⁱ Nutrition-specific interventions tackle the immediate causes of malnutrition, such as inadequate dietary intake, for example, through supplementation with micronutrients. Nutrition-sensitive interventions address the underlying causes of malnutrition, for example, by ensuring that dairy development does not reduce women's time for care-giving.

Lack of information and consensus on the role of livestock-derived foods in the nutritional status of mothers and infants

Research has already identified the types and amounts of nutrients required by pregnant and lactating women and by infants in the first 1,000 days of their lives. The key gap in evidence is an understanding and consensus regarding the role that different food groups play in meeting both the macronutrient (e.g. proteins) and micronutrient (vitamins and minerals) needs. In particular, livestock-derived foods (LDF) (i.e. edible products obtained from farm animals, such as meat, milk, eggs and their derived products) are nutrient-dense foods that can improve nutrition, not only acting as a direct source of such elements, but also indirectly, for example, through the improved bioavailability that consumption of LDF brings about. This report aims to help address this critical evidence gap.

This literature review and report examines both scientific evidence and grey literature, the latter—including government reports and publications produced by multilateral agencies and non-governmental organizations (NGOs)—to determine the feasibility and sustainability of using livestock-derived protein and other nutrients to meet nutritional targets sets for pregnant women, new mothers and infants in LMIC.

I. The role of livestock-derived foods in nutrition

The role of LDF and livestock in nutrition can be beneficial, detrimental or neutral, depending on the precise characteristics of a given population, the context-specific circumstances and the way LDF and livestock are used.

I.1. Potential nutritional benefits of livestock-derived foods

Insufficient nutrient intake, i.e. consuming amounts below recommended values, is common worldwide for certain micronutrients and is particularly extensive in LMIC, where many poor people subsist on substandard and monotonous diets consisting largely of the same cheap cereal and tuber staples day in and day out (Muhihi et al. 2012; Thompson and Meerman 2010). Although recommended nutrient intakes are well established for some nutrients, for others there are important evidence gaps, and guidance is unclear; young children and pregnant and breastfeeding women are typically most at risk of nutrient inadequacy due to their high nutrient requirements during phases of rapid growth and reproduction at a time when intake may be restricted (Karakochuk et al. 2018). This makes the consumption of nutrient-rich foods of particular importance during these life stages. In addition, nutritional deficiencies during these stages may lead to an intergenerational cycle of malnutrition: a malnourished mother is more likely to give birth to a low-birthweight baby, who will grow as a malnourished child and ultimately as a malnourished pregnant woman.

Micronutrient supplementation has been a widely used strategy over the last few decades and has been effective in improving the nutrition of undernourished populations to some extent (Bhutta et al. 2013). While ‘nutrition-specific’ interventions remain an important approach to address malnutrition, there has been growing interest in the potential of ‘food-based’ approaches to improve nutritional outcomes (Ruel et al. 2013). Such strategies can fulfil the requirements for diverse micronutrients simultaneously and sustainably, reducing antagonistic interactions in nutrient absorption among different nutrients as well as the risk of nutrient excess (Ruel 2001).

The WHO advocates ‘healthy diets’, meaning ‘diets which contribute to protecting against all forms of malnutrition, as well as non-communicable diseases’. These recommendations include increased consumption of fruits and vegetables and reduced animal fat intake (WHO 2015). This ‘healthy diets’ recommendation responds to, among other issues, the increasing consumption of meat, milk and eggs among richer populations in recent decades, leading to increasing incidences of over-consumption. In contrast, the diets of members of poor households in LMIC, particularly those of women and children, typically consist of energy-rich staples poor in nutrients, with little nutrient-rich foods such as pulses, milk, meat or eggs (Murphy and Allen 2003).

LDF are among the richest dietary source of micronutrients and their specific potential to improve micronutrient intake is well recognized (Allen 2008a; Allen and Gillespie 2001). Thus, LDF constitute a valuable opportunity to improve the diets of children and women during the critical stages of pregnancy and the early years of development. While the concentrations of various nutrients differ substantially among LDF, such as red meat, poultry, liver, milk and eggs (see Annex I), these foods share some important commonalities. Generally, LDF have excellent nutrient profiles, including macronutrients (high-quality protein and essential fatty acids) and micronutrients (see Annex I). In

addition, some vitamins and minerals contained in LDF are in a more 'biologically available' form, that is, better able to be absorbed than those in other foods (Randolph et al. 2007). This means, for example, that to achieve her daily requirements for iron, a woman would have to eat eight times more spinach than liver, even if the overall content in iron seems similar from the food composition tables (Gupta 2016). The higher bioavailability of iron in meat is due to the more absorbable biochemical presentation of iron in meat (haeme iron) and the iron in vegetables is usually bound to phytates which interfere with absorption. Similar cases exist for micronutrients such as zinc and retinol (vitamin A), deficiencies of which are leading causes of child mortality (Black et al. 2013). Also, as LDF are the only source of vitamin B12, a lack of these foods in a diet leads to B12 deficiency, which is highly prevalent globally and leads to macrocytic anaemia and neurological problems (Allen 2008b; Dror and Allen 2008).

Animal proteins are known to be superior to plant proteins in several ways: i) higher protein content of the dry matter (63–68% in beef meat vs <12% in staple foods of plant origin, with the exception of legumes (Wu 2016); ii) better protein digestibility (~95% in animals vs ~80–85% in plants (Wu 2016); and iii) higher protein biological value and consequent net protein utilization (as net animal protein utilization = 1, utilization of animal proteins is near-complete, while utilization of most plant-based proteins is much lower, e.g. wheat=0.53) due to a more balanced content in essential amino acids relative to human tissues (WHO 2007). Given that even in relatively more wealthy countries in Central and South America up to 30% of children have protein malnutrition (Wu et al. 2014), these quality differences matter. A study in Malawi recently showed that stunted children had lower serum concentrations of several essential amino acids, including lysine, methionine, threonine and glycine, that are deficient in foods of plant origin (Semba et al. 2016). The nutritional features of LDF can be summarized as follows (Box 1):

Box 1: Nutritional benefits of LDF during the first 1,000 days.

- High density of macro- and micronutrients per 100 g.
- Contain essential nutrients difficult or impossible to find in other foods.
- Contain micronutrients in biological forms that facilitate uptake into the body (bioavailability).
- Better digestibility and biological value of proteins, with amino acid profile matching human needs.
- Contain lower levels of anti-nutrient factors (i.e. compounds that interfere with the absorption of nutrients).

In addition to the high nutrient content of LDF, milk has been shown to improve linear growth in children. It is believed to have this effect by stimulating growth factors, namely insulin-like growth factor (IGF), possibly through casein, branched-chain amino acids, calcium and zinc (Dror and Allen 2011; Hoppe et al. 2006). Similarly, the combination of bioavailable micronutrients in meat has been found to benefit the cognitive development of children, particularly those in poor households where diets lack many nutrients that promote brain development (Gupta 2016). For all these reasons, consumption of even small amounts of milk, meat and eggs can contribute substantially to ensuring adequate nutrition. This makes LDF particularly important for impoverished women and children who, due to their life stage, have high micronutrient requirements and small intake volumes, while having low consumption of nutrient-dense foods. Specific evidence related to the first 1,000 days is discussed in Section 2.

It is worth noting that composition data is generally derived from analyses conducted largely on high-income country foods, which derive from animals raised in very different conditions and do not include the full spectrum of LDF that can be consumed in LMIC. Therefore, there is a need to improve existing food composition resources for more accurate understanding (de Bruyn et al. 2016); this is already taking place in some countries.

1.2 Potential negative impacts of livestock-derived foods on nutrition

The changes in lifestyles in developing and emerging economies are bringing about an epidemiologic transition, characterized by a marked increase in incidence of chronic non-communicable diseases, such as cardiovascular disease

and diabetes, co-existing with undernutrition (i.e. double burden of malnutrition). These diseases are related to a predominance of energy-dense diets combined with sedentary behaviours—a shift to foods rich in fat and sugars and low in fibre and micronutrients, along with little or no vigorous physical exercise. Evidence-based consensus agrees that the first two years of life are critical in preventing obesity (Karakochuk et al. 2018). Therefore, early feeding is no longer just a concern about undernutrition. Famine exposure in utero has been associated with increased prevalence of obesity but it has also been reported that lower cow-milk protein intake in infancy might diminish the risks of weight gain and adiposity at later ages (Koletzko et al. 2009). In addition, it has been shown that meat- and dairy-based complementary foods can lead to distinct growth patterns (Tang and Krebs 2014; Tang et al. 2018), with meat associated with greater linear growth without excessive gain in adiposity. Hence, the role of LDF needs to be carefully assessed, and a better understanding of the potentially modifiable risks and the mechanisms is needed (Karakochuk et al. 2018).

Higher levels of fat consumption globally has generally been attributed to increased access to cheap oilseed and vegetable oils and, to a lesser extent, to increased consumption of saturated animal fats (meat and milk) (Drewnowski and Popkin 1997). WHO recommendations to reduce consumption of animal fats are based on putative links between over-consumption of saturated fatty acids and obesity, heart disease, type-2 diabetes, and prostate and other types of cancer (Allen et al. 2008). However, the available evidence is not conclusive, mostly due to the intrinsic difficulty in conducting long-term longitudinal dietary studies, particularly related to nutrition during the first 1,000 days of life. There is evidence that high consumption of red and processed meats can increase the risk of bowel cancer and milk consumption is associated with increased risk of prostate cancer (WCRF/AICR 2007). There is also evidence suggesting a protective effect of milk against colorectal cancer and, potentially, bladder cancer (WCRF/AICR 2007).

Prevalence of obesity, cardiovascular disease and diabetes has been found to be associated with animal fats in cross-sectional ecological studies (MacDonald et al. 2009; Moussavi et al. 2008; Siegel et al. 2012). Randomized controlled trials (RCTs) replacing dietary saturated fat with linoleic acid showed effective lowering of serum cholesterol; but it is unclear whether this translates into a lower risk of death from coronary heart disease (Ramsden et al. 2016). A recent review indicated that most of the prospective studies and meta-analyses examining the relationship between milk consumption and cardiovascular disease concluded that there were no detrimental effects in terms of deaths due to cardiovascular disease or risk biomarkers (Lovegrove and Hobbs 2016). Also, there is increasing evidence that milk is associated with reduced blood pressure and arterial stiffness, possibly attributable to milk's specific composition (Lovegrove and Hobbs 2016). A recent meta-analysis of RCTs supports the idea that the consumption of red meat above 0.5 servings a day does not influence blood lipids and lipoproteins or blood pressure (O'Connor et al. 2016).

A recent, large 18-country, cohort study examined associations between diet and total mortality, and a range of cardiovascular events such as heart disease and stroke. There was no association between saturated fat—predominantly from animal-source foods (ASF)—and cardiovascular disease, myocardial infarction or mortality, and the group with the highest proportional saturated fat intake had a 21% lower risk of stroke than the group with the lowest intake. Consumption of animal protein was also associated with lower mortality (Dehghan et al. 2017; Miller et al. 2017; Mente et al. 2017). Although the authors controlled for socio-economic status, better represented LMIC than previous studies and may have better avoided previous biases, it is impossible to completely eliminate the effect of confounding factors (i.e. those that may be responsible for an observed effect) from a cohort study. Uncertainty around a causal relation between ASF and mortality is likely to prevail until well designed randomized controlled trials are undertaken.

Adding to the contribution of LDF to non-communicable diseases, they also cause FBD and allergies, as will be discussed in section 5. These factors have all contributed to a bad reputation of LDF. In relation to this, some populations may be more adapted to vegetarian diets than others. A recent study found that traditionally vegetarian populations in India, Africa and parts of east Asia had a genetic adaptation allowing them to 'efficiently process omega fatty acids into compounds essential for early brain development'. However, the 'vegetarian gene' is also associated with increased risks of heart disease and colon cancer (Kothapalli et al. 2016).

Furthermore, in LMIC the availability of cow milk may sometimes favour sub-optimal child-feeding practices. Exclusive breastfeeding is recommended for the first six months of life as the best feeding practice in early life, and ruminant milk is not advised before infants reach 9–12 months of age, however, cow milk is often given to younger infants. A study in

India found that children were commonly given cow milk starting at three months of age (Mayuri et al. 2012). Data from different ILRI studies (Wyatt et al. 2015) showed that cattle-keeping and other households with easy access to dairy cattle gave cow milk to children at a younger age (three months) compared to households with more limited access. In Kenya, only a third of children are exclusively breastfed for six months; this proportion drops to 2% in poor urban settings (Kimani-Murage et al. 2011). A study among urban poor in Kenya found that knowledge of breastfeeding was generally high but due to many constraints, including the prohibitive cost of baby formula, working women felt that their only viable option was using breast milk substitutes, especially cow milk and porridge (Kimani-Murage et al. 2015).

I.3 Synergies and trade-offs in the impacts of livestock-derived foods on nutrition

Several theoretical models have been developed to understand the drivers of poor nutrition in LMIC and how these drivers interact. Some of the more important frameworks are summarized in Annex 2. Given that rates of undernutrition are generally highest in rural areas and given the multidimensional influences of agriculture on rural and peri-urban livelihoods, interest in links between agriculture and nutrition is growing. Specific pathways in LMIC through which agriculture and agricultural interventions could influence nutrition outcomes have been identified (Ruel et al. 2013; Stuart et al. 2015), including:

- **Food production:** A direct source of food, i.e. household consumption of own produced milk, meat or eggs.
- **Income:** Agriculture as a source of income, i.e. wages for agricultural work or from sales of milk, meat or eggs. This money can be spent on foodstuffs (livestock-derived and other) and on non-food expenditures relevant to nutrition such as health and education.
- **Women's empowerment:** Agriculture can increase women's socio-economic empowerment and influence in decision-making processes in intra-household allocations of food or in expenditures on food or health.
- **Time allocation:** Agriculture can affect women's ability and time to manage care, feeding and health of young children.
- **Physical activity:** Some labour-intense agricultural activities, like other physical activity, may be beneficial to one's health, but may result in increased energy and nutrient expenditure not compensated by one's diet.
- **Health:** Agricultural practices can be hazardous to health and in turn to the nutritional status of the population involved.
- **Agricultural policy and food prices:** Supply-demand factors affect food prices which, in turn, affect the incomes of net sellers and the household food security of net buyers.

There are also nutritional risks that may arise from agricultural interventions. A household's increased income may not translate into improved nutrition for all or part of the household or there may be unintended negative shifts in social dynamics or environmental contamination (Dury et al. 2014). While links between agriculture and nutrition are unquestionable, these links are many, complex and not yet fully understood.

The impact pathways between livestock production and human nutrition have many commonalities with the general agricultural pathways to nutrition, whilst also presenting some specificities related to the animal production. Figure 1 presents the complex links between livestock keeping and a household's nutrition, well-being and health in LMIC (Randolph et al. 2007). The multiplicity of pathways shown indicates the difficulty in establishing, in a given setting, what the exact impacts of a livestock intervention will be on human health and nutrition, both for the household as a whole and particularly for the women and children (Randolph et al. 2007). Although there is a substantial body of evidence about some of these links, few appropriately designed studies have assessed the overall net effect of livestock keeping on human nutrition and health (Randolph et al. 2007). In addition, the specific weight of each of these pathways can vary substantially among populations, settings or even with time, depending on the season and whether LDF are in short supply or abundant.

[illegible]

The arrows indicate hypothesized causality between variables, with the plus or minus sign indicating the synergistic or antagonistic relationship, and the different types of arrows indicating different multiple-link causal chains. Source: Randolph et al. 2007.

The quantity and quality of nutrients in milk, meat and eggs makes LDF an important component of healthy diets, particularly for pregnant and breastfeeding women and young children in LMIC, owing to their increased need for high-quality food and the long-term consequences of malnutrition in these groups. There are, however, important health (and non-health) trade-offs to consider in the consumption of LDF and there is a clear need to target the promotion of LDF consumption and limit the intake of LDF in populations over-consuming these foods. At the same time, the benefits of are likely to be important in populations with low intakes of milk, meat and eggs and with diets generally poor in nutrient-rich foods. Strategies for increasing consumption of LDF in these nutritionally vulnerable groups should be considered and evaluated. In addition, clearer guidance on desirable/undesirable levels for LDF at each specific life stage might be helpful.

Because livestock play so many fundamental roles in the livelihoods of people in LMIC, they can impact nutrition both positively and negatively. The likely impacts on health should, therefore, be well understood, foreseen and monitored when livestock interventions are planned and executed, ensuring that such interventions are nutrition-sensitive and lead to positive impacts on people's nutritional status.

2. Contribution of livestock products to diets in low- and middle-income countries during the first 1,000 days of life

There is little systematically and comprehensively collected data specific to the consumption of LDF during the first 1,000 days of life in LMIC. However, information on the general average per capita consumption and trends can provide insight on consumption of LDF by pregnant women and infants compared to other food items. This section gives an overview of the current and predicted figures of LDF consumption patterns in LMIC in comparison with higher income regions. It also discusses the factors that underlie the consumption trends.

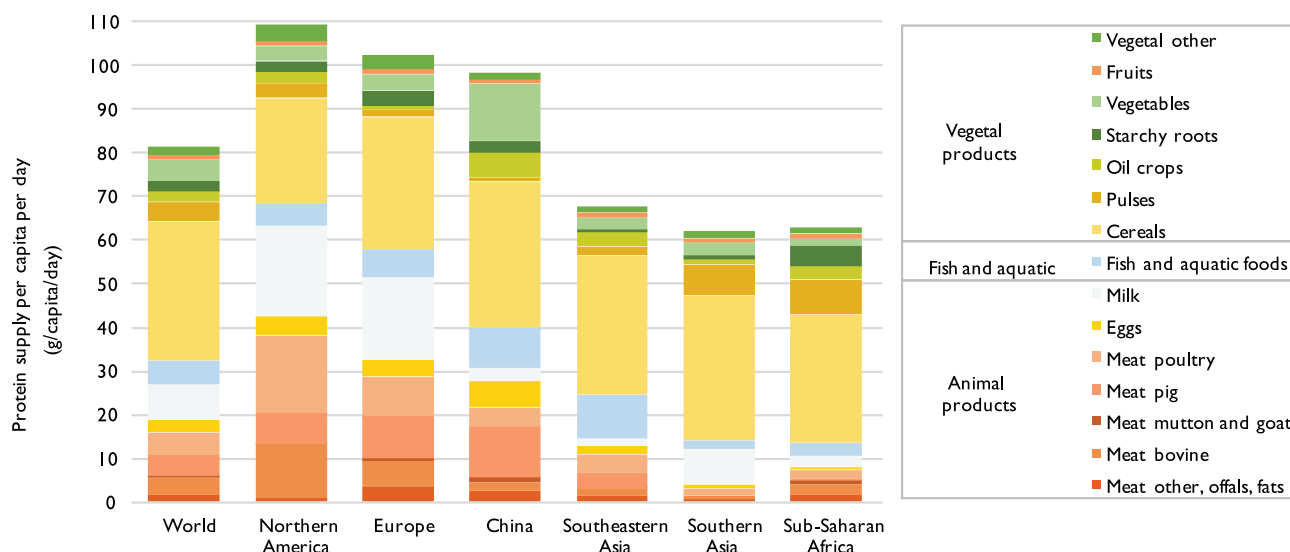
2.1 Contribution of livestock-derived foods to protein food supply in low- and middle-income countries

In LMIC, LDF constitute a small part of the overall diet in terms of quantity of food consumed and contribution to total protein and energy intake. However, they are an important source of protein and fat (Murphy and Allen 2003) and often an important part of expenditure on food (FAO 2012). While in 2013 both Northern America (NA) and Europe had total daily average per capita protein supply of 100–110 g, it was 60–70 g in Southeast Asia (SEA), southern Asia (SA) and sub-Saharan Africa (SSA) (Figure 2).

Protein is an essential part of a balanced healthy diet. It is usually the most costly component of any diet. Worldwide, LDF and cereals are the two most important sources of protein in diets, although the characteristics of protein in the two sources are very different. LDF constituted 50–58% of total protein supply in NA and Europe, and only about 20% in the three developing regions. Thus, in high-income countries, LDF are currently a more important protein sources than cereals, while in developing countries the reverse is the case; cereals represent about half of the supply in SA and SSA. These latter regions also had the highest share of total protein supply from pulses of 11–12%, compared to 1–5% in the other regions. Fish was an important source in SEA and China, although surpassed by vegetables in China.

There are marked differences in the composition of LDF supply between regions. In 2013, milk provided 30–40% of the daily average LDF protein supply in the world, NA and Europe, about 26% in SSA, and only about 10% in SEA and China. In comparison, as much as 70% of the LDF protein supply in SA was from milk. With India being the major part of SA, this can largely be explained by the smallholder-driven ‘white revolution’ that has placed India as the largest milk producer in the world (Basu and Scholten 2012). Pork consumption is a good example of how cultural preferences impact consumption: it amounts to 26% in SEA and as much as 38% of the daily LDF protein supply in China, but less than 5% in SSA. The latter region had the highest contribution of bovine meat (21%). Poultry meat consumption is around 20% of the average supply of proteins in all regions, except SA where it is only about 10%.

Figure 2: Total protein supply per capita per day differentiated for selected animal, vegetal and fish/aquatic products, for the world, five regions and China.

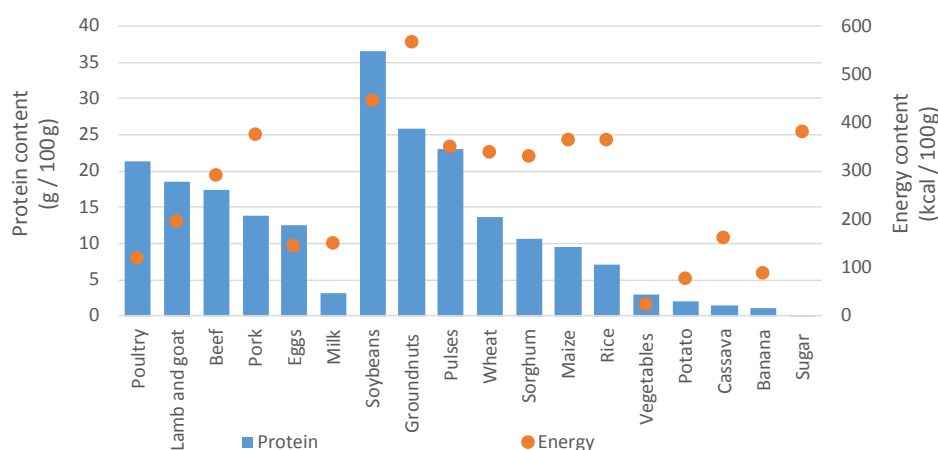


Data: FAOSTAT 2016.

2.2 Relative contribution of livestock-derived foods over time to per capita protein and energy supply

Taking into account the biological value of protein, their palatability and absence of anti-nutrition factors, LDF can best be compared to aquatic products and insects in terms of dietary value. They are superior to protein-rich vegetal products, such as pulses or soybeans, which in turn are superior to protein-poor vegetal products, such as cereals. Plant foods on average have less protein per portion consumed; they are limited in certain amino acids essential for human nutrition; they often contain anti-nutrients which make many nutrients unavailable including protein; some contain endocrine disruptors; and they are often less palatable (Chardigny and Walrand 2016). However, when only looking at the total protein and energy content per kilogram of fresh matter, several vegetal products have higher contents of both protein and energy (Figure 3).

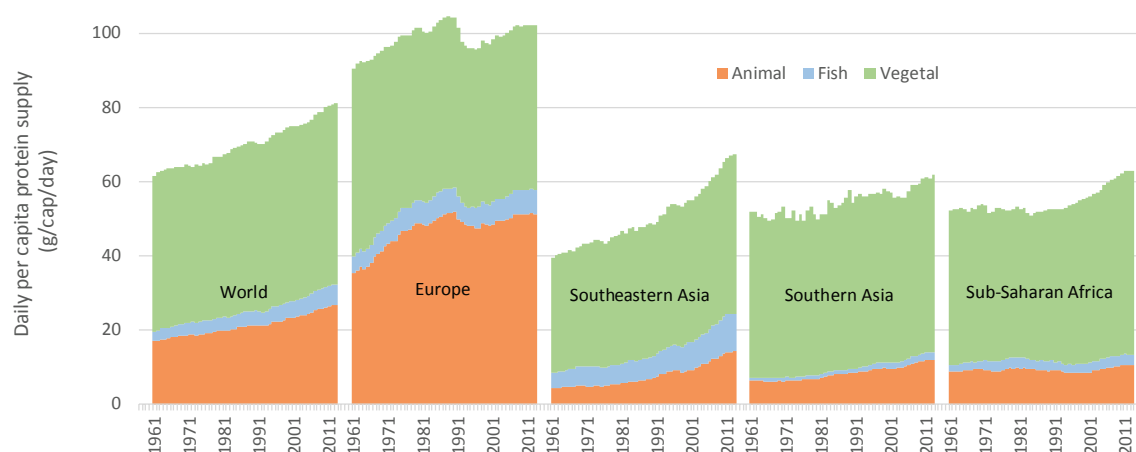
Figure 3: Protein and energy content per 100 g of fresh matter for selected foods of both animal and plant origin.



Data: USDA 2016.

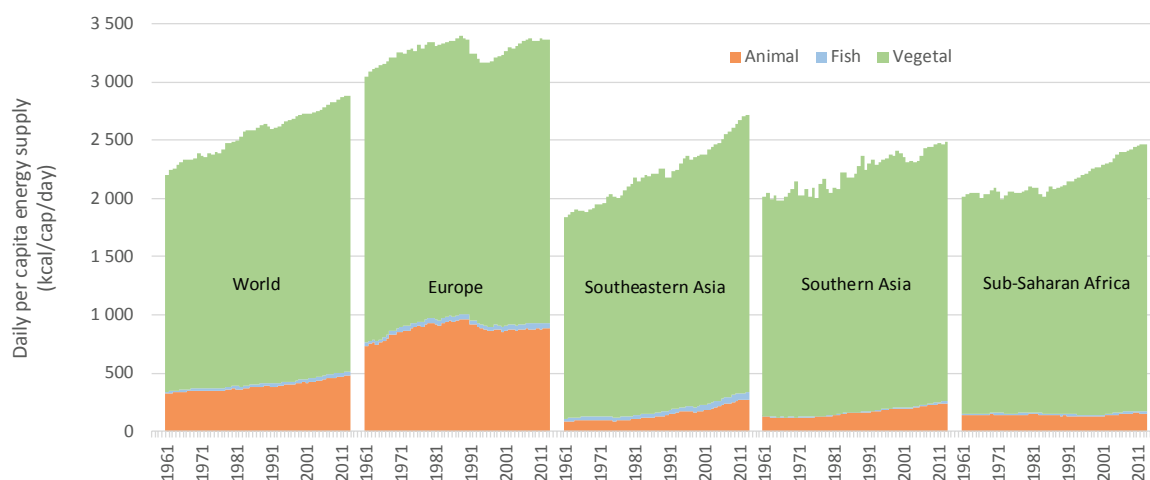
Figures 4a and 4b show the change in average daily per capita supply of proteins and energy from vegetal, fish and LDF between 1961 and 2013 for the world, Europe and the three developing regions, SEA, SA and SSA. Europe, despite impacts from the collapse of the Soviet Union, experienced little change during the last four decades. In contrast, during the same period SEA had a rapid increase in the overall supply of both proteins and food energy; since the 1960s, the share of the daily food supply of proteins from animal products doubled to 21%, from fish increased by half to 15%, and the share of total calories from both fish and animal products doubled to a total of 12% of supply. During the past five decades, SA also had an increase, but not as strong. SSA stands out. Although the total average daily supply of both proteins and calories have followed the pattern of SEA (albeit less marked), there is a major difference as the entire increase constitutes vegetal products. This aspect is of great importance as the lack of varied diets is believed to be one reason behind the still high levels of undernourishment, both overall and for underweight children (see Figure 8c and d, sub-Saharan Africa and western Africa) (FAO/IFAD/WFP 2015).

Figure 4a: Total daily per capita food protein supply, shown for animal products, fish and aquatic products and vegetal products, 1961–2013, for the world and four regions (g/capita per day).



Data: FAOSTAT 2016.

Figure 4b: Total daily per capita food energy supply, shown for animal products, fish and aquatic products and vegetal products, 1961–2013, for the world and four regions (kcal/ capita per day).

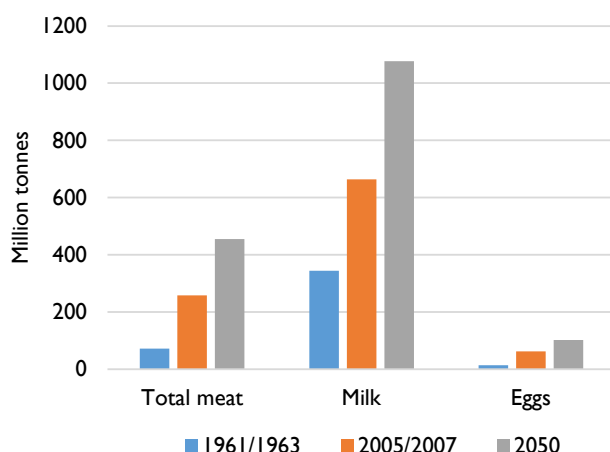


Data: FAOSTAT 2016.

2.3 Livestock production and consumption is trending strongly upwards with most of the growth in low- and middle-income countries

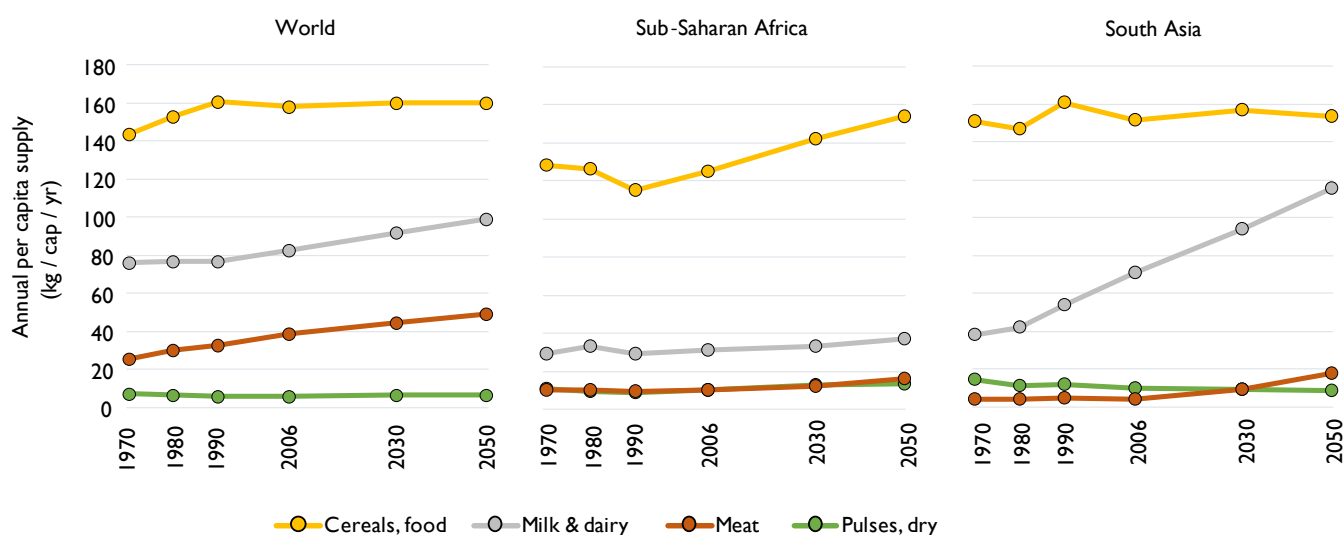
The last half-century has seen a strong growth in global production of meat (+260%), milk (+90%) and eggs (+340%) (Figure 5). This trend is predicted to continue in the coming decades. Compared with other protein sources, livestock product consumption is rising rapidly, whereas the long-term trend for pulses is of sustained consumption levels (Figure 6).

Figure 5: Global production (million tonnes) of livestock-derived food (1961–2050).



Data: Alexandratos and Bruinsma 2012.

Figure 6: Global annual per capita food supply (kg/capita per year) for selected food products, actual (1970–2005/2007) and predicted (2005/2007–2050) for: (a) world; (b) sub-Saharan Africa; and (c) south Asia.

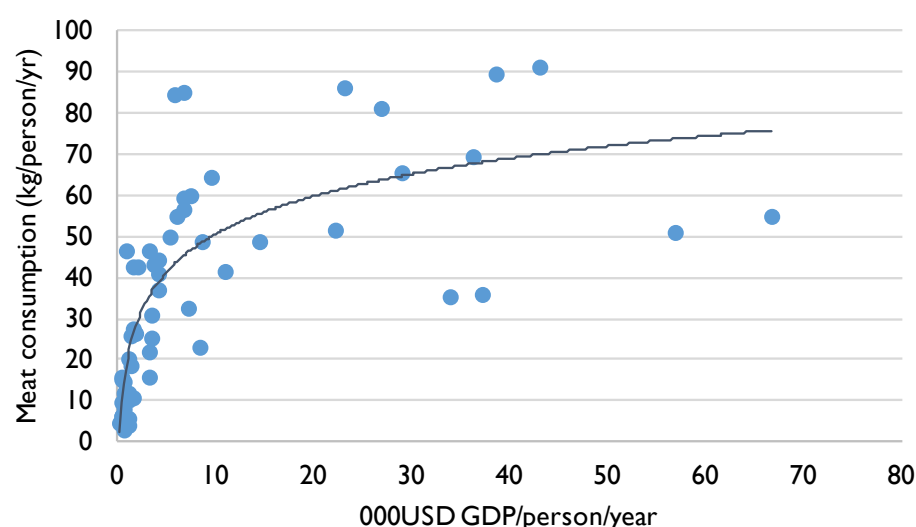


Data: Alexandratos and Bruinsma 2012.

The rapid increase in per capita consumption of livestock products has three main enabling factors that have allowed people to fulfil their common preferences to consume more ASF: increased wealth, reduction of the real price of LDF, and changing dietary preferences associated with urbanization and modernity (Delgado et al. 1999).

- i. Recent decades have seen overall increases in income in LMIC and declines in the number living in absolute poverty. In 2015, for the first time in history, less than one in ten live in absolute poverty (World Bank 2016). These long-term trends are the result of, among other things, economy-wide productivity gains, increased industrialization, better education, innovation and government spending on infrastructure. As countries become richer, their per capita consumption of livestock products also increases up to a point at which it levels off, although the extent of the increase depends on cultural and other factors (Figure 7).
- ii. The reduction in the (real) price of livestock products is related to increasing productivity and onward trend of feed costs. People in low-income countries spend a greater portion of their budget on food and are more responsive to income and food price changes than those in middle- and high-income countries. In real terms, world prices for all agricultural products are expected to decrease over the next decade, consistent with the long-term trend (OECD/FAO 2015). This is largely because productivity growth helped by lower input prices has outpaced the demand increases. Over the next 10 years, real prices are projected to decline from their 2014 levels but remain above pre-2007 levels. Favourable meat-to-feed price ratios over the coming period will support production growth, particularly for systems such as poultry and pork, which rely on intensive use of feed grains.
- iii. Urbanization is usually accompanied by increases in consumption of LDF. This is associated with higher incomes in urban areas, greater variety of food available and changing dietary preferences due to a different socio-cultural context (Regmi and Dyck 2001).

Figure 7: Meat consumption and GDP.



Data: World Bank.

Although global trends indicate a sustained growth in consumption of LDF, there are differences among regions. In SA, overall production and per capita consumption of meat and milk are both increasing, while the production of pulses and cereals is predicted to slightly decrease. In SSA, the production and consumption of meat and milk are expected to rise at an increased rate, although cereals are the commodity expected to figure more prominently in the food baskets in this region (Figures 6b and 6c).

While these figures represent regional trends showing a greater role of LDF in LMIC, it cannot be assumed that they represent improvements of the food basket or the diets for all population groups in the regions and both undernutrition and obesity co-exist in most of these countries (Black et al. 2013; Lobstein et al. 2015). The number (millions) and proportion of undernourished (%), and the proportion of underweight children (%), 1990–2015, are shown in Figure 8. A total of 795 million people were estimated to be undernourished in the world 2014–2016, with 780 million in LMIC. About 560 million, or 70% of all undernourished, are found in SSA, SA and SEA (Figures 8a, 8b and 8c).

Two goals to reduce national levels of undernourishment between 1991 and 2015 were the World Food Summit (WFS) target that aimed to half the number, and the Millennium Development Goal (MDG) hunger target that aimed to reduce the prevalence, both overall and in children under five years of age. Despite decreased prevalence of undernourishment in most developing regions over the past two decades, only SEA, of the three compared regions, reached both the MDG and the WFS targets. In both SA and SSA, the absolute number of undernourished individuals did not decrease; in SSA, the number even increased by 25%. In other words, interventions to reduce undernourishment kept pace with the continued and rapid population growth in these regions, but could not decrease the actual numbers of people suffering from undernourishment. Undernourishment, particularly for children, can be caused by a range of different factors, not only calorie or protein deficiency, but also poor hygiene, disease or limited access to clean water. These factors compromise the body's ability to absorb nutrients from food and eventually lead to manifestations of nutrient deficits such as stunting, wasting or being underweight (FAO/IFAD/WFP 2015).

Figure 8: Prevalence of undernourishment in: (a) southeastern Asia; (b) southern Asia; (c) sub-Saharan Africa; and (d) western Africa shown as total number of people being undernourished, the share of the population being undernourished, and the share of children under the age of five years being underweight.



Note: These graphs also show the World Food Summit (WFS) (1996) target to half the number of undernourished 1990–2015, and the Millennium Development Goal (MDG) (2001) hunger target to half the prevalence during the same period. Data: FAO/IFAD/WFP 2015.

Progress towards the MDG ‘hunger target’ is measured by two indicators: the prevalence of undernourishment and the prevalence of underweight children under five years of age. Where a lack of sufficient food is the main cause of being underweight, these two indicators normally move synchronously. However, where poor food utilization prevails, the two indicators are likely to diverge. Western Africa is one example of diverging trends for undernourishment and children underweight (Figure 8d). Higher availability of staple foods (see also SSA in Figure 4a and 4b) in large countries, like Ghana and Nigeria, reduced the undernourishment in the region to about 10%. However, due to prevailing dietary imbalances, insufficient quality of diets and inadequate hygiene conditions, the prevalence of underweight children remained at levels of more than 20%. Increased availability of carbohydrates is, therefore, unlikely to further improve overall food security in this area. Instead, interventions to prevent negative health outcomes, such as being underweight, wasting and stunting in children, should focus on the ability of poor people to access balanced diets and on overall living conditions (FAO/IFAD/WFP 2015).

2.4 Livestock product consumption in the first 1,000 days

Although the available data suggests that livestock products are an important protein source and that livestock food consumption is rising more rapidly than other foods in poor countries, there is less evidence on how much of this consumption is by children less than two years of age and pregnant mothers. Extensive studies on food consumption show that infants and pregnant women often have different consumption patterns than other family members. Intra-household distribution issues and cultural beliefs interfere with LDF consumption. For example, milk is often considered a suitable food for infants, while in some cultures eggs are not considered suitable for children (Iannotti et al. 2014). Across cultures, meat is the main target of prescriptions for pregnant women (Fessler 2002). Some information on consumption of LDF in the first 1,000 days is available from surveys carried out for research or development initiatives. The Demographic and Health Surveys (DHS) program has collected, analysed and disseminated accurate and representative data through more than 300 surveys in over 90 countries. Table 1 shows the average percentage of children consuming livestock protein in Africa and Asia in the 24 hours preceding the surveys of 2010–2014.

Table 1: Percentage of children reporting consumption of selected foods in low- and middle-income regions.

		Sub-Saharan Africa				Southern Asia				Southeastern Asia			
	Age (months)	Milk*	M,F,P**	Eggs	Legumes*	Milk	M,F,P	Eggs	Legumes	Milk	M,F,P	Eggs	Legumes
Breast-fed	0–6	5.6	2.1	0.9	1.0	15.8	0.1	1.1	0.4	6.1	1.9	2.4	0.6
	6–24	13.5	34.9	10.2	18.7	37.6	25.3	20.1	16.8	14.7	49.7	36.7	15.2
	Total	9.6	18.5	5.6	9.9	26.7	12.7	10.6	8.6	10.4	25.8	19.6	7.9
Non breast-fed	0–6	15.0	5.2	2.9	2.7	23.6	0.8	0.5	0	34.7	7.3	6.1	4.2
	6–24	23.9	50.5	16.5	24.0	62.3	35.1	28.7	21.8	23.8	65.8	45.9	19.8
	Total	19.5	27.9	9.7	13.3	43.0	18.0	14.6	10.9	29.2	36.6	26.0	12

Note: * Milk refers to milk other than breast milk. ** M,F,P refer to meat, fish and poultry. * Legumes includes nuts. Data source: DHS program; analysis this study.

DHS surveys give some insights into consumption of LDF by infants:

- A strong relation can be seen between mothers’ education and giving milk or milk products.
- A strong relation is also evident between higher wealth and higher consumption of LDF.
- Regional differences are marked: children in SA are overall more likely to receive milk, whereas children in SEA are more likely to be given eggs, meat, fish or poultry.
- There is considerable consumption of LDF at ages where exclusive breast milk feeding is recommended (less than six months).

2.5 Quantities of livestock products consumed by infants and pregnant women

DHS studies do not provide information on quantities of livestock products consumed by pregnant and lactating women or in children under two years of age. As such, they do not provide information on the contribution of LDF to dietary adequacy. Although there have been numerous surveys among different populations in LMIC, which include information on quantities, these have not been collected in a harmonized or systematic way, making it difficult to draw overall conclusions on quantities consumed in the first 1,000 days.

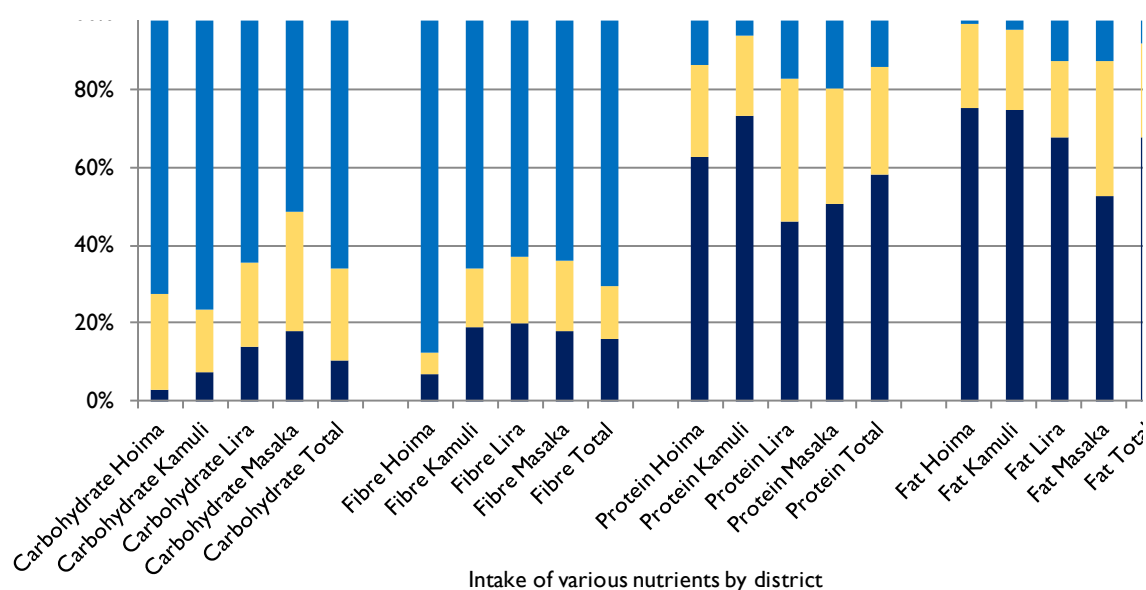
However, these studies can provide case studies and local insights. For example, a recent survey (2014) among poor families living in informal settlements in peri-urban Nairobi found almost 40% of the children did not consume milk daily. Meat and other LDF were eaten by very few children and only in small amounts (Table 2). Similarly, a survey in Kampala showed that the diets of children among poor communities were rich in carbohydrates and fibre and poor in proteins and fat (Figure 9).

Table 2: Nutritional indicators of participant children (1–3 years of age) in poor households of Nairobi.

Child dietary intake* (n=77)	Mean	% of children consuming
Milk intake [g/day]	137	61.0
Dairy products intake [g/day]	149	7.8
Beef meat intake [g/day]	12	5.2
Goat meat intake [g/day]	11	1.3
Chicken meat intake [g/day]	25	3.9
Egg intake [g/day]	35	5.2
Fish intake [g/day]	19	11.7
Total daily diet cost [KES]	65	

Note: *Children still breastfeeding. Source: Dominguez et al. data unpublished.

Figure 9: Diets of children in various districts of Uganda.



Source: Ouma et al. under review.

2.6 Conclusions

LDF are not a primary component of the diets in LMIC. Although LDF are an optimal source of protein, their contribution to the total protein intake in LMIC is still limited, contrary to what is observed in developed regions. Also, consumption patterns are very heterogeneous across regions and countries and different LDF are preferred in different countries. The increases in energy and protein intake registered in LMIC over the past decades have relied mostly on increased vegetable intakes rather than LDF. All LMIC regions have seen a falling prevalence of undernourishment overall and in children under five years of age, but undernourishment in absolute numbers prevails at 280 million in SA and has increased to 220 million in SSA. Overall, per capita supply of LDF (especially poultry, pork, milk and eggs) is rising, while that of pulses has remained constant over the years. Predictions indicate that the consumption of LDF will keep increasing in the coming years in SEA and SA and to a much lower extent in SSA.

There is very limited information on LDF consumption by infants and pregnant and lactating women. Surveys suggest that, despite the recommendations of the WHO of exclusive breastfeeding until six months, it is common practice in many LMIC to feed livestock products to children under six months of age, especially milk. Surveys conducted among families in poor urban and rural villages show that many children in these contexts are not getting adequate protein and their diets are far from adequate. The evidence confirms that there is considerable room to improve consumption of LDF among infant, children and pregnant and lactating women.

3. Empirical evidence on the impacts of livestock-derived foods on nutrition

3.1 Evidence on the links between livestock-derived foods and nutrition: a systematic literature review of interventions in the first 1,000 days

Reports from international organizations and research studies show that the majority of the poor populations in LMIC consume limited amounts of LDF, are frequently undernourished, and have low micronutrient intakes (Smith et al. 2013). It has been suggested that in such populations, the benefits of increased LDF consumption on nutritional outcomes could be more marked, given the high-nutrient profile of these food products (Gupta 2016). The potential for LDF to improve nutrition outcomes is generally well accepted, particularly in the case of the first 1,000 days (Smith et al. 2013) (see section 1.1 in this report). A number of studies, discussed in the sections below, have indicated the importance of LDF to leverage nutrition; much of this evidence, however, comes from observational cross-sectional studies, which do not allow us to make causal inferences. In general, the evidence on the effect of LDF on nutritional indicators is still limited and the results are mixed. To summarize the most relevant available scientific evidence on the effect of LDF on nutrition outcomes during the first 1,000 days, we conducted a systematic appraisal of peer-reviewed publications. The search focused on experimental designs testing the nutritional and health effects of (non-fortified) LDF consumption interventions in southern and southeastern Asian and African countries, which are the two areas with larger proportion of undernourished populations in the world. We chose to focus on these regions as the effect of LDF might vary among settings and in the context of complete diets and nutrient intakes. We identified and assessed the research studies testing the impact of LDF consumption among infants up to two years of age and pregnant and lactating women. The specific research question was: *‘Do interventions that increase consumption of LDF (i.e. meat, milk and eggs, and derived products) among children aged 0–2 years and/or among pregnant and lactating women improve nutrition outcomes during the first 1,000 days of life in southern and southeastern Asian and African countries?’* To make the findings more comprehensive, the search was expanded to include children up to 18 years of age, thus including adolescents. The findings were complemented with a discussion of the evidence from other regions and other types of study designs.

Methods

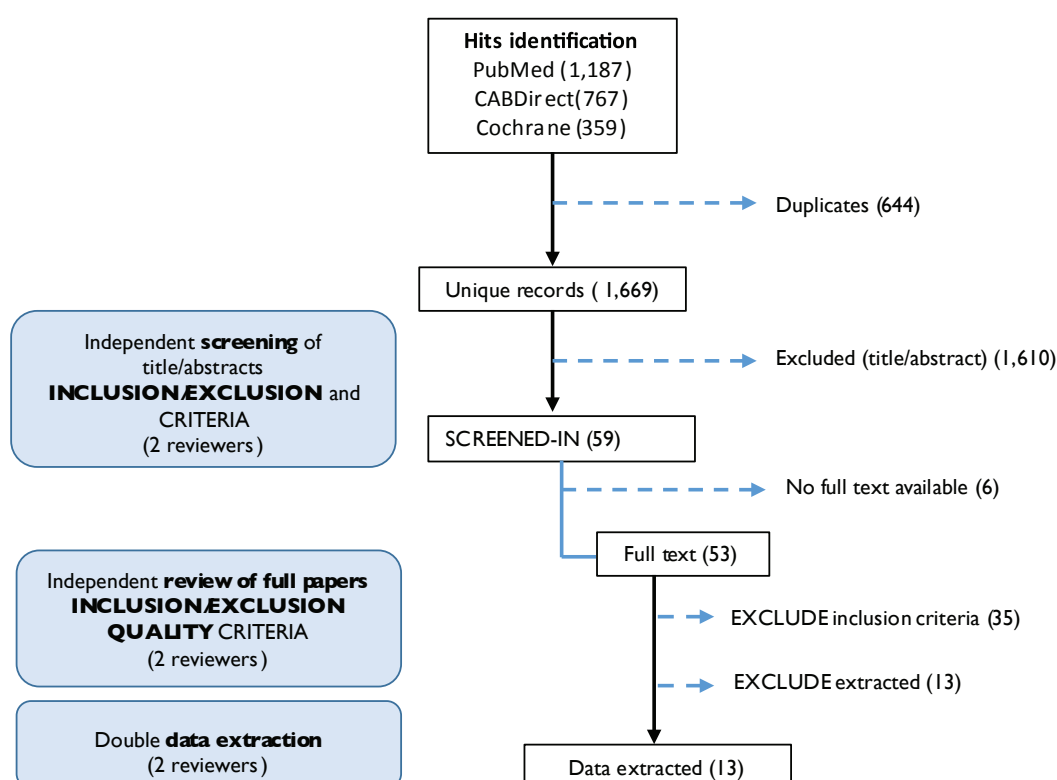
The protocol followed PRISMA principles (Preferred Reporting Items for Systematic review and Meta-Analysis). The literature search was conducted in three online databases: Pubmed, Cochrane and CABDirect. These were selected on grounds of suitability to capture such experimental designs and because they were expected to cover much of the available relevant literature. Database-specific search syntax was developed to capture all relevant papers while avoiding the retrieval of an unmanageable number of irrelevant papers. To make the findings more comprehensive, the search was expanded to include children up to 18 years of age. The search syntax and number of hits are presented in Annex 3. In order to select the most relevant studies to answer the research question, inclusion criteria were set as shown in Table 3.

Table 3: Inclusion criteria for the systematic review (PICO table).

Population	Geographic location: conducted in an LMIC in Africa and southern and southeastern Asia Age group: Children under 18 years OR pregnant women OR lactating women
Intervention	Addition to diet of LDF (i.e. milk and dairy products, eggs, meat, offal and their products coming from mammal and poultry farm animals), NOT as part of fortified foods or therapeutic foods or mixed diets (i.e. a dish containing LDF along with other food products)
Comparison intervention	No addition of LDF
Outcome	Nutrition outcome indicators. The primary outcomes considered were anthropometric measurements (e.g. height-for-age, weight-for-height, weight-for-age, body mass index) and micronutrient status markers. Other secondary outcomes were considered, such as cognitive development and other health related outcomes (e.g. diarrhoea).
Other issues	Publication date: before April 2016 Language: English (syntax is in English); any potential publications retrieved in French or Spanish will not be excluded.

We focused on papers presenting original research studies (i.e. not review papers) of randomized and non-randomized control trials in the first 1,000 days of life (i.e. observational studies were excluded). This was because although observational studies can indicate that LDF are associated with better nutritional outcomes, they cannot be used to prove LDF caused these outcomes. Studies lacking a control group or not presenting the results of analysis comparing intervention and control groups were also excluded. Again, these studies cannot attribute changes to LDF because they cannot eliminate the possibility that the change observed was due to something other than the LDF. Finally, papers reporting on the effect of LDF as part of therapeutic foods were excluded; in this case LDF are not a dietary component but rather a treatment product, with a specific formulation including LDF (frequently milk) and this was beyond the scope of this study. However, it is worth noting that therapeutic products are extensively and increasingly consumed in LMIC and the role of LDF in their preparation is important; this is another relevant question related to the use and benefits of LDF, particularly in children under five years of age, worth investigating separately. The stages of process are shown in Figure 10.

Figure 10: Stages of the screening process.



The search in the three databases returned a total of 2,313 studies, which were reduced to 1,669 after the elimination of duplicates. The titles and abstracts were uploaded to an Excel file database and screened in two stages. First, a double-blind screening was conducted, using the inclusion and exclusion criteria, by two different reviewers. All articles considered relevant by both reviewers were retained; articles considered relevant by just one reviewer were reviewed again by a third reviewer and a decision was made on eligibility. This process led to the exclusion of 1,610 studies, resulting in 59 studies for full paper screening. The full manuscripts were downloaded: six papers were not found accessible online (three of them seemed to be only abstracts). Finally, 53 full papers were read by two different reviewers each to: i) evaluate relevance (compliance with inclusion criteria) and ii) assess the quality (based on criteria such as an appropriate study design and reporting, and whether efforts had been made to minimise selection bias, according to Cochrane 'assessment of bias' guidelines). Removal of papers in the previous screening step was conservative; reasons for exclusion at this stage were still related to an ineligible design (i.e. experiment without control), inadequate food product (e.g. fortified or therapeutic food, complex dishes etc.) or ineligible country. A data extraction template was prepared on Excel and data was extracted and summarized from each of the final eligible papers by two separate reviewers who also assessed the risk of bias.

Some of the outcomes in the inclusion criteria (e.g. blood biomarkers) can experience variation related to the time of the day and other factors, but are generally objectively measurable indicators with considerable precision. The number of studies included in the review was limited, covering a broad number of different indicators. Therefore, the number of papers for each indicator and age group remains very low in all cases (e.g. two for lactating women, one for toddlers, two for haemoglobin or zinc, one for specific cognitive ability tests, etc.) which prevents any meaningful meta-analysis.

Results and discussion

Although the supplementation of women's and children's diets with LDF might be considered a relatively useful and feasible intervention to improve nutritional outcomes, the low number of research papers identified and selected in this review highlights the limited amount of evidence to inform policy guidelines and interventions. The studies retained at the final stage of the review included 13 manuscripts: 11 related to milk, 7 to red meat and 1 to eggs. None of the studies looked at poultry meat. Of these 13 papers, which correspond to only 8 different studies as several of the manuscripts present various outcomes of the same intervention study, only 3 investigated the effects of LDF during the first 1,000 days (1 in infants and 2 in lactating women). The other 10 involved older children. The key features of the selected peer-reviewed papers are compiled in Table 4 with brief description of the indicators in Annex 4. The quality of the papers was variable. Most studies lacked power calculations, the reporting was not always complete (i.e. several studies failed to fully report the selection criteria and the results of the analysis), the data analysis did not always appear to be completely sound and in some cases there were potential sources of bias, such as the difficulty to ascertain compliance during the intervention.

Livestock-derived foods during the first 1,000 days

The importance of quality, nutrient-rich food intake during the first 1,000 days has been discussed in the previous sections. Inadequate intake during gestation is known to have far-reaching adverse consequences in the offspring through foetal programming (e.g. impaired growth of foetuses and infants, high risk of metabolic syndrome, etc.). However, our review found no studies addressing the role of LDF in the nutrition outcomes of pregnant women in the settings under study. Two studies, albeit with small sample sizes, focused on lactating mothers, one in Sri Lanka (Tennekoon et al. 1996) and another in Burma (Khin-Maung-Naing and Tin-Tin-Oo 1987), the former intervening with ~50 g of skimmed milk powder and the latter with an unspecified amount and type of animal protein. The studies observed a positive effect on breast milk outcomes as well as on weaning practices:

- The Sri Lanka study found that the number of women giving additional foods at time of postpartum in the skimmed milk supplemented group was lower than in the control and the supplemented group introduced other feeds five weeks later than the control group ($p < 0.05$).

- The Burma study found a positive effect of animal protein diet supplementation in milk output and milk intake by children, but lacked the specifications on the type and amount of LDF tested.
- Finally, one study focused on young children (<2 years). The study was conducted in Kenya, comparing three different isocaloric diets (Long et al. 2012). The study found that, compared with the meat group, both the milk and the plain (control) groups had better growth rates for height (5.5 vs 6.0 cm) and mid-arm muscle area (MAMA) (73.6 vs 31.2 mm²), respectively. This role of meat in growth aligns with the findings from other studies (see Table 4), but this study looked at a reduced number of anthropometric indicators, with other potential benefits of meat not being explored.

Livestock-derived foods in children 2–18 years of age

Within our review, the majority of the studies in children were conducted among schoolchildren and mostly through school meals as these provide a good controlled vehicle for the interventions. In New Guinea, children aged 8–12.5 years were fed 25 g of skimmed milk powder per day at school for eight months, at the end of which they showed increased height (mean difference = 1.77 cm) and weight (mean difference = 0.86 kg) compared to the control group as well as increased immune response, as shown by total antibody titers at eight weeks (490 vs 170) (Mathews et al. 1974).

Seven–eight year old Vietnamese children, who supplemented their daily diets with 500 ml of plain milk for six months, saw a significant improvement in weight-for-age, showing a 13% reduction in the prevalence of underweight children in comparison to the control children (Lien et al. 2009). The milk interventions (i.e. regular milk and fortified milk) also seemed to have a positive effect on micronutrient status: intervention groups showed more than twice the levels of haemoglobin and near four times the ferritin levels, as well as reduced vitamin A and zinc deficiency prevalence.

In Malaysia, a study comparing nutritional outcomes in three groups (two supplemented with milk or eggs for six months, and one without supplements) did not find differences across the groups; the choice of indicators and statistical analysis conducted make it difficult to draw conclusions (Ihab et al. 2014).

In Iran, a study supplementing school children with milk looked at the effect on growth (weight, height and mid-upper arm circumference) as well as cognitive development, but it did not show any clear differences between the groups. This paper highlighted the potential differences between the responses of boys and girls, possibly related to the different age of the onset of puberty.

In Kenya, an RCT among primary-school children (6–14 years of age) assessed the effects of milk, meat or energy supplementation compared to a control group on micronutrient status and a variety of different anthropometric and development outcomes (Grillenberger et al. 2003; Hulett et al. 2014; Siekmann et al. 2003). The study found negligible effect of milk in child linear growth; however, younger (≤ 6 years) and stunted children showed a greater rate of height gain; both milk and meat improved arm-muscle mass and vitamin B12 status (McLean et al. 2007; Neumann et al. 2007). Compared to a baseline of various micronutrient deficiencies (i.e. iron, zinc, vitamins A, B2 and B12), after one year of the intervention, only the levels of vitamin B12 in blood experienced a statistically significant increase (Siekmann et al. 2003). Specifically, these LDF interventions (meat and milk) led to a marked decrease in low plasma vitamin B12 (<148 pmol/litre) prevalence among participants (i.e. 8.9% in the milk group and 4.5% in the meat group, compared to the baseline prevalence of 40.2% and 56.2%, respectively). In addition, meat improved cognitive performance, school test performance, leadership behaviour and physical activity (Neumann et al. 2007; Sigman et al. 2005; Whaley et al. 2003). This effect of meat on cognitive development is thought to be related to greater intake of vitamin B12 and more available iron and zinc. Together with high-quality protein, these may facilitate specific mechanisms such as the speed of information processing in learning tasks.

De Beer conducted a meta-analysis of the effect of dairy products and physical stature that combined different type of studies from different countries, including the studies above from Vietnam, Kenya and the Indonesian province of Papua as well as others from Europe, the United States of America (USA) and China. It identified two other studies

that related to the same school children in Papua which did not come up in this search (Malcolm 1970; Lampl et al. 1978). They both found that the children whose diets were supplemented with skimmed milk for 8 months showed increased height. De Beer concluded that there is moderate evidence (the most likely effect is 0.4 cm per annum additional growth, with 245 ml of milk daily) that dairy product supplementation stimulates growth (De Beer 2012).

It is believed that LDF could also play an important role in subjects with non-diet related causes of malnutrition, such as HIV, for which improved nutrition may delay the progression to AIDS and improve effectiveness of antiretroviral drug therapy. One study by Collin et al. (2016) examined the effect of skimmed milk supplementation in HIV positive children, naïve to antiretrovirals, comparing its effect against leaf-concentrate powder. The effect of both interventions in anthropometric measures and immune function markers did not differ; however, the study did not compare against a control group without supplementation of nutrient-rich foods and had a small sample size (Collin et al. 2016).

A new RCT is being conducted, examining the effect of three different high-nutrition isocaloric biscuits, formulated out of soybean, meat (dried beef) or wheat flour, to assess the value of increasing animal protein in diets of Kenyan HIV-infected women and their children (Ernst et al. 2014) but the results are not yet available. Outcome measures in this study include growth, lean body mass, muscle strength, development and child activity, and immune function, among others. It is expected this trial will add interesting and novel insights to the existing body of evidence around LDF and nutrition outcomes in children.

Limitations

In summary, in the reviewed studies we found some consistency towards a positive role of milk in linear growth and mid-upper arm circumference (MUAC) in children, although this effect was not found in all studies. Results focusing on child micronutrient levels were scarce and contradictory. The only study that assessed the effect of eggs was unable to demonstrate an effect on growth, but found the intervention to be positive for height. The two studies looking at cognitive skills related to school performance, leadership, etc. showed a stronger positive effect of meat and some positive effect of milk. Only two studies on women were included in the review, finding mostly no effect on a series of indicators (different in both studies), but showing a positive effect of milk in breastfeeding duration and some effect of animal protein in milk output.

A brief summary of the quality assessment and risk of bias of each of the included studies can be found in Annex 5. The main issues leading to bias were related to the study designs. Several relatively old studies and also some more recent ones were not systematic and specific enough in the reporting of the methods, making it difficult to assess the quality of relevant aspects such as randomization, allocation concealment or attrition. The nature of the intervention often made it difficult to render the participants and data collectors blind to the intervention. This lack of blinding in dietary studies can modify the normal diet of the participant. In the cases where the intervention was done at household level, adherence to the intervention (i.e. consumption) was often measured by self-reporting; it was difficult to assess whether the food item in the intervention had been fully consumed by the participant in the household or had been used by other members of the household.

This review found a limited number of research papers meeting our inclusion criteria. Those few papers covered different LDF. Milk was the LDF for which we found more studies, but there was only one study focused on egg consumption and none on poultry meat. Obviously, any effect reported for one LDF cannot be extrapolated to any other LDF. The review also found a limited number of studies by life stage (i.e. pregnant/women = 2, infants = 1, older children (2–14 years of age) = 5), often focusing on different outcomes. Again, the effect of LDF might be quite different for the different groups.

It is important to note that some of the indicators considered do not show immediate response to an intervention and are the result of long-term nutrition (e.g. stunting, cognitive development). Duration of supplementation varied from two weeks to almost two years. Most interventions lasted three months or more. The amount given was variable but considered a minimum of one cup of milk or 60 g of meat (only one study with eggs was found, which distributed two eggs).

Overall, these results bring some relevant evidence on the benefits of LDF to child nutrition and also highlight that different LDF can present different beneficial effects and can have different effects across different nutrition-related domains, potentially also varying according to specific characteristics (sex, child age, nutrition status etc.).

Indeed, there was some evidence indicating that malnourished children could benefit more from LDF consumption than normal children (Neumann et al. 2007). This variability, in addition to the fact that many studies have very small sample sizes and often do not include power calculations to indicate whether the lack of effect is real or due to a limited power of the study to detect differences, can result in seemingly inconsistent results. Also, the usual diet can also affect the results, particularly if they take place in populations already consuming significant amounts of, for example, milk, who may not experience such dramatic effects. All these factors could explain some of the counter-intuitive results. Studies conducting LDF diet supplementation at household level face clear difficulty in monitoring compliance: school interventions allow for better monitoring, which might explain why there is much more research in school children. Also, the quality and the type of analysis in these studies were not homogeneous. For all these reasons, caution is needed when interpreting the findings of our review.

Although it is accepted that well-designed RCTs are the best study design to assess the impacts of interventions, studies using single food items may not be the most valuable for policymaking and a failure to show an effect may be related to the delivery of the intervention. Therefore, these studies should be complemented by evidence from other types of studies.

Table 4: Overview of the reviewed intervention studies with livestock-derived foods and their effect in nutrition outcomes.

Country/ Study	Participants	Overall sample size	Intervention (quantity and frequency)	Intervention type	Outcomes measured	Effect of the LDF intervention	Statistical significance
1,000 days							
Kenya (Long et al. 2012)	Rural toddlers (11–40 months)	274	Red meat in porridge (370 g/day)	cRCT, ^{iv} 3 isoenergetic arms: plain porridge (no LDF), meat porridge, milk porridge.	HAZ	Milk>Plain>Meat	*
			Milk in porridge (360 gr/day)		MUAC	Milk>Plain>Meat	*
			5 days/week for 5 months		MAFA	No difference	NS
					MAMA	Plain/Milk>Meat	*
Sri Lanka (Tennekoon et al. 1996)	Undernourished lactating women (20–35 years)	60	Skim milk powder (400 g/week, daily intake), from 4 weeks postpartum, until 2–3 menstrual periods	RCT, 2 arms (skimmed milk vs no intervention); women recruited from postpartum ward, in matched pairs	Exclusive breastfeeding duration	Milk>Control	*
					Maternal BMI	No difference	NS
					Prolactin levels	No difference	NS
					Lactation amenorrhea duration	No difference	NS
					No. of feeds	No difference	NS
					Infant weight	No difference	NS
Burma (Khin-Maung-Naing and Tin-Tin-Oo 1987)	Lactating women (18–35 years)	21	Animal protein cooked in oil (unspecified) meal twice a day, for 14 days	RCT, 2 arms (animal protein vs control); women in the supplement group were offered a dish of curry at meal times	Milk output	Increased in ASF meal group compared to baseline	*
					Milk intake (baby)	Increased in ASF meal group compared to baseline	*
					Milk protein content	No difference in endline versus baseline in ASF meal group	NS
Additional criteria (children 2–18 years)							
Malaysia (Ihab et al. 2014)	Malnourished children (2–10 years)	90	Milk (500 ml/day)	RCT, 3 arms (milk group, vs egg group vs control); from food insecure households	Height	No difference	NS
			Eggs (2 eggs/day) for 6 months		Weight	No difference	NS
					MUAC	No difference	NS

Country/ Study	Participants	Overall sample size	Intervention (quantity and frequency)	Intervention type	Outcomes measured	Effect of the LDF intervention	Statistical significance
Iran (Rahmani et al. 2011)	Primary school children (first to third year)	469	Sterilized milk (250 ml/day) for 3 months	cRCT at 4 primary schools (milk vs control)	Weight Height MUAC IQ (Raven's coloured progressive matrices) Non-verbal test (Wechsler intelligence scale)	No difference No difference No difference No difference No difference	NS NS NS NS NS
Kenya (Grillenberger et al. 2003; Neumann et al. 2013; Siekmann et al. 2003; McLean et al. 2007; Sigman et al. 2005; Whaley et al. 2003; Hulet et al. 2014)	School children (6–14 years)	370–498	Githeri with milk (100g with 250ml); or Githeri with meat (140g with 85 gr; or Plain githeri (230g), for 21 months (5 days/week)	cRCT, 4 isocaloric arms (githeri ⁱⁱⁱ +milk vs githeri ⁱⁱ +meat vs githeri vs githeri with oil vs no intervention); intervention at primary school	Grade point WHZ ⁱⁱ Weight ⁱⁱ HAZ ⁱⁱ Height ⁱⁱ MUAC ⁱⁱ MAMA ⁱⁱ MAFA ⁱⁱ Triceps skinfold ⁱⁱ Subscapular skinfold ⁱⁱ Haemoglobin ⁱ Plasma ferritin ⁱ Serum iron ⁱ Serum zinc ⁱ Serum copper ⁱ	No difference No difference Meat/Plain githeri/ Milk>Control No difference Milk>Meat/Plain githeri/ Control only in young children with low baseline HAZ Milk/Plain githeri> Control>Meat Meat>Milk>Plain githeri/ Control Meat>Milk>Plain githeri/ Control No difference No difference No difference No difference No difference No difference No difference No difference	NS NS * NS * * * NS NS NS NS NS NS NS NS

Country/ Study	Participants	Overall sample size	Intervention (quantity and frequency)	Intervention type	Outcomes measured	Effect of the LDF intervention	Statistical significance
			cRCT, 4 isocaloric arms (githeri ⁱⁱⁱ +milk vs githeri+meat vs githeri vs githeri with oil vs control); intervention at primary school		Plasma folate ⁱ	No difference	NS
					Plasma retinol ⁱⁱ	No difference	NS
					RBC riboflavin ⁱ	No difference	NS
					Plasma Vitamin B12 ⁱⁱ	Meat>Milk> Plain githeri/Control	*
					Test scores ⁱⁱ	Meat>Milk> Plain githeri/Control	*
					Raven's coloured progressive matrices ⁱⁱ	Meat>Milk/Plain githeri/Control	*
					Verbal meaning test ⁱⁱ	No difference	NS
					Arithmetic test ⁱⁱ	Meat/Plain githeri>Milk/Control	*
					Leadership ⁱⁱ	Meat>Plain githeri>Milk/Control	*
					Low activity ⁱⁱ	Control/Plain githeri/ Milk>Meat	*
					High activity ⁱⁱ	Meat>Plain githeri/ Milk>Control	*
					Initiative ⁱⁱ	Meat>Plain githeri/Milk>No intervention	*
					Solitary play ⁱⁱ	No difference	NS

Country/ Study	Participants	Overall sample size	Intervention (quantity and frequency)	Intervention type	Outcomes measured	Effect of the LDF intervention	Statistical significance
Vietnam (Lien et al. 2009)	School children (7–8 years)	444	Milk and fortified milk 250mlx2/day for 6 months (6 days/ week)	RCT, 3 arms (Regular milk vs fortified milk vs no intervention); intervention at primary school	Underweight % WAZ Wasting % WHZ Stunting % HAZ Haemoglobin	Reg milk/ Fortif > No intervention No difference No difference No difference No difference No difference Fortif/ Reg milk > No intervention	* NS NS NS NS NS *
					Anaemia %	Fortif > Reg milk > No intervention	*
					Ferritin	Reg milk/ Fortif > No intervention	*
					Vit A deficiency	Reg milk/ Fortif > No intervention	*
					Zinc deficiency	Reg milk/ Fortif > No intervention	*
					Iodine deficiency	No difference	NS
					Height	Milk > No intervention	*
					Weight	Milk > No intervention	*
					Total antibody titers	Milk > No intervention	*
					IgG antibody titers	No difference	NS
New Guinea (Mathews et al. 1974)	School children (8–12.5 years); growth retarded	54	Skimmed milk powder (25 gr protein/day) for 8 months (5 days/week)	Non-randomized controlled trial, 2 arms (skimmed milk vs no intervention); intervention at board school			

i One year follow up; ii Two year follow up; iii Githeri, a traditional meal made from maize and beans; iv CRCT stands for cluster randomized control trial; *p-value<0.05; NS, non-significant; BMI, body mass index; HAZ, height-for-age Z-score; IgG, immunoglobulin G; MAFA, mid-arm fat area; MAMA, mid-arm muscle area; MUAC, mid-upper arm circumference; RBC, red blood cells; WAZ, weight-for-age Z-score; WHZ, weight-for-height Z-score. Only significant relations were reported above; associations not reported implies they were not significant. A brief description of the indicators can be found in Annex 4.

3.2 Other related studies

Additional scientific evidence from RCTs explored the links between LDF intake and child nutritional outcomes, but were excluded from our systematic review on the basis of the geographic location, absence of control, or fortification. For example, an RCT of LDF conducted in China compared the difference in anthropometric measurements of 1,471 toddlers 6–18 months of age, receiving daily (isocaloric) supplementary feeding regimes of pork meat or cereals as complementary food, for one year (Tang et al. 2014). From the longitudinal assessment, the meat group showed a statistically significant greater linear growth (increase of 13.0 cm versus 12.75 in cereal group, p -value=0.01) and a smaller decline in length-for-age (-0.43 Z-scores vs -0.54 in cereal group, p -value<0.01). An RCT conducted in the Ecuadorian highlands provided one egg per day to children aged 3–9 months for six months and the growth and micronutrient results were compared with a control with no intervention. Both groups received social marketing messages (Iannotti et al. 2017a; Iannotti et al. 2017b). No allergic reactions to eggs were reported. An increase of length-for-age Z-score of 0.63 was found in egg supplemented children compared with the control, as well as a reduced prevalence of stunting by 47% and increased plasma concentrations of micronutrients such as choline (effect size: 0.35, 95% CI: 0.12–0.57); betaine (0.29, 0.01–0.58) or methionine (0.31, 0.03–0.60), while no significant differences were found for vitamin B12, retinol, linoleic acid or α -linolenic acid. This indicated that the early introduction of eggs can significantly improve growth and other markers. However, it was only compared with a non-intervention group, making it difficult to establish the comparative effect of eggs in relation to other supplementary foods.

In the US, infants were assigned to complementary feeding of meat or cereal; meat was associated with greater linear growth and weight gain (p -value< 0.05) (Tang and Krebs 2014). In New Zealand, it was shown that consumption of iron-fortified milk could increase iron stores in healthy toddlers and that increased intakes of red meat could prevent the decline of iron stores (Szymlek-Gay et al. 2009). Also, a study was conducted in four sites (Guatemala, Pakistan, Democratic Republic of the Congo and Zambia) to test whether 12 months of daily intake of beef, added as a complementary food, would result in greater linear growth compared to a micronutrient fortified supplement; it found no difference (Hambidge et al. 2011; Krebs et al. 2012). However, this study also did not include a control group consuming the usual diet (likely nutrient-deficient), failing to investigate the net effect of LDF compared to a normal diet. In addition, a review of the efficacy of 15 complementary feeding trials concluded that supplements containing at least some dried milk significantly improved growth in length in 12 of the trials; however, the feeds often contained other additional ingredients, and included fortified foods (Allen and Gillespie 2001). Mongolian and Chinese women who were supplemented with milk showed significantly higher serum folate concentrations during gestation, as well as in the cord blood at birth, compared to controls. Their infants also had better birth weight and height (Li et al. 2014).

Beyond LDF, research studies have been conducted in non-livestock ASF, such as fish or insects, which are also good sources of quality animal protein. Many fish studies have been conducted using derived products such as fish oil, frequently used in supplements, to assess the role of fatty acids on cognitive development. One study investigated fish flour/ ground fish in relation to fish fatty acid composition and its effect on child cognition and bone density, with positive results (i.e. significant higher levels of eicosapentaenoic and docosahexaenoic acid, better performance in different cognitive tests and increased bone density among children consuming fish flour/ground fish) (Dalton et al. 2009).

An RCT was conducted to assess the efficacy of a cereal containing caterpillars on reducing stunting and anaemia in six-month old infants in a rural area in the Democratic Republic of Congo (Bauserman et al. 2015). The study of 125 children who were followed up for one year, found no difference in prevalence of stunting (67% versus 71%, P =0.69) or in estimates of body iron stores (6.7 versus 7.2 mg/kg body weight, p -value= 0.44) between the intervention and control groups, but infants in the intervention group had higher haemoglobin concentrations than the control group (10.7 versus 10.1 g/dl, p -value= 0.03) and lower prevalence of anaemia (26 versus 50%, p -value= 0.006). In general, it is important to note that given the multifactorial nature of malnutrition, stunting is not solely attributable to inadequate micronutrient intakes and therefore might not be modifiable simply by increasing the nutrient content of complementary foods.

Moreover, although observational studies are unable to demonstrate causality in the relationship between LDF and nutrition outcomes, various studies have tried to explore this link providing interesting insights. For example, a recent research on ASF and stunting in early childhood with DHS data from 46 countries documented the low ASF consumption patterns (particularly for eggs and meat and in sub-Saharan Africa) in different regions, explored the reasons for this low consumption, focusing on price, and finally examined how this consumption is associated with stunting. Heady et al. (2017) found a strong association with consumption of any animal-source food, with dairy and fish being the most important. These results also suggest that there are multiple barriers to ASF consumption, including cultural barriers or supply-side constraints resulting in high prices of ASF. Research conducted using Optifood (linear programming software) has also highlighted the important contribution of LDF to dietary adequacy in young children, particularly for difficult nutrients like iron and zinc (Fahmida et al. 2014; Ferguson et al. 2015).

Consumption of ASF in Cambodia was associated with reduced risk of stunting and underweight (Darapheak et al. 2013). While observational studies in developed countries should be considered with caution given that the baseline diets are likely to differ substantially from those of LMIC, some showed interesting evidence that increased milk consumption during pregnancy was associated with increased birth weight and length, and that this effect might even span into early adult age (Hrolfsdottir et al. 2013). A systematic review on milk and dairy consumption during pregnancy in Western women showed that whilst two studies reported no association, four reported positive associations of birthweight with milk and/or dairy consumption, suggesting that moderate milk consumption relative to none or very low intake is positively associated with foetal growth and infant birthweight (Brantsaeter et al. 2012). Also, the effect on blood pressure in the adult offspring of women advised to eat a high-animal protein, low-carbohydrate diet during pregnancy was assessed in Scotland (Shiell et al. 2001). Adults (27–30 years old) born to mothers with greater consumption of meat and fish in the second half of pregnancy had higher systolic blood pressure. Furthermore, higher diastolic pressure in the offspring was associated with mother's fish consumption. The authors suggested that this effect could be a response to the metabolic stress imposed on the mother by an unbalanced diet. It is also important to highlight that effects could be different at different stages of pregnancy. A review of the dietary determinants of iron deficiency of young women in industrialized countries found that in cross-sectional studies only meat intake was consistently (and positively) associated with higher serum ferritin concentrations, but this effect might be affected by the simultaneous consumption of foods with inhibitory factors (Beck et al. 2014). Similarly, a meta-analysis across 24 cross-sectional studies showed that adult vegetarians have significantly lower serum ferritin levels than their non-vegetarian controls (Haider et al. 2017). This evidence together generally indicates that the effects of LDF consumption can be highly context-specific and dependent on the relative presence of different diet components, which can substantially differ by region, country and possibly also at subnational level, as well as on the baseline diet and nutritional status. The effects also seem to be heterogeneous among different LDF and among different population groups.

3.3 Further research needs

Some of the issues identified through this review of the published scientific literature include: a) studies having small sample sizes and, therefore, likely limited power to detect small effects (power calculations were often not presented in the reviewed articles); b) a lack of a comprehensive assessment of all potential nutrition outcomes (i.e. although physiological and instrumental variations are possible, measurement of micronutrient biomarkers in blood or urine are gold standards in these types of studies, though sample collection can be logistically challenging and analysis expensive. Anthropometric measurements, however, require simple technology and moderately skilled staff can easily be trained, although measurement errors are possible due to anthropometrist/ measurement tool bias or misreporting of age in children, which are aggravated by small sample sizes. Moreover, the potential for side-effects related to non-communicable diseases needs to be assessed, looking at early markers); and c) the study design and data analysis plan are not always best suited to disentangle the net effect of LDF on the outcomes. Also, observational studies in this field are complex due to the intrinsic difficulty of measuring diets, the high number of relevant nutrients, the effect of substitutions and difficulties in measuring specific nutrient absorption. New methods and study design to gather reliable evidence on dietary aspects should also be explored to expand the body of knowledge in this area.

Even though there is limited evidence on LDF during the first 1,000 days, evidence from older children and the fact that LDF represent the most significant source of some nutrients, suggests that consumption of these products would provide nutritional benefit during the first 1,000-day period. Furthermore, it is believed that even low amounts of LDF are likely better than no intake and are particularly beneficial for individuals with high nutrient requirements. According to the small number of experiments identified in our review and the limitations observed, this topic still deserves much attention and further research is needed on the ability of LDF to improve nutrition in the general population and specifically during the first 1,000 days. Understanding this effect better will be important for targeting strategies. Some of the studies in the range of children 2–18 years include children up to 14 years, thus including adolescent age. It has also been suggested that analysis by sex could be of use and differential effects might be found. This raises the issue of the role of LDF in adolescent girls and how this can contribute to nutrition during the first 1,000 days, which may deserve more attention.

More studies with robust sample sizes, isocaloric diets and/or usual diets, and a comprehensive set of outcomes are necessary. School meal programs offer a powerful setting for such experiments, but exclude the youngest children, a critical age group. Specific settings where dietary intakes can be appropriately monitored in vulnerable toddlers and women, such as in orphanages or refugee camps, need to be identified where these types of interventions can be tested. These interventions must explore not only the effect of different types of LDF, including eggs and poultry meat, for which very few studies have been conducted so far, but also place emphasis on dose-response effects and monitoring long-term health effects where possible. Also, research should foster a better understanding on the biology of LDF (e.g. strengthen knowledge on the different micronutrient bioavailability of animal diets versus vegetable diets) and additional components beyond nutrients that can have beneficial effects for growth and/or health. Additionally, beyond the benefits of LDF as part of healthy diets, the role of these foods as a vehicle for fortification or as a component of therapeutic foods can also be explored.

Beyond nutritional aspects, the relationship between the price of a food and its likely consumption among poor populations is an important concern. In order to recommend increased intakes of LDF in resource-limited populations, specific feasibility and sustainability studies will need to be conducted to ensure LDF are available and affordable to the target populations.

3.4 Conclusions

From the review it can be observed that few investigators in LMIC have utilized a relatively straightforward intervention, such as feeding supplemental milk/meat/eggs to one study arm of infants and young children to compare against a control arm of no intervention or equicaloric intervention. In addition, many of the existing studies have a poor design and low power, making it difficult to observe an effect, even if there is one. Similarly, positive results need to be interpreted with caution. Although some of these studies show interesting evidence of the value of meat/milk versus other food groups to improve growth and development (i.e. the evidence supports that milk is important in growth and meat has strong cognitive effects), particularly in LMIC, there is at present inconclusive evidence on such effects as well as a need to understand how much LDF are necessary for optimal growth and development outcomes. This limits the ability to inform policy and to indicate how to scale up certain interventions such as school meals with LDF. The roles of egg and poultry meat have not been appropriately explored according to the existing literature and the findings from our literature review. Finally, malnutrition is multifactorial and, therefore, improving specific complementary food(s) should be implemented along with other important interventions, such as nutrition education, water and sanitation, etc. In addition, in view of the call for a global reduction in the consumption of LDF—primarily related to concerns regarding non-communicable diseases, the environment and sustainable development in general—it will be important to highlight the potential need for the prioritization of vulnerable groups, thus getting the right balance and contributing to reduced inequality.

4. The impact of livestock interventions on nutrition outcomes in the first 1,000 days

4.1 Agriculture interventions and nutrition

Healthy and productive animals produce more milk, meat, or eggs and this generates greater incomes for farmers. Better incomes and more LDF availability in livestock-farming households can increase LDF consumption and improve diets of children, men and women. Such reasoning suggests that interventions that improve livestock productivity could plausibly also bring nutrition and health benefits to livestock-keeping households and their communities.

To test this hypothesis, a growing body of scientific literature is seeking to analyse the evidence for impacts of agricultural (including livestock) interventions on nutrition outcomes and, more importantly, on the nutritional status of individuals in farming households.

The experience and consequences of the 'green revolution' can be taken as the first evidence of how agriculture interventions can provide significant achievements in agriculture productivity as well as at the social and economic levels. However, achievements were not uniform across the countries: what was considered the most promising intervention to eradicate hunger and malnutrition, failed to improve micronutrient malnutrition and resulted in decreased diet diversity in many LMIC (Pingali 2012).

Many scientific studies exploring how agriculture interventions (i.e. activities aimed at improving agricultural yields and productivity) affect household and individual nutrition outcomes often report positive effects on food production, consumption of micronutrient-rich foods and, to some extent, on dietary diversity in farming households. Positive effects on individual micronutrient status or anthropometry have been more rarely reported (Leroy and Frongillo 2007; Masset et al. 2012). Despite the mixed and limited scientific evidence, the existing literature seems to suggest that agriculture interventions have the potential to improve nutrition outcomes (e.g. diet diversity, energy and protein intake) and, likely, affect individual nutritional status (e.g. anthropometric measures, micro- and macro-nutrients levels in blood) in the beneficiaries' households and communities (Ruel et al. 2013; Ruel et al. 2018). Whether this is through a direct effect of such interventions on the availability of more and nutritious food products in the households, or whether this is through indirect pathways, such as increased incomes or women's empowerment, is not fully understood and likely varies according to the type of intervention (Berti et al. 2004; Pandey et al. 2016). Beyond their possible net effect on nutrition, agriculture interventions often address key determinants of malnutrition, such as poverty, disempowerment and food insecurity, creating conducive environments that potentiate the effects of other nutrition-sensitive programs (i.e. those that address immediate determinants of nutrition). In addition, because agriculture interventions are often implemented at large scale and target nutrition-vulnerable populations, they can act also as platforms to increase coverage and scale of such nutrition interventions (Ruel et al. 2013).

While this is widely accepted for agriculture interventions in general, the degree to which this applies to livestock interventions is less understood and there is even less evidence on pregnant women's and infants' nutrition outcomes. As discussed in Section 1 of this report, the pathways that link livestock production to maternal and child nutritional

outcomes are many and complex. LDF are more nutrient-dense than many other foods, but they are also marketable, more prone to dietary taboos and more likely to transmit FBD (Traore et al. upcoming; Grace et al. 2015). Moreover, livestock production is also accompanied by a range of co-benefits and negative externalities. Many factors are at play to determine how activities at livestock production level may cascade down to modify diets and ultimately improve nutritional status. In this section, we summarize the scientific literature on the topic, examine the plausible pathways that explain the livestock impacts on nutrition, and identify gaps and opportunities for future research into promising interventions.

4.2 Livestock interventions and nutrition

We conducted a literature search to identify reviews that synthesise the findings from impact assessments of livestock interventions. First, papers on the topic were identified through consultation with researchers in this field, and further papers were identified when reviewing those articles. To widen our reach, we conducted a systematic search of two online databases: PubMed and CABDirect. This search produced 268 titles/abstracts, but only one relevant article.

The first attempt to describe the role of animal production interventions on nutrition was made by Leroy and Frongillo (2007) in a review summarizing literature around this topic. They identified 10 evaluated livestock interventions, including dairy, poultry and goat production, three of which also included a nutrition education component. Overall, reviewed projects reported improvements in livestock production and increases in income and expenditure. The impacts on dietary intake were, however, mixed: a dairy cooperative project in India found that, overall, households in villages with cooperatives consumed less milk, but that the nutrient consumption of dairy-farming households in such villages increased while it fell in non-milk producing households. Dairy households before the intervention mostly consumed milk or sold it locally; distant markets offered a higher price, and income benefited the diets of dairy farming households while non-dairy households in those villages had less access to milk. On the other hand, in a project to improve dairy productivity in Kenya, women in dairy-farming households reported increased milk consumption. None of the studies explored the specific effects of the interventions on child nutrition outcomes. Another dairy project in India reported an association between the amount of milk produced in the household and the dietary protein intake of children aged 1–4 years, with intake only adequate in dairy-farming household producing at least 5 litres of milk per day.

Other livestock projects had similarly reported improvements in household dietary intakes. In Ethiopia, households adopting improved dairy breeds were found to consume more energy, fat, protein, retinol and iron than non-adopters. Assessments of three different poultry production interventions (backyard or home poultry production) also reported improvements in LDF consumption and in diet diversity. Of the 10 livestock interventions reviewed by Leroy and Frongillo, only four measured nutritional status of individuals: they found improvements that could be plausibly, but not certainly, attributed to the interventions (Leroy and Frongillo 2007). An interesting observation was that most projects that measured nutritional status (i.e. including it as an explicit outcome) combined the livestock interventions with a nutrition education component. This suggests that those projects were probably aiming for nutritional impacts and, unlike most livestock projects, the livestock interventions were designed as nutrition-sensitive interventions. Because of the integrated nature of the intervention in these studies, it is not possible to estimate the disaggregated effect derived from the livestock intervention alone.

Despite these interesting observations, the evidence base on the nutrition impact of livestock interventions remained small and the impact assessments reported previously suffered from important design and methodological caveats that question the reliability of the results (e.g. Girard et al. 2012). While this is a general problem observed in most studies aimed at assessing the impact of complex agriculture interventions, it seems to be particularly prominent in the assessment of livestock interventions (Masset et al. 2012). A review of the literature conducted a few years later by Masset et al. (2012) reported overall impact trends in line with the findings from Leroy and Frongillo (2007). This review used a more rigorous quality assessment of papers and found that, while dairy and fisheries interventions were over-represented in the initial literature search compared to other agriculture interventions (i.e. home gardens and bio-fortification), these livestock interventions were poorly represented in the final list of quality-approved selected

papers (one and three papers, respectively), confirming the fact that most studies used designs that are sub-optimal for the purpose of measuring impact.

A subsequent review of literature by Girard et al. (2012) used a more rigorous approach to select studies that met minimum quality criteria and excluded interventions that had additional nutrition intervention components, to better disentangle the impact of the agriculture intervention on the outcome(s) of interest. Once more, the review found only studies on interventions based on poultry, fish-farming or dairy production (cattle or goats). The review reports important findings regarding the impact of agriculture interventions on health and nutrition outcomes, but due to the way results are presented in an integrated manner, it is not possible to extract the key effects of the livestock interventions. In line with previous findings, the researchers found that interventions on poultry production and home gardening, including a nutrition education component targeting women, improved consumption of eggs and improved diet diversity scores in the participant household. It is important to note that Girard et al. (2012) reports that home-gardening projects without an animal production component also showed positive impacts in nutrition outcomes; some also showed improvements in LDF consumption. As discussed earlier, improvements in the diet composition and increased LDF consumption may be more strongly associated with increased income and increased knowledge on nutrition rather than an increase in home food production.

Finally, the most recent review paper by Ruel et al. (2018) summarizes new evidence generated over the past four years from a range of nutrition-sensitive agriculture interventions, including livestock (Ruel et al. 2018). The review reveals a clear increase in the numbers and improvement in the quality of the evaluations of agriculture interventions, including two livestock-focused programs evaluated through experimental or quasi-experimental designs, and four additional homestead food production programs that included a livestock component (three of which measured nutrition outcomes in the first 1,000 days). A livestock-focused intervention in Rwanda based on the transfer of dairy cows or meat goats to poor households reported increased dairy and meat consumption in beneficiary households and marginal effects on children's weight indicators, although the approach to data analysis does not allow us to confirm if such effects are indeed attributable to livestock ownership.

Analysis of data from a livestock donation intervention (goats, cows and draft cattle) in Zambia also found that recipient households increased expenditure in LDF (milk and meat), with clear increases in milk consumption, but not in meat. It reports that the livestock donation affected diet diversity, increasing consumption of more nutritious food items and moving gradually from staple foods to more luxury food products (Kafle et al. 2016). This study also found that households who did not receive animals increased their expenditure on milk and meat, suggesting that the livestock intervention modified the food environment in the community (e.g. more LDF availability and consequent reduction in prices) and can potentially achieve nutrition impacts beyond the direct beneficiaries (Jodlowski et al. 2016). Other encouraging results were reported in the assessment of an integrated women's empowerment and livestock intervention in Nepal, where beneficiaries were found to have improved income, animal ownership and child anthropometry measures with larger effects, including dietary diversity and LDF consumption by children, observed after longer participation in the program. Researchers also reported differential impacts based on location and season.

Several other initiatives integrated livestock as part of a broader agriculture intervention. Overall, findings were that such interventions showed an impact on various factors in the pathways linking agriculture and nutrition, with some of the studies reporting impacts on nutrition-related measures (anaemia, Hb). However, none of the interventions reported impacts on stunting or other nutrition measures, which could be due to a lack of power of the studies to detect effects or due to the brevity of the follow-up periods. All these interventions were in general a combination of agriculture, education and women's empowerment interventions, confirming that improving nutrition seems to require interventions that address various among the multiple determinants of undernutrition, including access to food, health, education and empowerment.

Despite the still scant availability of literature confirming the unequivocal role of livestock interventions on nutrition, the review summarizes the findings reported from cross-sectional studies exploring factors that may be associated with nutritional outcomes. Although these studies are unable to confirm the causal links between livestock and nutrition outcomes, all studies reported that livestock ownership improved diet diversity, nutrient intake and LDF

consumption; results that aligned with the findings from earlier studies. In the case of dairy cow interventions, they also found an association with milk consumption and improvements in HAZ. Most studies, however, reported that many factors seem to modify this effect, including market access, income, number of livestock kept and animal diseases, among others. The review of the literature shows that the evidence base around the effect of livestock interventions on nutrition outcomes is increasing, both in quantity and quality. Most observations studies point to positive associations between certain livestock interventions and nutritional outcomes, including some concrete nutrition-related measures. Experimental studies confirming a causal relationship are few, and compelling evidence is still lacking, but the current findings suggest a positive role of livestock interventions to affect nutrition, including in the first 1,000 days.

4.3 Understanding the complex links between livestock and nutrition

The complexity of livestock interventions and the limitations on the design and methodologies of the available studies make it difficult to draw clear conclusions on the impact of livestock interventions on nutrition outcomes. The available data from the few research studies on the subject does not allow an estimation of the magnitude of such effects. However, it seems that the contribution is more likely to be positive than negative (Webb 2013). Two recent reviews have concluded that evidence exists on an impact of agriculture interventions in various steps along the pathway between production and nutrition (e.g. increased income and expenditure) despite the fact that those impacts may not translate into final nutrition outcomes (Ruel et al. 2013). This reinforces the message that to achieve a positive impact on nutrition status, livestock, and agriculture interventions in general, need to be purposely designed and account for broader aspects that contribute to the linkages between livestock and nutrition. This is the basis of a recent publication from the FAO presenting detailed guidance for the design of nutrition-sensitive agriculture interventions (FAO 2015).

Widening the scope and the target of agriculture interventions to invest in other types of capital beyond agricultural productivity has been found to make them more successful in terms of nutritional impact. Berti et al. (2004), in their review of agriculture interventions, examined the extent to which those interventions had also included one or more of five types of 'capital'— financial, human, natural, physical and social. Their analysis revealed that interventions targeting more capital investments had more positive nutrition and health outcomes and no negative outcomes. They conclude that 'investing broadly in the target population—and not just in the agriculture intervention—does seem to improve prospects for positively impacting on the health of the people' (Berti et al. 2004). In both agriculture and livestock interventions the literature is consistent on two aspects: agriculture (including livestock) interventions are more successful at improving nutrition outcomes when they (i) are coupled with a nutrition education component and/or (ii) when they target women (Kawarazuka and Béné 2010; Pandey et al. 2016). Box 2 illustrates with two examples the importance of these two aspects in the links between livestock production and nutrition.

Box 2: Women's empowerment and education as key links in the pathways to nutrition.

Incomes, purchasing power and purchase choices. Better incomes can directly lead to improved maternal and child nutrition if part of the economic resources are channeled into better diets. This can only happen, however, if two requirements are met: those making the purchase choices are, first, knowledgeable and appreciate the importance of an adequate diet and, second, have access to the economic resources to purchase the relevant food products. In most households in poor rural settings, women are in charge of managing the house and the feeding of the family. In many contexts they may own small livestock (sheep, goats or poultry) and be in control of the income generated through this activity. Even though they may not have control over the entire household income, they commonly are in charge of food purchases and administer the food expenditure (FAO 2011a). Therefore, livestock and agriculture interventions that promote women socially and economically may have higher chances to impact on the food consumption patterns of children, and household members in general, and, therefore, in their nutrition status. This explains why livestock and agriculture interventions targeting women and including nutrition education are in a better position to demonstrate nutrition outcomes.

Availability of LDF and consumption. Improvements in livestock productivity will lead to production of more meat, milk or eggs by farming households. Whether that translates into increased consumption of this product by the farming household depends on various factors, including household priorities. A household may prefer to divert food production to the market in order to generate an economic asset that will allow payment of health or education fees, improvements in the farm, the house or other economic activities. Diets and nutrition compete with those other interests or priorities (FAO 2012). Knowledge can shape attitudes and behaviour towards improved family and children feeding habits. However, that knowledge can only translate into improved nutrition if those acquiring the knowledge have control over the economic resources. Again, increasing knowledge of those making consumption choices and empowering them to have more control over their resources are key to harvest the fruits of livestock production interventions.

Nutrition-sensitive livestock interventions that target women appear better placed to improve nutritional outcomes in livestock-keeping families, but it is still unclear if, and to what degree, this translates into better nutrition status of children. Improving nutritional outcomes of children, including during the first 1,000 days, may require additional investments through, for example, nutrition education or behaviour change communication strategies, to shape child feeding habits and the diets of pregnant and lactating women.

4.4 Evidence gaps and future research questions

The reviews from the literature demonstrate that only a small range of livestock interventions have been assessed in relation to their potential to impact nutrition outcomes of household members. Most of these targeted dairy cattle and poultry, and promoted livestock production at the household level through improved breeds and feeds, or distribution of small stock or poultry for home-production. Most of them were also part of more comprehensive development programs, in which the livestock intervention was integrated with other activities that also support livelihoods or mediate in the pathway to outcomes (i.e. technical training on animal farming and access to credit, promotion of both animal and plant production, nutritional education campaigns). This obviously limits our capacity to discern the net effect that the livestock component had on nutrition. It is encouraging to see an increasing number of livestock interventions with explicit nutrition outcomes in their design, so we shall expect to see more evidence in the coming years of the potential nutrition benefits of such interventions (Ruel et al. 2018).

There remains a problem with study quality, as illustrated by the small number of papers which are eligible if rigorous quality screening is applied (Berti et al. 2004; Ruel et al. 2013; Webb and Kennedy 2014). Common problems appear to be: lack of experimental design; lack of power to detect effects, even if present; measuring intermediate outcomes rather than nutritional status; measuring consumption of single foods and not whole diets; failure to specify primary outcomes or to adjust for multiple comparisons. It is crucial that studies and methodological approaches to assessing

impact are carefully designed to avoid missing opportunities to generate robust evidence. With an increasing number of on-going or planned agriculture interventions in LMIC (Hawkes et al. 2012) we expect that more nutrition-focused rigorous assessments will be undertaken and the evidence base around the topic will expand in the near future.

Most studies measured outcomes at household level and failed to provide disaggregated effects on children, pregnant and lactating women. There are no suitable assessments of the nutrition impact of pig and sheep production interventions, yet these livestock feature importantly in the assets of poor farmers across the world. Similarly, livestock interventions that go beyond direct increases in milk, meat or egg productivity have not been looked at. For example, animal health interventions can boost productivity by reducing morbidity and mortality. Disease outbreak in animals has been documented to have devastating impacts on health and livelihoods of farming communities and households. The nutritional value of LDF is closely linked to their safety (lack of biological or chemical hazards) and quality (i.e. appropriate fat and protein composition). Interventions that focus on improving milk and meat quality and safety can have a direct impact on nutritional outcomes. Similarly, preservation techniques can affect food quality and help preserve or decrease the nutritional value of LDF. None of these types of interventions have to date been assessed (Ruel et al. 2018).

Finally, most of the available scientific literature reports the impact of a very limited range of livestock interventions on the nutritional outcomes of livestock-keeping households. A much larger population, including non-farming households in rural areas, and dwellers in urban and peri-urban areas, require LDF to meet their nutritional needs. Many interventions beyond the production stage and along livestock value chains could be leveraged to improve health, nutrition and well-being of poor non-farming households. These include interventions with butchers and dairy traders (i.e. hygienic practices and handling of food products), animal live-markets and food retailers, among others. Such interventions have a great potential to ameliorate the living environment and, through complex and indirect pathways, impact on nutrition outcomes. These are, however, complex interventions, including many steps and actors, so the challenge of monitoring and evaluating rigorously their impact on nutrition must be dealt with.

4.5 Conclusions

The scientific evidence base on the impact of livestock interventions on children's and women's nutritional outcomes is, to date, very limited. The intrinsic complexity of livestock interventions and poor methodological designs of the available impact studies means that current scientific evidence is not only limited but also weak. Specific evidence on the impact in the first 1,000 days of life is non-existent.

The limited available evidence can be summarized as suggesting that livestock interventions do improve production, incomes and expenditure, can improve nutrient consumption and diets, and may improve nutritional outcomes in children and women. The lack of conclusive evidence on the latter can be partly blamed on poor study designs and assessment methods that are inadequate to establish the existence of a causal link between intervention and nutrition. Another reason is the narrow focus that livestock interventions traditionally have: interventions that are comprehensive, addressing, or accounting for, the different aspects that mediate in the pathways between livestock and nutrition seem more likely to show impacts on nutrition status. Moreover, beyond the net impact on nutrition outcomes, nutrition-sensitive livestock interventions that address the underlying causes of malnutrition can potentiate the effect and scale of nutrition-specific interventions, helping achieve nutrition impacts at scale.

An increasing number of nutrition-sensitive livestock interventions having explicit nutritional outcomes are being implemented, with better experimental designs and more robust monitoring and analytical methods, which show promise in the generation of the needed evidence to consolidate our knowledge on the links between livestock and human nutrition.

5. Livestock-derived foods, associated diseases and implications for nutrition in the first 1,000 days

5.1 Links between livestock-derived foods, disease and nutrition in the first 1,000 days

LDF have many virtues but there are also many concerns about their consumption and production. This section focuses on negative health effects of LDF and how these in turn affect nutrition. For nutritionists, the first 1,000 days is a key age group; however, this concept is rarely encountered in disease studies. Instead, other categories are used, for example, infant (child less than one year) or child (person younger than 19 years old). This means extracting FBD data for the first 1,000 days is difficult and sometimes not possible. In this summary, we supplement the limited existing evidence with findings from broader studies on children and adults. The exception is the limited literature on hazards found in infant formula and complementary feeds, which is mainly relevant to the first 1,000 days.

Hazards in infant formula and complementary feeds

Human milk is the best form of nutrition for babies but, despite efforts to promote breast-feeding, infant formula is commonly given in developing countries. Most formula is based on bovine milk and may be contaminated by bacteria. *Salmonella* spp. and *Cronobacter* spp. have been identified as pathogens of most concern (WHO 2007). Moreover, studies in developing countries have found home-prepared infant formula feedings frequently contaminated with multiple pathogens: *Salmonella* and *Escherichia coli*, particularly enteropathogenic *E. coli*, have been commonly isolated (Ma et al. 2009). After six months, all infants need complementary foods to fulfil their protein and micronutrient needs. Bovine milk and starchy gruel are two of the most common types. Studies from developing countries also show that complementary feeds, whether or not containing LDF, are commonly contaminated with pathogens.

It is often assumed that contaminated water, rather than contaminated food, is the major source of risk for infants. However, many studies related to infant diarrhoea have demonstrated that contamination levels are higher in weaning foods than in drinking water (Barrell and Rowland 1980; Imong et al. 1989; Henry et al. 1990; Motarjemi et al. 1993; Lanata 2003; Kung'u et al. 2009). In a study in an urban slum in Baroda, India, Sheth et al. (2000) found that the incidence of infant diarrhoea remained high due to contaminated foods, while the drinking water was found to have no coliforms. While excellent progress is being made in attaining water targets, food safety remains in the doldrums; it is likely that unsafe food will increasingly be cited as a leading cause of infant diarrhoea and stunting.

A study that used Demographic and Health Survey data from nine African countries with high childhood diarrhoea mortality found that the introduction of complementary foods was significantly associated with diarrhoea (Odds ratio 1.3) (Ogbo et al. 2017). A longitudinal study in seven countries, including two in Africa and two in Asia found that

high-er entero-pathogens were associated with stunting even in the absence of diarrhoea (especially *Campylobacter* and toxigenic *E. coli*) (MAL-ED 2017).

Several studies by ILRI (published and unpublished) have found aflatoxins in milk at levels well above Codex standards. One cross-sectional study found a positive relationship between aflatoxin M1 in infant's diets and stunting, but no relationship between aflatoxin B1 and stunting. A systematic review found eight studies on the key problems and critical actions for complementary food production in LMIC. The most common problems were: storage of cooked food at ambient temperatures for an extended period, (identified in seven studies); use of raw food products containing high levels of pathogens (six studies); contamination with pathogens from hands (six studies); inadequate reheating of food in terms of temperature and/or time (five studies); contamination with pathogens from utensils (four studies); and inadequate initial cooking of food (three studies) (Woldt et al. 2015).

In this report, we consider two pathways through which LDF-associated diseases could affect the first 1,000 days (see Annex 4). The first is illness acquired through LDF consumption and the second is illness acquired as the result of production, processing, retail, handling and disposal of LDF (this is relevant to pregnant women). LDF-associated causes of diseases transmitted through or associated with consumption include:

- Food-borne pathogens causing infectious diseases. Young children, whose immune systems are still developing, and pregnant women, whose immune systems are modulated, are more vulnerable to FBD (Lund 2016). Infectious FBD commonly manifests as diarrhoea, which is strongly associated with stunting and vice versa (Checkley et al. 2008; Guerrant et al. 2013; Richard et al. 2014). Around half the burden of infectious diseases results from non-gastrointestinal manifestations; these can also cause under-nutrition through reduced appetite and increased nutrient requirements resulting from inflammation, infection or other catabolic conditions (Tappenden et al. 2013).
- Toxins are poisonous substances produced within living cells or organisms. Aflatoxins are of most concern to the safety of LDF. They are produced by fungi, which infest staple crops and are transferred to milk. Studies in developing countries show that milk often contains aflatoxins above Codex Alimentarius limits (Atherstone et al. 2016; Mulunda et al. 2013). Several studies show an association between aflatoxins and stunting but a causal relation (though very plausible) has not yet been demonstrated (Leroy 2013). One paper found an association between intake of aflatoxin in milk and stunting (Kiarie et al. 2016). Generally, toxins are more of a problem in plant and marine foods than in LDF (Dolan et al. 2010).
- Anti-nutrients are naturally occurring substances that diminish or inhibit the utilization of nutrients (e.g. phytates, tannins). They are ubiquitous in plant-derived foods but may also be present in LDF. For example, raw eggs contain avidin, which inhibits biotin absorption.
- Chemicals may be industrial (e.g. pesticides, food additives) or natural (e.g. toxic metals). (Toxins are considered chemical hazards by some but not others). The chemical hazards often transferred via LDF for which there is most evidence of adverse health impacts are cadmium, dioxin, arsenic, mercury, fluoride and highly hazardous pesticides (Grace 2015a). Children are biologically more vulnerable to chemicals than adults (Landrigan and Goldman 2011).
- Allergens are proteins that can produce adverse immune responses in sensitive people: they can lead to acute, severe reactions or even symptoms similar to malnutrition (Boye 2012). Food allergies are associated with low weight and poor nutrition outcomes in children, linked both to dietary restrictions and modifications as well as poor feeding skills and/or maladaptive feeding behaviours (Mehta et al. 2013). However, food allergies appear to be much less common in LMIC than high-income countries (Boye 2012). Food allergies peak in the first two years of life, then diminish as tolerance develops (Gray and Levin 2014). Cow milk and eggs are important sources of allergens in LMIC (Prescott et al. 2013). The most commonly implicated foods among Asian children were cow milk and eggs (Lee et al. 2013). In Africa, few studies have been carried out and most used unreliable self-reports, so, while food allergies are often reported for milk, eggs, and meat, it is difficult to estimate their relative importance compared to other foods (Kung et al. 2014).
- Food intolerances are non-immunological adverse reactions to food as the result of pharmacological effects, non-coeliac gluten sensitivity or enzyme/transport defects. Lactose intolerance results from an enzyme deficiency (lactase) and is common in LMIC, but rare before four–five years of age (Vandenplas 2015). However, a subgroup of

severely undernourished children with secondary lactase deficiency due to severe diarrhoea or severe enteropathy may benefit from products with even more restricted lactose content (Grenov et al. 2016).

- Faecal bacteria (non-pathogenic) may be present in large amounts in LDF and consumption is associated with environmental enteric dysfunction, an incompletely defined syndrome of inflammation, reduced absorption and barrier function of the small intestine (Mbuya and Humphrey 2016). In LMIC, livestock faecal matter is more widespread than human faecal matter (Headey and Hirvonen 2016) and infants may often ingest faeces from livestock present in compounds or houses (Ngure et al. 2014), sanitation, and hygiene (WASH).

In addition to diseases caused by agents in food, over-consumption of LDF as part of an imbalanced diet is associated with obesity, which in turn is associated with many pre-, peri- and post-natal complications in mother and child, while obesity in infants increases the risk of several non-communicable diseases including diabetes (Ellulu et al. 2014).

Livestock production can also indirectly affect nutrition in the first 1,000 days through routes not related to consumption of LDF. Indirect pathways that have negative impacts through causing disease in humans include:

- Zoonoses acquired by contact or aerosol: Zoonoses are diseases transmissible between animals and people. Participation in livestock farming or value chains brings people in contact with livestock and their secretions and excretions; these may transmit zoonotic pathogens. Children and infants are at elevated risk of zoonoses because of their weaker immune systems, poor hygiene practices, attraction to animals, and behaviours such as eating soil (Macpherson 2005). A meta-analysis found positive associations between exposure to livestock and diarrhoea in young children (Zambrano et al. 2014).
- Emerging disease and pandemics: Livestock production, especially in extensive systems and if accompanied by land-use change, can lead to the emergence of new diseases (Jones et al. 2013). Around 75% of new and emerging human diseases (including many antimicrobial-resistant organisms) are zoonotic (Woolhouse and Gowtage-Sequeria 2005). These have the potential to sicken and kill large numbers of people and to damage economies. Notable recent livestock-associated emerging diseases include highly pathogenic avian influenza (HPAI), Middle East respiratory syndrome, West Nile virus disease and Rift Valley fever.

Other pathways between LDF-associated disease and nutrition that are not mediated through human disease include:

- Animal disease and disease control: Animal disease can reduce the availability of LDF and, thereby, impact on food security. Based on official figures (which greatly underestimate losses), around 400,000 livestock equivalents are lost each year, with around half in LMIC. Of this, around 40% is due to death and the remainder is due to disease control (World Bank/FAO/OIE 2011). Few studies have investigated the links between disease control and nutrition. Kavle et al. (2016) reported that an avian influenza outbreak resulted in mass culling of chickens in Lower Egypt but not Upper Egypt. Decreased dietary diversity, reduced poultry consumption, substitution of nutritious foods with sugary foods and increased stunting was also seen in Lower Egypt but not Upper Egypt (Kavle et al. 2016).
- Food scares: FBD can also indirectly affect nutrition if consumers avoid LDF because of concerns over food safety. Although impacts are generally short-lived, long-run effects are also reported (Bialowas et al. 2007). In LMIC, especially in Asia, concerns are high and rising, and this pathway between LDF and nutrition may be increasingly important (Grace and McDermott 2015). One study found that during the melamine scare, there was a significant drop in dairy product consumption for most households with children under the age of 6 (Qiao et al. 2012). While there is little information on the current nutritional impact of food scares, women appear more concerned about FBD risks than men (Al-Sakkaf 2015).

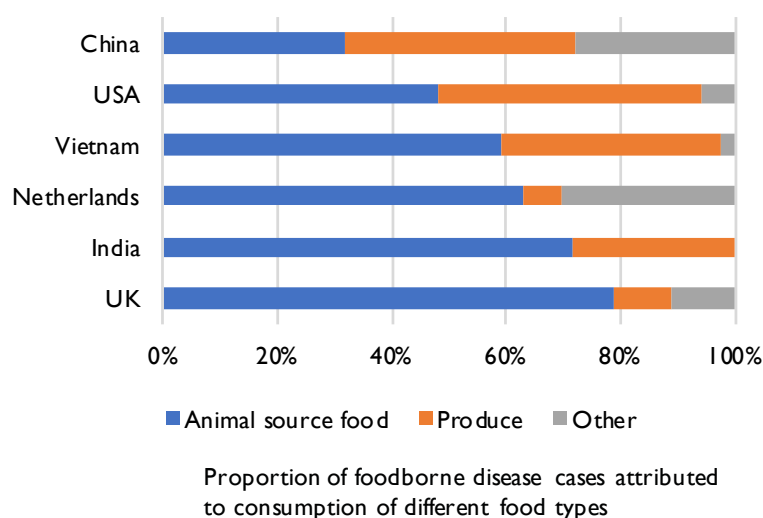
Animal disease outbreaks, disease outbreak control and food scares are strongly associated. An *ex ante* study modelled the effect of a potential HPAI outbreak in Kenya considering both reduction of poultry through disease and disease control and reduction in demand. This suggested the outbreak would increase stunting from 34% to 38% (Iannotti and Roy 2013).

The previous section attempted to provide a comprehensive listing of diseases associated with LDF, but as most of the known and quantified human health burden is the result of infectious FBD, the rest of this section focuses on this.

5.2 Livestock-derived foods and infectious food-borne diseases

Unfortunately, there are no global assessments for the health burden of FBD resulting from consumption of LDF. In LMIC there is less information on burden associated with LDF than on burden associated with specific hazards or pathogens. In high-income countries, most FBD result from consuming ASF (i.e. LDF and food derived from aquatic animals) and contaminated produce (i.e. fresh fruits and vegetables). The weaker data from LMIC shows a similar pattern (Figure 11).

Figure 11: Attribution of food-borne disease to different types of food.



Source: Grace 2015 adapted.

Children are more exposed to food-borne hazards because of their lack of control over food preparation and propensity to behaviours that increase risk (such as eating soil and animal faeces). They are also more vulnerable to the consequences of infection because of their developing immune system, small body size, lower levels of stomach acid and other factors. Relative to older children and adults, children under five years old are most at risk from acute consequences of chemical, bacterial and protozoal hazards, and least at risk from chronic consequences of aflatoxins (Havelaar et al. 2015).

While women generally have stronger immunity than men (Berghella et al. 2012), pregnancy results in an immunological transformation, which can alter susceptibility and disease outcomes (Silasi et al. 2015) (Box 3). There are many taboos around consumption of LDF (Fessler 2002), perhaps utilitarian in origin as they tend to protect pregnant women from hazards common in LDF, but food taboos also reduce women's access to food. In some cultures, there may be systematic differences in consumption between men and women, even in the absence of formal taboos. For example, in Nigeria and Somalia, women consumed more low value offal (a risk for diarrhoea) and men more high value muscle meat (Grace et al. 2012).

Box 3: Listeriosis and toxoplasmosis in pregnancy

Listeria monocytogenes is often acquired from dairy products, meat, seafood and vegetables. According to the US Centres for Disease Control and Prevention (CDC), pregnant women are 10 times more likely than other people to be infected and the outcomes for their baby can be fatal (CDC 2013).

Toxoplasma gondii is acquired when people ingest cysts passed in cat faeces or eat under-cooked meat. Pregnant women can also become infected from sheep, but this is rare (Osborne 2015). Infection can result in abortion or birth defects.

A recent report by the Foodborne Disease Burden Epidemiology Reference Group (FERG) of the WHO provided the first global estimate of FBD (Havelaar et al. 2015). Its database is incomplete but estimates are conservative². It is estimated that FBD are responsible for a very high burden of disease, comparable to malaria, HIV/AIDS or tuberculosis. The global burden of FBD caused by the 31 hazards considered in 2010 was 33 million disability adjusted life years (DALYs); children under five years old bore 40% of this burden. Most of this burden (98%) falls on LMIC and 97% of the burden is due to the biological hazards (bacteria, viruses and parasites) that mainly contaminate fresh foods (Havelaar et al. 2015).

The FERG report also provides evidence on the relative importance of different causes of FBD. Although the report does not provide estimates of health burden by food type, an indication of the importance of LDF can be given by cross-referencing this with the literature on the association between hazards and food types and zoonoses. Considering the health burden on children less than five years of age, a category which overlaps extensively with the first 1,000 days, just 11 pathogens are responsible for 90% of the burden; for people aged five years and above, an approximate proxy for pregnant women, 14 pathogens are responsible for 90% of the burden. Their association with LDF is given in Table 5. It can be seen that 5 out of 16 of the top pathogens have a livestock reservoir (7 have an animal reservoir) and 7 are associated with LDF consumption (10 with ASF consumption).

Table 5: Percentage of the burden of food-borne diseases attributed to different pathogens for children under five years of age and people over five years and association of pathogens with livestock-derived food.

	<5	> 5 years	Association with livestock-derived food and livestock
Enteropathogenic <i>E. coli</i>	18	5	Any foods exposed to faeces; beef and chicken are commonly implicated; humans are reservoirs.
Non-typhoidal <i>S. enterica</i>	13	13	Often associated with LDF; animals are reservoirs, especially food animals.
<i>Campylobacter</i> spp.	12	4	Poultry and raw milk are common sources; animals are reservoirs, especially poultry.
Enterotoxigenic <i>E. coli</i>	11	4	Contaminated food or water; humans are reservoirs.
<i>Salmonella</i> Typhi	9	15	Source usually contaminated water; humans are reservoirs.
Norovirus	7	8	Contaminated water and produce but any food can be contaminated; humans are reservoirs.
<i>Taenia solium</i>	6	12	Pork consumption maintains transmission; the pig is the reservoir.
<i>Shigella</i> spp	6	2	Mainly raw food; chicken and dairy have been associated; humans are reservoirs.
<i>Ascaris</i> spp	4	1	Consumption of contaminated crops; there is zoonotic potential but extent is unclear.
Hepatitis A virus	4	5	Water or food contaminated with faeces; humans are reservoirs.
<i>Toxoplasma gondii</i>	3	2	Undercooked or raw meat; sheep and cats are reservoirs.
<i>Vibrio cholerae</i>	3	7	Source water; ice, contaminated food and seafood. Lives in salt and fresh water.
<i>Paragonimus</i> spp	0	4	Crustaceans; reservoir are crustacean-eating animals including cats and dogs.
<i>Mycobacterium bovis</i>	0	3	Raw dairy products; cattle are reservoirs.
<i>Clonorchis sinensis</i>	0	3	Fish; fish-eating animals are reservoirs, especially dogs.
<i>Salmonella paratyphi</i>	2	3	Humans are reservoirs; source usually contaminated water.
	98	91	

Source: Havelaar et al. 2015 and Food and Drug Administration 2012.

² Comparing FERG estimates with those from countries with good health data we see that while FERG estimates were 9.2 million cases of FBD in the USA, Canada and Cuba in 2010, official figures suggest 52 million annual cases in the USA and Canada around the same time (Scallan et al. 2011; Thomas et al. 2013).

5.3 Reducing food-borne diseases associated with livestock-derived foods in low- and middle-income countries

There is relatively little good-quality evidence on improving food safety in LDF in LMIC. Evidence from high-income countries show that FBD is preventable and approaches that take a whole value chain approach and get buy-in from the private sector are most effective (Grace 2015b). The same review came to the following conclusions:

- Policy reform is important, but not sufficient to improve food safety in domestic markets, and can have unanticipated harmful effects on livelihoods, nutrition and food safety.
- There is little evidence that shifts to large-scale, formal sector food production and retail will reduce FBD, at least in the short term. Some aspects of industrial agriculture and modern retail can reduce risk (for example better management) while others tend to increase risk (for example long, complex value chains).
- Providing and upgrading infrastructure is expensive and the evidence for sustainability and food safety benefits is weak. To maximize benefits, infrastructure should be appropriate and there should be simultaneous investments in using and maintaining infrastructure.
- Giving training to farmers in good agricultural practices has been successful when linked to high-value markets (e.g. export) but there is little evidence for success in domestic mass markets.
- Training other value chain actors has had limited success but is unlikely to succeed without incentives for behaviour change.
- Technologies, both traditional and novel, can improve food safety and work best when they are accompanied by changes in the institutional structure that motivate change in behaviour.

5.4 Conclusions

LDF may affect nutrition through a number of consumption-related pathways: pathogens causing diarrhoea or other illness; toxins causing illness are associated with stunting; faecal bacteria associated with enteric dysfunction; allergens causing illness; or excess consumption associated with non-communicable disease. FBD may also adversely affect nutrition and health through indirect pathways related to livestock production and processing: zoonotic diseases causing illness; emerging diseases causing illness and economic damage; animal diseases reducing LDF availability and causing economic loss; and responses to diseases reducing availability of LDF.

FBD is probably the most important pathway through which LDF negatively affect nutritional outcomes. Very recently, systematic studies have allowed comprehensive estimates of FBD; these show FBD are responsible for a health burden comparable to malaria, HIV AIDS or tuberculosis. Children under five years old bear a disproportionate amount of this burden and pregnant women often have greater vulnerability to FBD. Most of the burden of FBD falls on LMIC and most is due to biological hazards (virus, bacteria, protozoa and macro-parasites). While the literature on foods responsible for diseases is weaker, LDF, along with aquatic foods and produce, appear to be the foods most often implicated as causes of FBD; more than half of the biological hazards covered in the first global assessment of FBD have a livestock reservoir.

The existing evidence suggests that the hazards associated with LDF can have significant adverse effects on health and nutrition. This implies that the overall benefits of LDF in improving nutrition in the first 1,000 days need to take into account any additional health risks. More importantly, efforts to promote LDF among communities who could benefit from this must go hand in hand with efforts to improve and assure food safety.

6. Livestock-derived food and implications for sustainability

This chapter centres on sustainability aspects of LDF consumption and emphasizes three aspects: (i) it presents a broad view of sustainability, that includes social, health, economic and environmental aspects, aligned to the Sustainable Development Goals of Agenda 2030 (UN 2015); (ii) it focuses on LMIC, where many of the problems and solutions related to environmental sustainability are very different from high-income regions; and (iii) it puts an emphasis, where possible, on the first 1,000 days of life, focusing on pregnant women and children under two years of age, not the whole population.

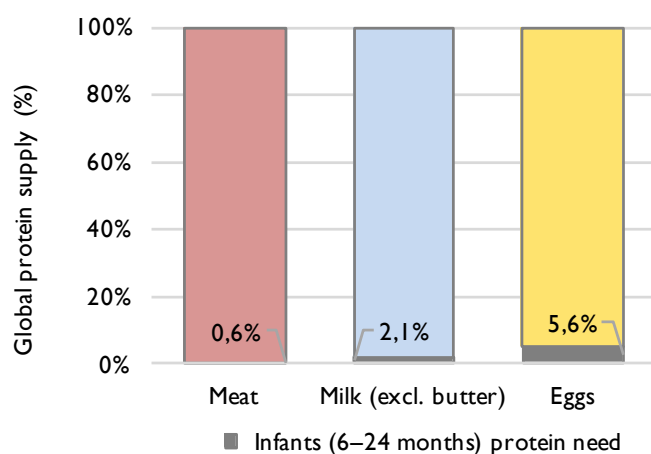
6.1 The first 1,000 days in a global sustainability context

Most studies assessing the sustainability of the livestock sector and livestock-derived foods consider average per capita food supply or adult diets. Sustainability and environmental impacts are not disaggregated with respect to pregnancy, lactation and early childhood. This makes it difficult to gather evidence on the sustainability of LDF and the first 1,000 days in LMIC.

In addition, the ongoing and necessary assessment of the natural resource use and environmental impacts of the global livestock sector often results in requests for uniform across-the-board solutions, although the role of livestock and LDF is quite different when comparing different regions and different population strata (below and Chapter 2). In particular, the benefits from providing LDF during the first 1,000 days risk being overlooked in the broad and urgent process of promoting efforts to improve the overall sustainability of livestock production. However, the total amount of LDF needed to fulfil nutritional requirements during the first 1,000 days in LMIC equals only a small fraction of total global production. Figure 12 shows a back-of-the-envelope calculation of the global protein quantity required to meet infant needs aged 6–24 months in relation to the global protein supply from three major LDF: meat, milk and eggs. In this example, total protein needs for direct intake during early childhood can be met by either 0.6% of the protein in meat, 2.1% of the protein in milk or 5.6% of the protein in eggs. There would be additional demand from women during pregnancy and lactation, nevertheless, these figures show the scale of the challenge.

Consequently, even if environmental considerations will require dramatic reductions in global LDF consumption, it should be possible to safeguard or increase access to LDF during the first 1,000 days, particularly in settings where there is a deficit. Thus, there is no contradiction between ensuring (i) sufficient nutritional intake of LDF by vulnerable children to reduce the frequency of stunting, wasting and dampened cognitive development, and (ii) the long-term sustainable use of the planet, if both global and per capita LDF consumption are reduced.

Figure 12: Global protein quantity required to meet infant needs, 6–24 months, shown in relation to the global protein supply from three major LDF categories, meat, milk and eggs in 2012.



Data: FAOSTAT 2018 and analysis in this study.

Although only a small fraction of global livestock production is needed during the first 1,000 days, this LDF supply still is part of the sustainability equation, and therefore needs to be placed in context. This chapter considers sustainability aspects of LDF consumption and emphasizes three: (i) it presents a broad view of sustainability, that includes social, health, economic and environmental aspects, aligned to the Sustainable Development Goals of Agenda 2030 (UN 2015); (ii) it focuses on LMIC where many of the problems and solutions related to environmental sustainability are very different from those in high-income regions; and (iii) it puts an emphasis, where possible, on the first 1,000 days of life, focusing on pregnant women and children under 2 years of age, not on the whole population.

6.2 Sustainability of agriculture, and livestock production in low- and middle-income countries

The United Nations High Level Panel of Experts defines sustainable agricultural development for food security and nutrition as: ‘Agricultural development that contributes to improving resource efficiency, strengthening resilience and securing social equity/responsibility of agriculture and food systems in order to ensure food security and nutrition for all, now and in the future’ (HLPE 2016).

This wider view and broader understanding of sustainability is well attuned to the context of smallholder livestock farmers striving to optimize the use and benefits from often scarce and unpredictable natural resources in intertwined mixed-crop-livestock systems (Herrero et al. 2010). Here, animal keeping makes multiple contributions to the economic and social well-being, providing not only highly nutritious high-value foods that are both strategic and critical in diets, but also income, assets for financial insurance, the primary source of organic fertilizer, traction and often important energy and social functions, among others (Smith et al. 2013).

For smallholders, livestock can also help build resilience to shocks at household level, including those resulting from climate change, partly due to animals’ ability to adapt to marginal conditions and withstand climate shocks. For example, studies in Zambia show that livestock diversification is higher where climate variability is greater, indicating that exposure to climate risk induces diversification, and households engaging in diversification were found to be less likely to fall below the poverty line (FAO 2016). While livestock are more resilient to climate change than standing crops, adverse impacts may include increase in diseases, heat stress, losses due to extreme events, and marginal systems (e.g. pastoralism) becoming less viable (HLPE 2016).

The demand-driven ‘livestock revolution’ (Delgado et al. 1999) has accelerated in most LMIC in recent decades. Projected continued urbanization, relatively rising affluence and diet change towards more meat, milk and eggs will lead to an increased demand for and production of LDF (Alexandratos and Bruinsma 2012) (see Chapter 2.). A continued increase in livestock production and consumption will have major implications on all four aspects of sustainability.

6.3 Livestock production and environmental sustainability

The global agricultural system, including the livestock sector, is an enormous user of natural resources. The massive scale of resources used makes management decisions along every crop and livestock value chain very important. The cumulative effect from even small-scale changes can result in substantial global environmental impacts. Hence, managing future livestock production will be important for sustainability. Already, agriculture, and specifically livestock, is heavily impacting five of the nine ‘planetary boundaries’, i.e. biosphere integrity, climate change, freshwater consumption, land system change, and nitrogen and phosphorus flows (Rockström et al. 2009; Steffen et al. 2015).

LDF production has major environmental impacts:

- The livestock sector is the largest human land user (Haberl 2015) utilizing 30% of global terrestrial biomes (Foley 2005), including pastures and 33% of all croplands (Steinfeld et al. 2006). Retracting in developed countries (Alexandratos and Bruinsma 2012), there is still an expansion of agricultural land use in other regions, for example into the Amazon rainforest (Morton et al. 2006).
- The total water demand for feed production, crops and grazed biomass constitutes 27–29% of the global agricultural consumptive water use, including both water withdrawals and rainfed soil moisture (year ca. 2000) (de Fraiture et al. 2007; Mekonnen and Hoekstra 2012); when drinking and servicing water are included, the use equals 17% of global agricultural withdrawals (Mekonnen and Hoekstra 2012).
- The most assessed and highlighted specific environmental impact from livestock production is greenhouse gas (GHG) emission, with an estimated 14.5 % of anthropogenic emissions. Livestock systems with cattle and buffalos alone account for 70% of the emissions from the livestock sector (Gerber et al. 2013).

Another dimension of environmental sustainability is competition over resource use between agricultural production of food and feed (e.g. (Mottet et al. 2017; van Zanten et al. 2016). While the conversion efficiency is higher on average for monogastric animals (pigs and poultry) than for ruminants (cattle, goats and sheep) (Bouwman et al. 2005; Nijdam et al. 2012; Wirseni 2003), ruminants are better at converting non-human-edible biomass to LDF. One example showing this is a recent study that estimated the average global feed demand for 1 kg of boneless meat to be 2.8 kg human-edible feed in ruminant systems compared with 3.2 kg in monogastric systems (Mottet et al. 2017).

Livestock systems in LMIC, where the first 1,000 days are most threatened, are generally on the relative extreme end of inefficiency, with extensive systems, high resource use and high GHG emissions per kg produced. Livestock keeping also includes animals kept for uses other than production, including large herds with cattle, sheep and goats in parts of Africa as indicators of status and wealth and as capital reserves, as well as millions of holy cows in India. Although inefficient by some measures, smallholder livestock keeping in LMIC largely relies on feed consisting of grazing, browsing, crop residues and other types biomass not edible by humans. This also presents an enormous opportunity to produce more with same the resource use. However, any change of livestock systems in these communities needs to take into account a range of religious, cultural and societal considerations (see further below).

A third dimension of environmental sustainability is LDF losses along the value chain. In fact, the most expensive resource use and the most expensive environmental impacts are those linked to foods never used. Over the last decade, many studies have focused on quantifying and understanding the mechanisms behind food losses. Overall, losses and waste of LDF tend to be lower than other commodities, reflecting their higher value (FAO 2011b; HLPE 2016). The pattern of losses also differs between high and low-income countries; the major share of livestock losses in sub-Saharan Africa happens before slaughter, while in member states of the Organisation for Economic Co-operation and Development, it is at the retail and consumer stages (FAO 2011b).

6.4 Livestock-derived food diets and sustainability

Sustainable diets can be defined narrowly, addressing just one environmental goal (such as reducing GHG emissions) or broadly encompassing social, economic, human health and animal welfare aspects (Garnett 2014a, 2014b). A number of comparisons have been made at global level, between production systems in different socio-economic and agro-climatic contexts (Aleksandrowicz et al. 2016; Davis et al. 2015; Garnett 2014b; Garnett et al. 2015; Hallström et al. 2015; Herrero et al. 2015; Ranganathan et al. 2016; Springmann, Godfray et al. 2016; Springmann, Mason-D'Croz et al. 2016). Better consumption data in high-income countries has nevertheless allowed for more in-depth analyses in these contexts (e.g. Drewnowski 2014; Friel 2010; Gerbens-Leenes et al. 2013). Environmental impacts, however, may be different in LMIC. For example, a recent study found methane and nitrous oxide emissions from cattle excreta on Kenyan grasslands to be lower than estimates derived from models in industrialized countries (Pelster et al. 2016).

The relative 'score' of meat-based diets varies greatly between studies, due in part to the lack of a common methodology for life-cycle analysis and reflecting the heterogeneity of livestock production systems at global, national, subnational and farm level, as well as the aspects of sustainability considered (Bailey et al. 2014; Eshel et al. 2014; Weber and Matthews 2008). There is broad consensus that diets low in LDF and high in fruit, vegetables and legumes offer the greatest co-benefits in terms of human nutritional outcomes and environmental sustainability (Aleksandrowicz et al. 2016; Bajželj et al. 2014; Garnett et al. 2015; Herrero et al. 2016; Mekonnen and Hoekstra 2012; Nijdam et al. 2012; Reynolds et al. 2015; Scarborough et al. 2014; Stehfest et al. 2009; Wellesley et al. 2015). Meat from ruminants, such as cattle, sheep and goats, is associated with a particularly high environmental impact (de Vries and de Boer 2010; Gerber et al. 2013; Nijdam et al. 2012). However, recommended diets mostly have less LDF than western diets but more than consumed by the poorest in LMIC. The Mediterranean diet allows 2–3 eggs, 500 g of meat and 14 glasses of milk a week (Altomare et al. 2013), much more than, for example, currently consumed by adult women in poor areas of Nairobi: 0.4 eggs, 60 g of meat and 7 glasses of milk a week, (ILRI unpublished). Moreover, some vegetarian diets actually use more land, or have greater climate impacts, than diets with some meat (Peters et al. 2007; Rööß et al. 2016; Vieux et al. 2012). For example, a study compared 10 different diets in the USA and concluded that those incorporating some LDF (especially milk and eggs) use less land than their vegan alternatives (Peters et al. 2007). Moreover, most studies only consider adult diets and the environmental impacts that have not been disaggregated with respect to their effects on the first 1,000 days of life. This makes it difficult to gather sustainability evidence on LDF and the first 1,000 days in LMIC, the subject of this report.

Transforming diets is not straightforward (Wellesley et al. 2015). A recent review found there was little evidence overall that any of the strategies to change diets towards a lowered intake of LDF were effective: evidence from LMIC was especially poor (Kiff et al. 2016). It also reviewed strategies for reducing food loss and waste. Here, findings were more positive: a range of technical, value chain and policy measures can effectively reduce food waste and losses in LMIC. However, returns to investing in reducing food waste may be considerably lower than other options such as investing in food security or agricultural research (Rosegrant et al. 2015).

Few studies have looked at the links between LDF and economic, social or health sustainability in LMIC or the trade-offs between different aspects of sustainability. As mentioned earlier, livestock are associated with disease emergence. One recent study estimated that the annual cost of influenza pandemics was equivalent to the cost of climate change (Fan et al. 2016). Shifting to more intensive production in most cases leads to a decrease in GHG emissions per unit of LDF produced. However, intensive systems are also associated with increased risk of disease emergence and pandemics: avian influenza is only one of many zoonotic diseases with pandemic potential. A comprehensive sustainability assessment would weigh the benefits of reduced GHG against the increased risk of a pandemic in determining the trade-offs between extensive and intensive production (see Chapter 5 for further discussion of livestock-associated human diseases including antimicrobial resistance).

6.5 Solutions

Transforming smallholder livestock production systems to become more sustainable, considering multiple aspects of human and environmental health (HLPE 2016), has real potential to improve the quality of low-income diets as well as addressing a range of other development challenges, including significantly reducing poverty and more efficient use of natural resources. The recent assessment of increasing consumption in Africa confirms that mixed crop livestock and pastoral systems will be the main source of such LDF in the coming decades (Herrero et al. 2013).

In high-income countries, an often-suggested solution to reduce environmental impacts from the livestock sector is to reduce the current high intake of LDF. Unrealistically, this is often also the proposed solution across the globe (e.g. Foley 2011). In many LMIC, where the intake of LDF is rising from very low levels (Figures 2, 4a and 4b) and where livestock plays vital and multiple roles for many smallholders, it is likely more relevant and feasible to use a strategy that works to achieve livestock production systems with minimal environmental impacts per unit of LDF consumed (Garnett 2013; Kiff et al. 2016).

One example is the large technical potential to reduce GHG emissions from the livestock sector, which are estimated to be as much as half of the potential of the agriculture, forestry and land-use sectors. Management options include sustainable intensification of livestock production, carbon sequestration in rangelands, reduced emissions from manure and reductions in the demand for livestock products (Herrero et al. 2016). However, since the overall supply of LDF globally is projected to dramatically increase, driven by demand in LMIC, with a forecast of about a 100% increase of animal protein supply between 2000 and 2050 (Havlik et al. 2013), the overall emissions would increase even if the full mitigation potential can be reached.

Recent enteric methane research focusing on LMIC point to huge co-benefits between emissions savings and livelihood gains, through herd and health management, nutrition and feeding management strategies, genetics and other strategies. Three country cases show potentially that Uruguay can achieve a 42% emissions reduction together with an 80% beef production increase (FAO et al. 2017a); Ethiopia can achieve a 65% emissions reduction with a 225% beef production increase (FAO et al. 2017b); and Bangladesh can reduce emissions by 17.5% alongside an increase in milk production of 27% (subsistence) and 24% (commercial) (FAO et al. 2017c).

6.6 Evidence gaps and further research needs

Research on the environmental impacts of the livestock sector has mainly focused on GHG emissions. The shifts towards, and impacts of, LDF-rich diets, along with increasing emphasis on sustainable agriculture, require further and broadened efforts to understand dietary synergies and trade-offs. This will require assessment of multiple natural resource uses and environmental impacts for a mix of food items, considering both energy and nutritional content, and for a range of human diet needs, considering health, age and sex. Such research should be based on data from both high-income countries and LMIC and consider cascading synergies and trade-offs at multiple temporal and spatial scales.

A more comprehensive view of sustainability of livestock production systems and LDF consumption is especially relevant to LMIC. Only when both biophysical and socio-economic dimensions are considered can environmental optimization and sustainable societal development be achieved. More research must be based on empiric data from less developed regions; it is here that 87–88% of global population live now and in the next century (UN 2017); it is here the ‘Livestock Revolution’ is happening (Delgado et al. 1999); it is here that agriculture is going through rapid socio-ecological changes; and, therefore, it is here that the potential to impact the future is the largest.

Moreover, the research needed to assess the neglected area of sustainability of a desirable LDF supply during the first 1,000 days of life, focusing on pregnant women and children under two years old, will benefit from the research suggested above. Based on the assumption that it is the most vulnerable and least privileged mothers and children who will benefit from additional LDF supply, it will be important to use the broader view of sustainability that includes

social, health, economic and environmental aspects. A broader approach can, for example, capture trade-offs between immediate implementation of strategies to reduce GHG emissions and alternative long-term strategies aimed at reducing stunting and sub-optimal mental development among children, in order to make coming generations better equipped to transform their society to be more sustainable.

Through the Paris agreement to combat climate change and adapt to its effects and Agenda 2030, the global community has made commitments to implement the processes necessary to transform agriculture and make it more sustainable. Livestock production will be key to fulfilling these agreements. During formulation and implementation of these targets in LMIC, there is an opportunity to ensure that the necessary LDF supply for the first 1,000 days is protected and promoted. In addition, realizing the aims of the Paris agreement and Agenda 2030 in LMIC will require improved data collection systems and processes, not only to provide evidence of current practices, but also for monitoring and evaluation. Every country will be held accountable for attaining their SDG targets and their Nationally Determined Contribution targets. This will include systems that build on what is already being collected and make the best use of new technologies, like mobile telephony, drones and remote sensing.

6.7 Conclusions

Environmental sustainability is just one element of overall sustainability. There may be tradeoffs, e.g. intensive production which produces less GHG per unit of livestock production, that can be more conducive to the emergence of pandemic diseases than less intensive production. It is important to keep in mind the multiple contributions to economic and social well-being that livestock rearing gives many millions of smallholder farmers in LMIC, including highly nutritious high-value foods, assets for financial insurance, the primary source of organic fertilizer and drought power to cultivate cropland, among others.

In terms of environmental sustainability, the livestock sector is a major resource user and generates multiple environmental impacts. These differ between high-income countries and LMIC and the optimal approach to managing them also differ. The potential to improve the environmental sustainability per unit of LDF produced is particularly high in LMIC. The dramatically increased demand for LDF projected to take place in LMIC over the coming decades will require considerable efforts to make use of this potential. Even so, it is likely that environmental impacts will intensify. With an environmentally-optimized livestock system, however, there is clear potential for these increases to be minimized.

While the environmental impact of the global livestock sector is likely to remain net-negative, livestock can make important environmental contributions in specific contexts (e.g. pastoralism in marginal landscapes, provision of manure in smallholder-mixed farming, utilization of crop residues). One way to reduce resource use and environmental impacts would be to improve the efficiency of livestock production systems in LMIC, as it is most unlikely that total production in any scenario will be limited; however, this should not be to the detriment of other aspects of sustainability.

Encouragingly and most important, in the general trend of increased demand of LDF in LMIC, the needs for the first 1,000 days of life are relatively small and can be met while decreasing overall LDF consumption. Thus, the small quantity required to improve the dietary situation for pregnant mothers, during lactation and during early childhood makes it possible to safeguard this supply in LMIC, while also complying with commitments under the Paris agreement and the 2030 Agenda.

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Annexes

Annex I. Key micronutrients provided by livestock-derived foods

LDF	Meat	Milk	Eggs	Consequences of deficiency	Prevalence of deficiency
Ca	0	+++	0	Nutritional rickets and inhibited bone growth and density; maternal increased risk of preeclampsia.	Global estimates not available. WHO estimates that low intakes are common and nutritional rickets is reappearing
Fe (heme)	+++	0	0	Anaemia; impaired growth, immune function, cognitive development and school performance in children; lowered work capacity; maternal mortality.	Estimated 1 in 4 people worldwide has iron deficiency (WHO global database on iron deficiency)
Fe (total)	+++	+	+		
Zn	+++	+	+	Pregnancy complications; low birth weight; impaired immune function, mortality, growth faltering; diarrhoea.	Estimated 1 in 5 world's population is at risk of inadequate intake
Vit A	+	++	+++	Growth faltering; impaired development; xerophthalmia and blindness; impaired immune system; increased mortality; skin infections.	Low serum retinol concentration affects 33% of the preschool age children and 15% of pregnant women in populations at risk of VAD worldwide (WHO Global Database on Vitamin A Deficiency)
Vit B12	+++	++	++	Megaloblastic anaemia; gastrointestinal symptoms neurological symptoms; demyelinating disorder of the central nervous system.	High prevalences reported worldwide, particularly deficient in vegetarian diets with no supplementation
Folate	+	+++	+	Anaemia; slow growth rate; during pregnancy, higher risk of premature infants and neural tube defects; depression.	Little data available, suggesting that deficiencies could affect many millions

Ca: calcium; Fe: iron; Vit: vitamin; Zn: zinc

Source: Allen et al. 2008; Randolph et al. 2007

Annex 2. Causal frameworks related to nutrition and livestock

Multiple agriculture-nutrition impact pathways frameworks that had been proposed to help conceptualise the linkages between agricultural activities and (positive or negative) nutritional outcomes. These frameworks have contributed to a better understanding of how context changes might influence those nutritional outcomes in LMIC and to pinpoint where in the chain of events the change could be expected. In addition, they can inform the development and interpretation of indicators and proxy indicators and guide the programming of nutrition interventions.

A lot of the current thinking about malnutrition was influenced by the 1990 UNICEF 'Nutrition conceptual framework' (Figure a), which brought clarity to the causes of malnutrition. This framework distinguishes between immediate (related to food intake and disease), underlying (food security, care and health) and distal or basic causes, such as poverty, employment, socio-economic and political context, etc. establishing the basis for multidisciplinary to achieve enhanced nutrition. It was recently used in The Lancet series 'Maternal and Child Nutrition 2013' as a basis to build a framework for action to achieve optimum nutrition and development during the first 1,000 days of life (Figure b) (Black et al. 2013). The UNICEF and the Lancet frameworks, however, do not make explicit the rich net of pathways and interactions between each of the categories, leaving it at a high level of abstraction (e.g. maternal disease could negatively affect care practices, as could much time spent working in food production) (Webb 2013). Agriculture affects both dietary adequacy and disease through numerous multiple-link causal pathways, with interacting and sometimes counteracting processes.

Figure a: Adapted UNICEF conceptual framework.

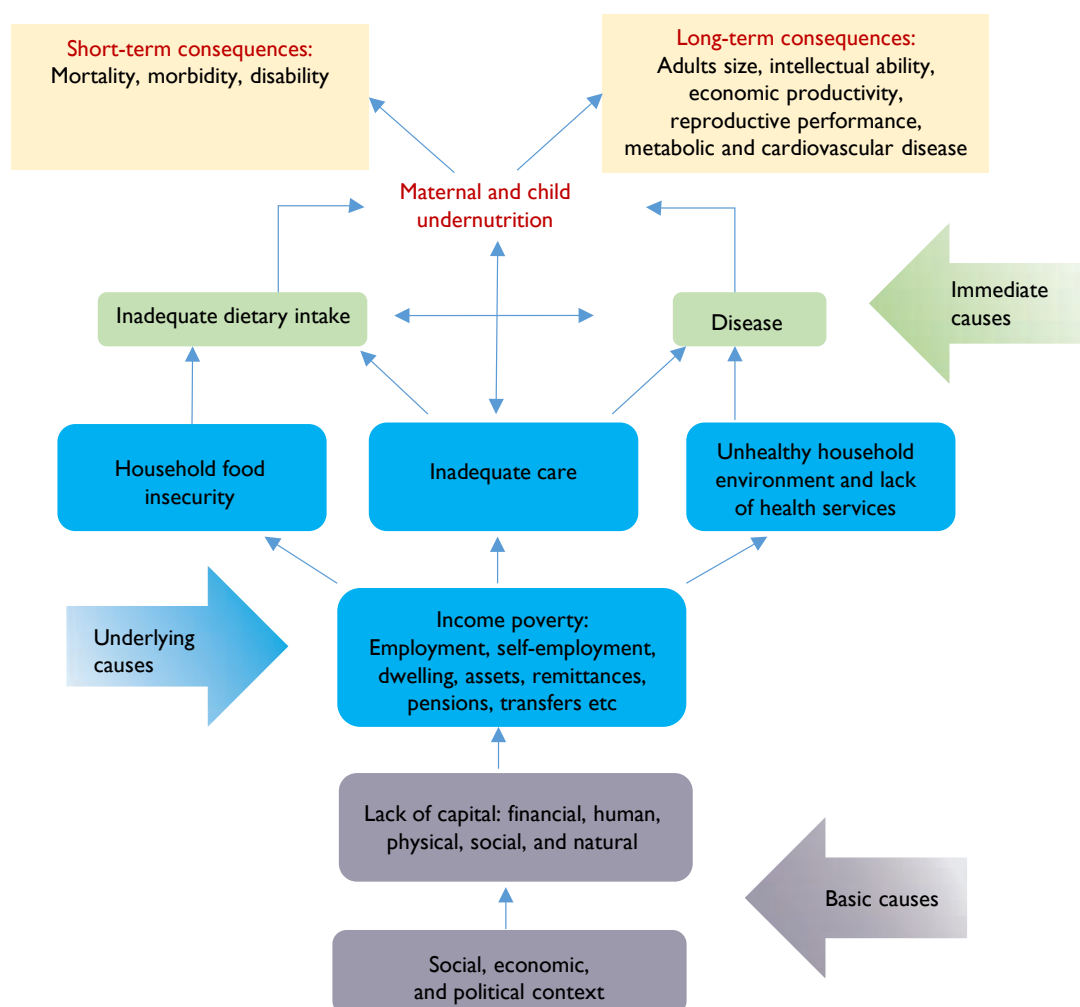
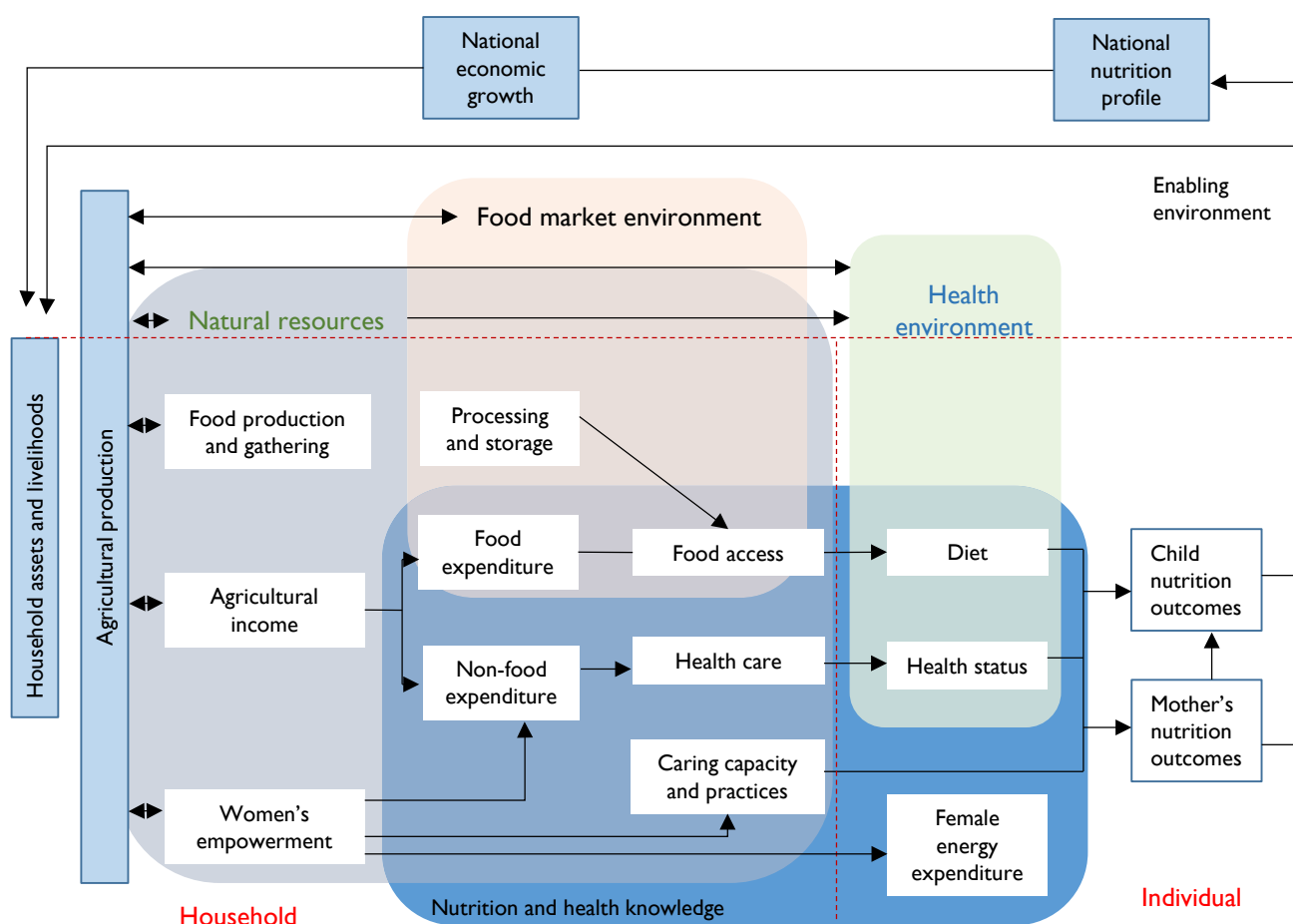


Figure b: Framework for actions to achieve optimum foetal and child nutrition and development.



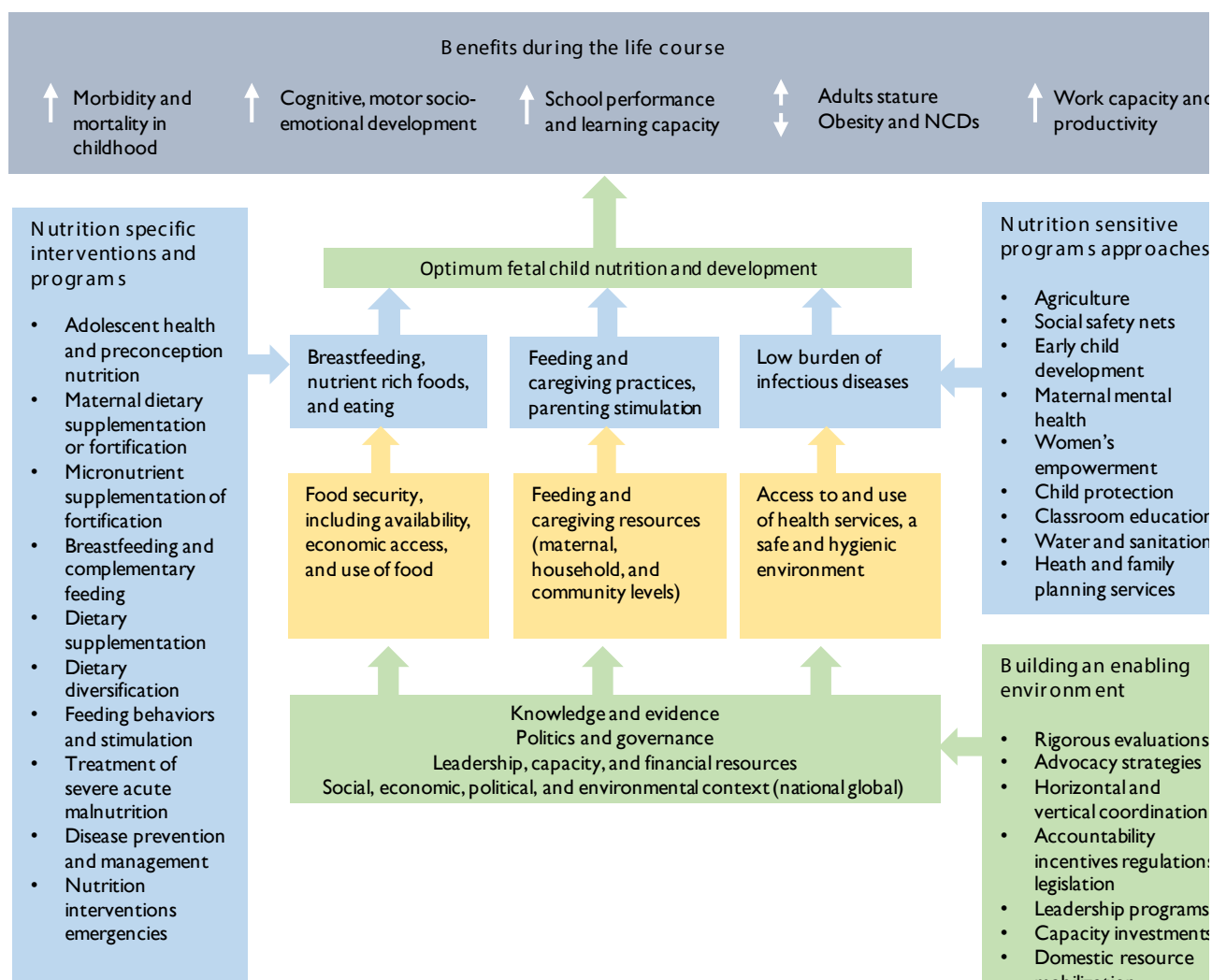
Source: The Lancet series Maternal and Child Nutrition 2013 (Black et al. 2013)

Herforth and colleagues developed a specific conceptual framework (Figure c) which describes these links in more depth adding important dimensions, such as gender or physical activity (Herforth and Harris 2014). However, it does not develop the dimensions of food systems and food safety (of key importance for ASF). Different layers are relevant (individual, household, community, supply chain, country, global levels) as well as different stakeholders, which are not always sufficiently represented in this framework.

Dury and colleagues went further (Figure d), introducing essential issues such as intra-household inequalities, drivers of dietary choices, seasonality, women's health, etc. (Dury et al. 2014), clarifying some of the multiple direct and indirect pathways. In addition, Dury's framework establishes an inventory of potential risks (i.e. negative impacts in nutrition) that may arise in agriculture interventions, such as lack of translation of income into improved nutrition of all or part of the household, shift from the production of nutrition-rich foods to cash foods, negative shifts in social dynamics, environmental contamination, etc. (Dury et al. 2014).

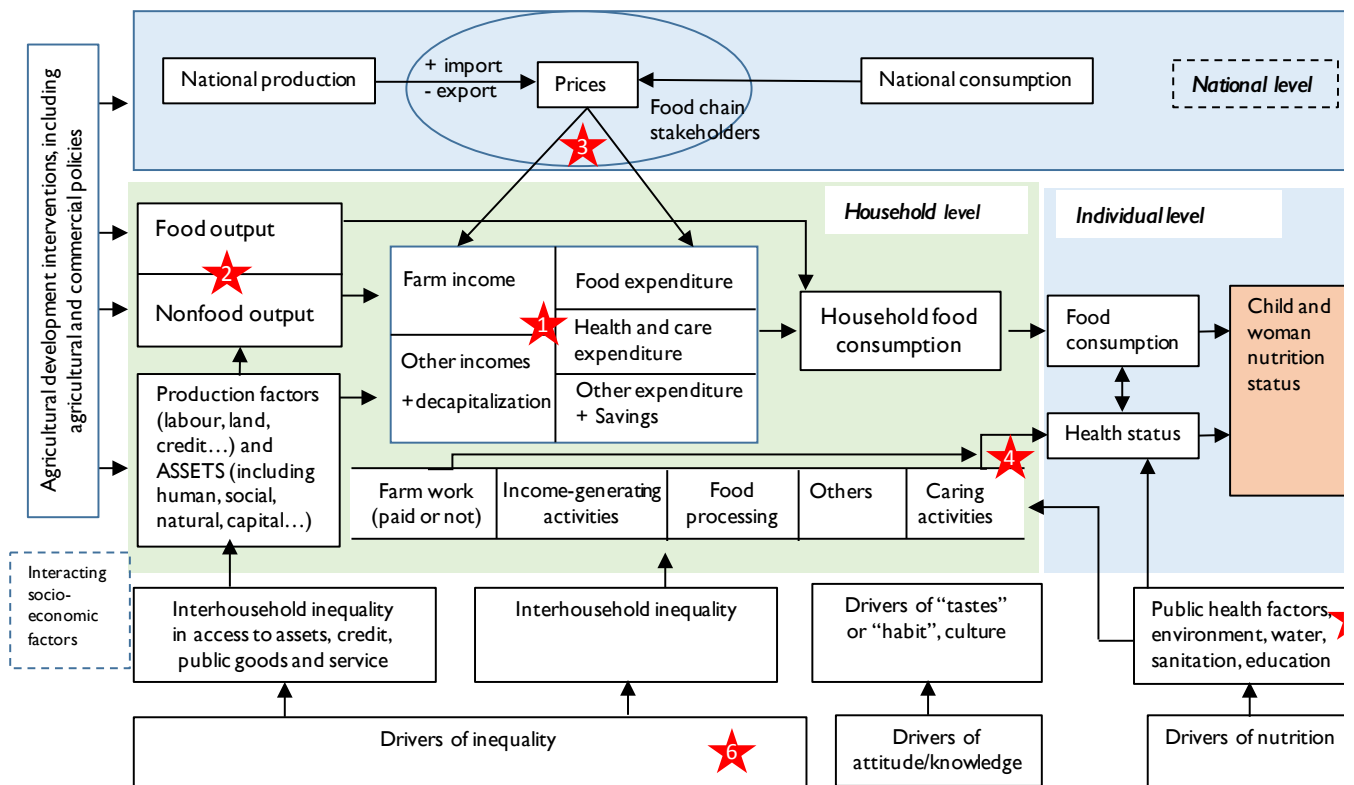
All these frameworks relate to agriculture in a broad sense. Impact pathways of livestock to nutrition are specific cases of the agriculture pathways and are less developed. Randolph and colleagues described (Figure 1) the complex linkages between livestock keeping and a household's nutrition, wellbeing and health in LMIC (Randolph et al. 2007). The benefits of livestock extend into other forms of agriculture due to the contribution to traction and nutrition cycling services to increase food crop production. Livestock also have other social purposes such as capital accumulation or status.

Figure c: Conceptual framework linking agriculture and nutrition.



Source: Herforth et al. 2014

Figure d: Main risks in the agriculture-nutrition impact pathways.



The red stars indicate the areas of risks.

Source: Dury et al. 2014

Annex 3. Search syntax for the systematic review on the first 1,000 days (20 April 2016)

Database	Syntax	No. of hits (20 April 2016)
Pubmed:	(Infant OR child* OR (pregnan* AND (woman OR women)) OR (lactat* AND (woman OR women)) OR breastfeed*) AND ("trial" OR experiment OR supplementation OR intervention) AND (diet OR supplement OR consumption OR nutrition* OR feed*) AND (meat OR milk OR egg OR dairy OR "animal source food" OR fish OR "animal products" OR "foods of animal origin") AND (Developing Countries OR Africa OR Africa, Northern OR Africa South of the Sahara OR Africa, Central OR Africa, Eastern OR Africa, Southern OR Africa, Western OR Asia OR Asia, South OR Asia, Southern OR Asia, Southeastern OR Afghanistan OR Algeria OR Angola OR Bangladesh OR Benin OR Bhutan OR Botswana OR Brunei Darussalam OR Burkina Faso OR Burundi OR Cambodia OR Cameroon OR Cape Verde OR Central African Republic OR Chad OR Comoros OR Congo OR "Cote d'Ivoire" OR Djibouti OR "Democratic Republic of the Congo" OR East Timor OR Egypt OR Eritrea OR Ethiopia OR Gabon OR Gambia OR Ghana OR Guinea OR Guinea-Bissau OR India OR Indonesia OR Iran OR Kenya OR Laos OR Lesotho OR Liberia OR Libya OR Madagascar OR Malawi OR Malaysia OR Maldives OR Mali OR Mauritania OR Mauritius OR Morocco OR Mozambique OR Myanmar OR Namibia OR Nepal OR Niger OR Nigeria OR Pakistan OR Papua New Guinea OR Philippines OR Rwanda OR Senegal OR Seychelles OR Sierra Leone OR Singapore OR Sri Lanka OR Somalia OR South Africa OR Sudan OR Swaziland OR Tanzania OR Thailand OR Togo OR Tunisia OR Uganda OR Vietnam OR Zambia OR Zimbabwe)	1187
Cochrane	(Infant OR child* OR (pregnan* AND (woman OR women)) OR (lactat* AND (woman OR women)) OR breastfeed*) AND ("trial" OR experiment OR supplementation OR intervention) AND (diet OR supplement OR consumption OR nutrition* OR feed*) AND (meat OR milk OR egg OR dairy OR "animal source food" OR fish OR "animal products" OR "foods of animal origin") AND (Developing Countries OR Africa OR Africa, Northern OR Africa South of the Sahara OR Africa, Central OR Africa, Eastern OR Africa, Southern OR Africa, Western OR Asia OR Asia, South OR Asia, Southern OR Asia, Southeastern OR Afghanistan OR Algeria OR Angola OR Bangladesh OR Benin OR Bhutan OR Botswana OR Brunei Darussalam OR Burkina Faso OR Burundi OR Cambodia OR Cameroon OR Cape Verde OR Central African Republic OR Chad OR Comoros OR Congo OR "Cote d'Ivoire" OR Djibouti OR "Democratic Republic of the Congo" OR East Timor OR Egypt OR Eritrea OR Ethiopia OR Gabon OR Gambia OR Ghana OR Guinea OR Guinea-Bissau OR India OR Indonesia OR Iran OR Kenya OR Laos OR Lesotho OR Liberia OR Libya OR Madagascar OR Malawi OR Malaysia OR Maldives OR Mali OR Mauritania OR Mauritius OR Morocco OR Mozambique OR Myanmar OR Namibia OR Nepal OR Niger OR Nigeria OR Pakistan OR Papua New Guinea OR Philippines OR Rwanda OR Senegal OR Seychelles OR Sierra Leone OR Singapore OR Sri Lanka OR Somalia OR South Africa OR Sudan OR Swaziland OR Tanzania OR Thailand OR Togo OR Tunisia OR Uganda OR Vietnam OR Zambia OR Zimbabwe)	359

Database	Syntax	No. of hits (20 April 2016)
CABDirect	(title: (Infant OR child* OR (pregnan* AND (woman OR women)) OR (lactat* AND (woman OR women)) OR breastfeed*) OR ab: (Infant OR child* OR (pregnan* AND (woman OR women)) OR (lactat* AND (woman OR women)) OR breastfeed*)) AND (title: ("control* trial" OR experiment OR supplementation OR intervention) OR ab: ("control* trial" OR experiment OR supplementation OR intervention)) AND (title: (diet OR supplement OR consumption OR nutrition*) OR ab: (diet OR supplement OR consumption OR nutrition*)) AND (title: (meat OR milk OR egg OR dairy OR "animal source foods" OR fish OR "animal products" OR "foods of animal origin") OR ab: (meat OR milk OR egg OR dairy OR "animal source foods" OR fish OR "animal products" OR "foods of animal origin")) AND (title: ("Developing Countries" OR Africa OR "Africa, Northern" OR "Africa South of the Sahara" OR "Africa, Central" OR "Africa, Eastern" OR "Africa, Southern" OR "Africa, Western" OR Asia OR "Asia, South" OR "Asia, Southern" OR "Asia, Southeastern" OR Afghanistan OR Algeria OR Angola OR Bangladesh OR Benin OR Bhutan OR Botswana OR "Brunei Darussalam" OR "Burkina Faso" OR Burundi OR Cambodia OR Cameroon OR Cape Verde OR "Central African Republic" OR Chad OR Comoros OR Congo OR "Cote d'Ivoire" OR Djibouti OR "Democratic Republic of the Congo" OR "East Timor" OR Egypt OR Eritrea OR Ethiopia OR Gabon OR Gambia OR Ghana OR Guinea OR Guinea-Bissau OR India OR Indonesia OR Iran OR Kenya OR Laos OR Lesotho OR Liberia OR Libya OR Madagascar OR Malawi OR Malaysia OR Maldives OR Mali OR Mauritania OR Mauritius OR Morocco OR Mozambique OR Myanmar OR Namibia OR Nepal OR Niger OR Nigeria OR Pakistan OR "Papua New Guinea" OR Philippines OR Rwanda OR Senegal OR Seychelles OR "Sierra Leone" OR Singapore OR "Sri Lanka" OR Somalia OR "South Africa" OR Sudan OR Swaziland OR Tanzania OR Thailand OR Togo OR Tunisia OR Uganda OR Vietnam OR Zambia OR Zimbabwe) OR ab: ("Developing Countries" OR Africa OR "Africa, Northern" OR "Africa South of the Sahara" OR "Africa, Central" OR "Africa, Eastern" OR "Africa, Southern" OR "Africa, Western" OR Asia OR "Asia, South" OR "Asia, Southern" OR "Asia, Southeastern" OR Afghanistan OR Algeria OR Angola OR Bangladesh OR Benin OR Bhutan OR Botswana OR "Brunei Darussalam" OR "Burkina Faso" OR Burundi OR Cambodia OR Cameroon OR Cape Verde OR "Central African Republic" OR Chad OR Comoros OR Congo OR "Cote d'Ivoire" OR Djibouti OR "Democratic Republic of the Congo" OR "East Timor" OR Egypt OR Eritrea OR Ethiopia OR Gabon OR Gambia OR Ghana OR Guinea OR Guinea-Bissau OR India OR Indonesia OR Iran OR Kenya OR Laos OR Lesotho OR Liberia OR Libya OR Madagascar OR Malawi OR Malaysia OR Maldives OR Mali OR Mauritania OR Mauritius OR Morocco OR Mozambique OR Myanmar OR Namibia OR Nepal OR Niger OR Nigeria OR Pakistan OR "Papua New Guinea" OR Philippines OR Rwanda OR Senegal OR Seychelles OR "Sierra Leone" OR Singapore OR "Sri Lanka" OR Somalia OR "South Africa" OR Sudan OR Swaziland OR Tanzania OR Thailand OR Togo OR Tunisia OR Uganda OR Vietnam OR Zambia OR Zimbabwe))	767

Annex 4. Summary of indicators used in the systematic review

Indicator	Description
Exclusive breastfeeding duration	Number of months under exclusive breastfeeding—i.e. while the infant only receives breast milk without any additional food or drink, including water.
No. of feeds	Number of times a child is given the breast in a day.
Prolactin levels	Prolactin is a protein that in humans is best known for its role in enabling to produce milk.
Milk output	Quantity of breast milk produced (g).
Milk intake (baby)	Quantity of breast milk consumed by the child (g).
Milk protein content	The content of protein in breast milk (g/100ml).
Lactation amenorrhea duration	Length of the temporary postnatal infertility that occurs when a woman is amenorrheic (not menstruating) and fully breastfeeding.
WHZ ¹	Weight-for-height Z-score is an indicator of wasting or thinness, indicating in most cases a recent and severe process of weight loss, which is often associated with acute starvation and/or severe disease.
HAZ ²	Height-for-age Z-score is an indicator of stunted growth, reflecting a process of failure to reach linear growth potential as a result of suboptimal health and/or nutritional conditions.
MUAC ³	Mid-upper arm circumference is the circumference of the left upper arm, measured at the mid-point between the tip of the shoulder and the tip of the elbow (olecranon process and the acromium). It is used for the assessment of nutritional status and is a good predictor of mortality.
MAFA	Mid-arm fat area is a derived measure from middle arm measurements, and is an indicator of fat stores.
MAMA	Mid-arm muscle area is a derived measure from middle arm measurements, and is a good indicator of lean body mass and thus skeletal protein reserves.
Maternal BMI	Body mass index is a value derived from the mass (weight) and height of an individual to classify underweight, overweight and obesity.
Triceps skinfold	Triceps skinfold is the width of a fold of skin taken over the triceps muscle and is a good predictor of body density (and hence percentage total body fat).
Subscapular skinfold	Subscapular skinfold is measured in the site just below the shoulder blade; situated below or on the underside of the scapula and is also used for assessment of body fat.
Haemoglobin	Haemoglobin is the iron-containing oxygen-transport protein in the red blood cells that is involved in the transport of oxygen, which is measured to assess anaemia.
Plasma ferritin	Ferritin is an intracellular protein that stores iron and releases it in a controlled fashion, used to assess iron-deficiency anaemia.
Serum iron	Serum iron is a medical laboratory test that measures the amount of circulating iron that is bound to transferrin.
Serum zinc	Serum zinc is a measure to detect zinc deficiency.
Serum copper	Serum copper is a measure to detect copper deficiency.
Plasma folate	Serum folate is a measure to detect folate deficiency.
Plasma retinol	Serum retinol is a measure to detect vitamin A deficiency.
RBC riboflavin	Riboflavin content in red blood cells is a measure to detect vitamin B2 deficiency.
Plasma vitamin B12	Plasma B12 is a measure to detect vitamin B12 deficiency.
Iodine in urine	Urine iodine is a test to assess the levels of iodine.
IQ (Raven's coloured progressive matrices)	Raven's progressive matrices are a nonverbal group test typically used in educational settings, measuring abstract reasoning and regarded as a non-verbal estimate of fluid intelligence.
Non-verbal test (Wechsler intelligence scale)	Wechsler intelligence scale is an individually administered intelligence test for children which generates a Full Scale Intelligence Quotient which represents a child's general intellectual ability.
Total antibody titers	Antibody titer is a measurement of how much antibody an organism has produced that recognizes a particular epitope, expressed as the inverse of the greatest dilution (in a serial dilution) that still gives a positive result.
IgG antibody titers	Immunoglobulins G (Ig G) are the main type of antibody found in blood and extracellular fluid allowing it to control infection of body tissues.

¹WHZ: Wasting is defined as the percentage of children whose weight-for-height is less than -2 standard deviations from the median of the WHO Child Growth Standards.

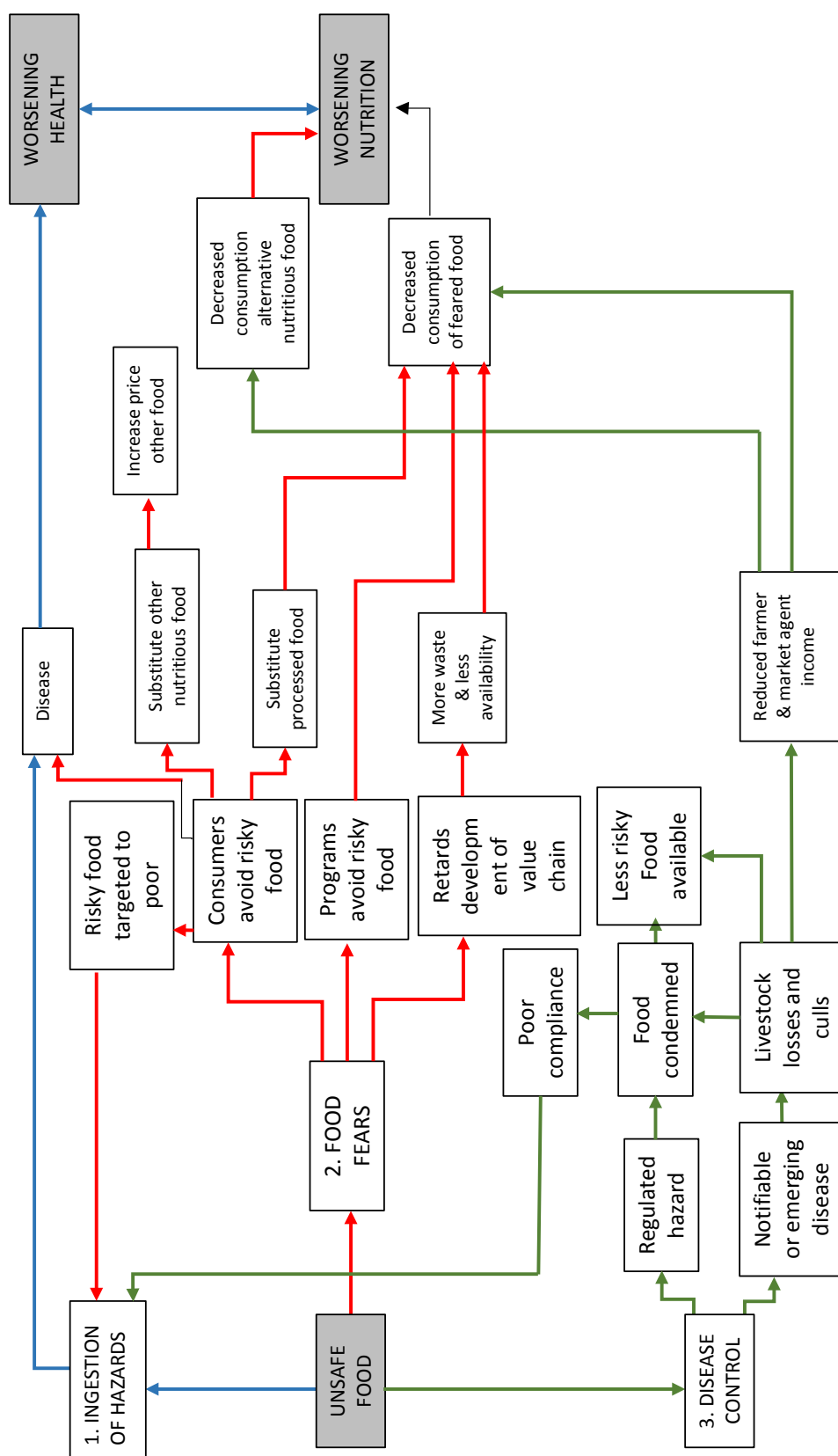
²HAZ: Stunting is defined as the percentage of children whose height-for-age is less than -2 standard deviations from the median of the WHO Child Growth Standards.

³MUAC: Underweight is defined as the percentage of children whose weight-for-age is less than -2 standard deviations from the median of the WHO Child Growth Standards.

Annex 5. Quality assessment

Study	Quality assessment	Risk of bias
Kenya (Long et al. 2012)	High	Randomization (method unspecified) Double-blinding
Sri Lanka (Tennekoon et al. 1996)	Moderate Limited sample size	Randomization of matched pairs of subjects and of allocation Exposure (i.e. consumption of supplement) was self-reported Lack of blinding
Burma (Khin-Maung-Naing and Tin-Tin-Oo 1987)	Moderate/low Very small sample size and no power calculations	Randomization Unknown process of selection of participants Lack of detail regarding blinding and randomization
Malaysia (Ihab et al. 2014)	Moderate/low Limited sample size and no power calculations No control in the statistical analysis	Randomized (method unspecified) Potential issues with compliance (food supplied at the household level and monitoring based on mother report; a number of mothers express reluctance of the children to eat the supplement) Not-blinded
Iran (Rahmani et al. 2011)	Moderate/low Over-simplified statistical analysis, lack of specification of analysis There was no adjustment for multiple comparisons	Participants were children in schools allocated to either intervention or control, but the analysis did not account for this Lack of blinding Generally, lack of specification of methods, but it seems that an education intervention beyond the supplementation took place
Kenya (Grillenberger et al. 2003, Hulett et al. 2014, McLean et al. 2007, Neumann et al. 2013, Siekmann et al. 2003, Sigman et al. 2005, Whaley et al. 2003)	Generally high Some of the sub-studies had small sample sizes and lacked power calculations Statistical analysis generally good but potential issues of multiple testing	Randomization at the school level Lack of blinding There was no adjustment for multiple comparisons
Vietnam (Lien do et al. 2009)	Moderate Statistical analysis not ideal to provide individual information for non-fortified milk alone.	Randomization (method unspecified) Double-blind The data of the questionnaire was self-reported There was no adjustment for multiple comparisons
New Guinea (Mathews et al. 1974)	Moderate Limited sample size	Non-randomized No presentation of baseline characteristics

Source: Grace forthcoming



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