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Animal source foods: Sustainability problem or malnutrition and sustainability solution? Perspective matters

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ABSTRACT:

Globally, two billion people suffer from micronutrient deficiencies, 151 million children under five suffer from stunting, and millions more have impaired cognitive development related to poor nutrition. This is partly due to insufficient consumption of animal-sourced foods (ASF), which supply multiple bioavailable nutrients that are lacking in the cereal-based diets of the poor. Yet, reports like the one recently published by the EAT-Lancet Commission, solely focus on the threat of ASF consumption on sustainability and human health, overestimate and ignore the tremendous variability in the environmental impact of livestock production, and fail to adequately include the experience of marginalized women and children in low- and middle-income countries whose diets regularly lack the necessary nutrients. Yet animal-source foods have been described by the World Health Organization as the best source of high-quality nutrient-rich food for children aged 6–23 months. Livestock and ASF are vital to sustainability as they play a critical role in improving nutrition, reducing poverty, improving gender equity, improving livelihoods, increasing food security, and improving health. The nutritional needs of the world's poor, particularly women and children, must be considered in sustainability debates.

The notion that raising livestock and consuming animal-source food (ASF; milk and dairy products, meat, fish, and eggs) is fundamentally incompatible with sustainable development is flawed. Negative perceptions of the role of livestock in many sustainability debates arise from overestimation of the environmental footprint of livestock production (Steinfeld et al., 2006), a focus mainly on overconsumption of ASF in middle-to high-income countries (MHIC) and, as demonstrated recently by Poore and Nemeck (Poore and Nemecek, 2018), a narrow interpretation of sustainability that focuses on one, albeit important, indicator – climate change (Steinfeld et al., 2006; Gerber et al., 2013; National Academies of Sciences, Engineering, and Medicine, 2019). Even the recent widely discussed EAT-Lancet Commission report (Willet et al., 2019), which focusses on "healthy diets" as well as climate change, uses a narrow interpretation that inadequately represents the urgent dietary situation of many people living in low- and middle-income (LMIC) countries. Both of these reports advocated substantial reductions in consumption of ASF on the basis that existing diets threaten sustainability because of their environmental footprint and/or human health impacts. While the objectives of developing dietary guidelines that safeguard human and planetary health are laudable, the narrative of the EAT-Lancet Commission inadequately accounts for the existing needs of many people and it has been criticized for various reasons including unaffordability (Hirvonen et al., 2019; Gupta and Bharti, 2019), misleading environmental estimates (American Society of Animal Science, 2019), nutritional inadequacies (Teicholz, 2019) and overall omissions, including in areas relating to equity and livelihoods (Hadaad, 2019). The EAT-Lancet Commission report recommendations can have a major negative impact on global appreciation of the importance of ASF in diets, even though it mainly considers MHIC perspectives. There is a danger that it could be adopted without further deliberations on the impacts in LMICs, endangering the health and livelihoods of large sections of the populace.

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For the almost 800 million extremely poor people who live on less than $1.90/day and subsist on a diet heavily based on starchy foods, as well as for millions more who are slightly better off, more – not less – ASF will be required for sustainable development, as ASF provide not only calories but, more importantly, the nutrients required for achievement of human development potential. Indeed, in many cases, ASF are the only accessible source of such nutrients for the poor. Though the EAT-Lancet Commission report briefly states that more meat and other major protein sources should be consumed by low income populations that subsist on starch diets to mitigate malnutrition, this critically important fact is contradicted in the key messages and executive summary, which advocate low or less ASF consumption. If the recommendations in the key messages of the EAT-Lancet commission report to eat less ASF are adopted by poor pregnant and lactating women in LMIC, they could maintain the current high stunting rates, and the associated physical and cognitive development problems. Furthermore, livestock and fish production meaningfully contribute to the ability of these very vulnerable populations to achieve other equally important targets of sustainable development, including income growth and gender equality. Thus, efforts to achieve sustainable development must include a more nuanced understanding of livestock and consider their important implications on the lives of the poor.

Undernutrition causes almost half of child deaths globally and undermines the long-term health of populations and the physical and cognitive development of children (Black et al., 2008, 2013; Development Initiatives, 2018). According to WHO, stunting (low-height-for-age), an important indicator of chronic undernutrition, affected approximately 150.8 million (22.2%) of children under five in 2017, particularly in sub-Saharan Africa and Asia, where stunting rates exceeding 30% still occur (UNICEF/WHO/World Bank, 2018). Stunting begins *in utero* and is greatest during the first 1000 days of life, from conception to age 2 years (De Onis and Branca, 2016), though the adverse effects persist for many more years later. This means that the *first one thousand days* post conception is a critical time for proper nutrition for the mother and child (Victora et al., 2010). In the long term, chronic malnutrition reduces cognitive and physical development, increases rates of sickness and death from common illnesses, and reduces educational outcomes and lifelong productive capacity (Black et al., 2013). Nutrient deficiencies in infancy may trigger permanent epigenetic changes in metabolism, which lead to poorer health later in life, when stunted children go on to consume high-calorie, low-nutrient diets common in developing countries. This combination of metabolic changes and inadequate diets result in adults being at increased risk of non-communicable diseases such as hypertension, cardiovascular disease, and Type 2 diabetes, compared to those who were not stunted (Prendergast and Humphrey, 2014). Stunting also has intergenerational effects: low birthweight is more common among infants whose mothers and even grandmothers were stunted during early childhood (De Onis and Branca, 2016). In addition, childhood stunting is estimated to deliver a per capita income penalty of 9–10% of gross domestic product (GDP) in Sub-Saharan Africa and South Asia (Galasso et al., 2016).

Key determinants of stunting include poor maternal health and nutrition before and during pregnancy and lactation, inadequate breastfeeding, inadequate maternal diets that compromise breastmilk quality, poor feeding practices for infants and young children, and unhealthy environments for children (Black et al., 2008; De Onis and Branca, 2016; Sinha et al., 2018). Deficiencies of vitamin A, iron, iodine, zinc, B_{12}, and folic acid – the most deficient micronutrients globally and particularly in diets of children and pregnant women – contribute to poor growth, intellectual impairment, perinatal complications, and increased risk of morbidity and mortality (Bailey et al., 2015).

Animal-source foods are the best available sources of high-quality nutrient-rich food for children aged 6–23 months (WHO, 2014). Compared to plant foods, ASF supply greater quantities of higher quality protein and more bioavailable vitamin A, vitamin D_3, iron, iodine, zinc, calcium, folic acid and key essential fatty acids. Animal source foods (ASF) generally contain more bioavailable iron than plant foods, and consuming ASF with plant-based foods increases the absorption of iron in the latter (Englemann et al., 1998; Neumann et al., 2002; Navas-Carretero et al., 2008). Similarly, consuming fish with vegetables increases the absorption of vitamin A and some fish species contain twice as high vitamin A concentration of vegetables as carrots or spinach (Kawarazuka and Béné, 2010; Vilain et al., 2016). In addition, ASF are the only natural source of vitamin B_{12}, the deficiency of which – prevalent in individuals consuming low amounts of ASF in the developing world – is associated with developmental disorders, anemia, poorer cognitive function, and lower motor development (Stabler and Allen, 2004). Based on their composition of micro- and macronutrients, as well as essential amino acids, increasing ASF consumption is likely to be more effective at reducing stunting than single nutrient supplementation, a strategy which is further complicated by the irregular and often unsustained availability of nutrient supplements outside the main cities of LMIC. A recent randomized controlled trial in Ecuador found that providing one egg a day to children 6–9 months old for a year reduced stunting and underweight (indicators of chronic and acute malnutrition in infants) by 47 and 74%, respectively, and caused no allergies (Iannotti et al., 2017). These nutritional benefits are much greater than those achieved by interventions not including ASF (Panjwani and Heidkamp, 2017). Importantly, a recent attempt to validate the Ecuador study in rural Malawi (Stewart et al., 2019) with 660 similarly-aged infants failed to affect stunting. As indicated by authors, this may have occurred because of the low stunting rates among the target population and their frequent consumption of fish, another important ASF, which would have supplied critical nutrients lacking in the basal diet. A recent analysis of 130,432 children aged 6–23 months from 49 countries documented strong associations between stunting and a generic ASF consumption indicator, as well as dairy, meat/fish, and egg consumption indicators, and showed that consuming ASF was strongly negatively associated with child stunting (Headey et al., 2018). In particular, stunting levels were notably higher in regions where ASF consumption was low such as South Central and SE Asia and West, Central Eastern, and Southern Africa. Other research underscores the importance of meat and milk in improving the growth outcomes of children (Neumann et al., 2007; De Beer, 2012). A recent meta-analysis involving 62 trials and 30,000 participants in 61 countries from five continents reported that ASF supplementation to pregnant mothers, infants or children improved birth weight, children's weight and reduced stunting (Pimpin et al., 2019), though improvements in weight were more pronounced than those in height. Interestingly, another recent meta-analysis (Shapiro et al., 2019) with fewer (21) studies across 14 countries, found no consistent relationship between ASF consumption and stunting, length/height, weight, head circumference, and anemia, and the authors attributed this to inconsistencies in the design of the studies.

Deficiencies of nutrients that are critical for neurological development and present in ASF (vitamin B_{12}, vitamin A, iron, zinc, docosahexanoic acid, and iodine) have been associated with brain-related disorders, including low intelligence quotient, autism, depression, and dementia (Gupta, 2016). Supplementation of basal diets of Kenyan school children with small amounts of meat or milk increased their test scores by 45 and 28%, respectively, and an earlier studies by the same group (Neumann et al., 2007) showed that meat supplementation was associated with increased cognitive skills, leadership behavior, physical activity, and initiative (Hulett et al., 2014). Maternal fish consumption during pregnancy was associated with greater cognitive development in infants postnatally (Daniels et al., 2004). Also, a recent review of the evidence from eight intervention and 10 observational studies with data from 61,066 adults and 26,299 children (age range:1–16 years) across eleven countries, revealed that ASF supplementation or ASF based-diets increased cognitive functions (test and exam scores) and fluid intelligence and verbal skills by at least two-fold (Balehegn et al., 2019).

Clearly, ASF can be vital for meeting the first global target of the WHO Comprehensive Implementation Plan on Maternal, Infant, and Young Child Nutrition, which calls for a 40% reduction in the number of stunted children under five by 2025 (WHO, 2014).

While there is evidence that some individuals should decrease consumption of certain types of ASF to improve their health (USHHS & USDA, 2015), achieving and maintaining recommended daily allowances of different food groups including ASF should be the target (USHHS & USDA, 2015; Buttriss, 2016). To this end, *increasing* access to and consumption of moderate amounts of ASF should simultaneously be a global priority for people in areas where undernutrition remains a persistent problem, particularly for infants and women of child bearing age. Unfortunately, recent attention to and focus on the negative impact of livestock production skews this discussion. By focusing on production systems that service the ASF demand of high income countries and the negative impact of overconsumption there, global attention and dialogue neglects the perspective and needs of the large number of people living in LMIC, among whom *increasing* ASF consumption could prevent stunting and improve overall health and development outcomes. Sustainability of the planet must consider nutritionally vulnerable populations, women, and children, and the impact that low consumption of ASF has on their lives and futures – a perspective mostly missing or underrepresented in scientific analyses or heated discussions on the impacts of ASF production on climate change. What is also missing is an understanding of how low the consumption of ASF is among the poor, particularly in LMIC, where starch-based diets are typical. For example, mean annual per capita meat consumption in the bottom four meat-consuming countries (Sudan, India, Bangladesh, and Ethiopia) is less than one-thirtieth of that in the top four (Brazil, Uruguay, Australia, and USA; Fig. 1). There is a decreasing trend in the proportion of stunted children in various countries across the world with increasing per capita consumption of meat, based on the data in Fig. 1. While this association at country level cannot be interpreted as evidence of a causal relationship, and while it may reflect the income elasticity of certain ASF like meat, it further supports the study of Heady et al. (Headey et al., 2018), the meta analysis of Pimpin et al. (2019) and the hypothesis that ASF has beneficial effects on child growth, which requires further evaluation at the individual level in diverse settings.

In 2015, the United Nations adopted a resolution to transform the world by 2030 by achieving 17 ambitious Sustainable Development Goals (SDGs). These include no poverty; zero hunger; good health and wellbeing; good-quality education; gender equality; decent work and economic growth; affordable clean energy; and climate action, among others (UN, 2018). Though the goals build on the historical Millennium Development Goals, they have been expanded explicitly to include goals and metrics to which developing countries need to strive. The new goals illustrate clearly that *all* countries have important work ahead if global sustainability is to be achieved, and that there are inherent and important differences in what work remains. It is important to note that livestock are indispensable for the achievement of the SDGs, partly because they play an essential role in the lives of the poor (Smith, 2017). Detailed descriptions of the role of livestock in achieving the SDGs were given by LGA (2016) and FAO (2018a). Some of the main highlights are as follows: Poverty elimination is highly unlikely without attention to the livestock sector, the world's fastest growing agricultural sub-sector, making up five of the ten highest value commodities in the world (LGA, 2016) and accounting for 40%, on average, of the global agricultural GDP in developing countries (Steinfeld et al., 2006; LD4D, 2018; GLAD, 2018). Increasing food security and eliminating hunger without livestock would be an even greater challenge than it already is for over half of the world's poor people who rely on the sector for subsistence, as well as income, insurance, and food (LGA, 2016; FAO, 2012; FAO, 2018a). Furthermore, livestock production allows food production on 57% of the earth's land that cannot be used for crop production (Mottet et al., 2017); and livestock production supplied 25% of protein and 18% of calories consumed globally in 2016, both of which are required for nutritional security (FAOSTAT, 2016-2018 cited by Mottet et al., 2017). Livestock provided draught power.or traction for about a third of farmers in developing countries (Bruinsma, 2003), though a more recent estimate is 50% of the world's farmers (World Bank, 2009). Livestock manure provides organic fertilizer for over 50% most of the world's croplands, converting waste products into inputs for production of high-value food (Bruinsma, 2003; FAO, 2018b). The manure plays an important role in replenishing soil organic matter, which is critical for maintaining soil health and quality and hence sustaining crop productivity and restoring degraded soils (FAO, 2018b). For millions, manure also serves as an important building material and

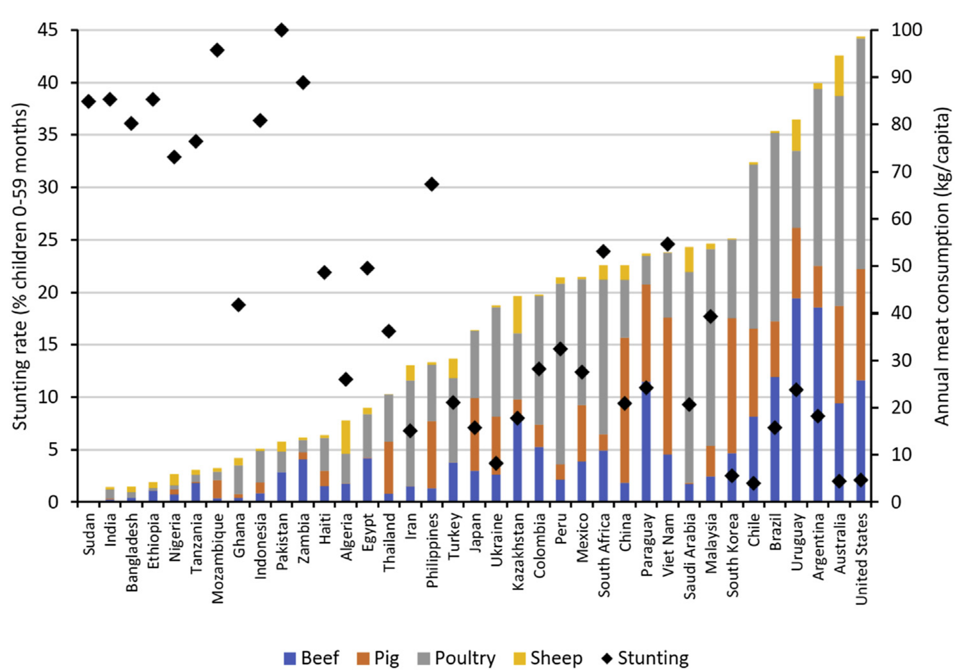

Fig. 1. Meat consumption per capita and stunting rate estimates in different countries (Adapted from OECD (2018) and UNICEF-WHO-World Bank (2017).

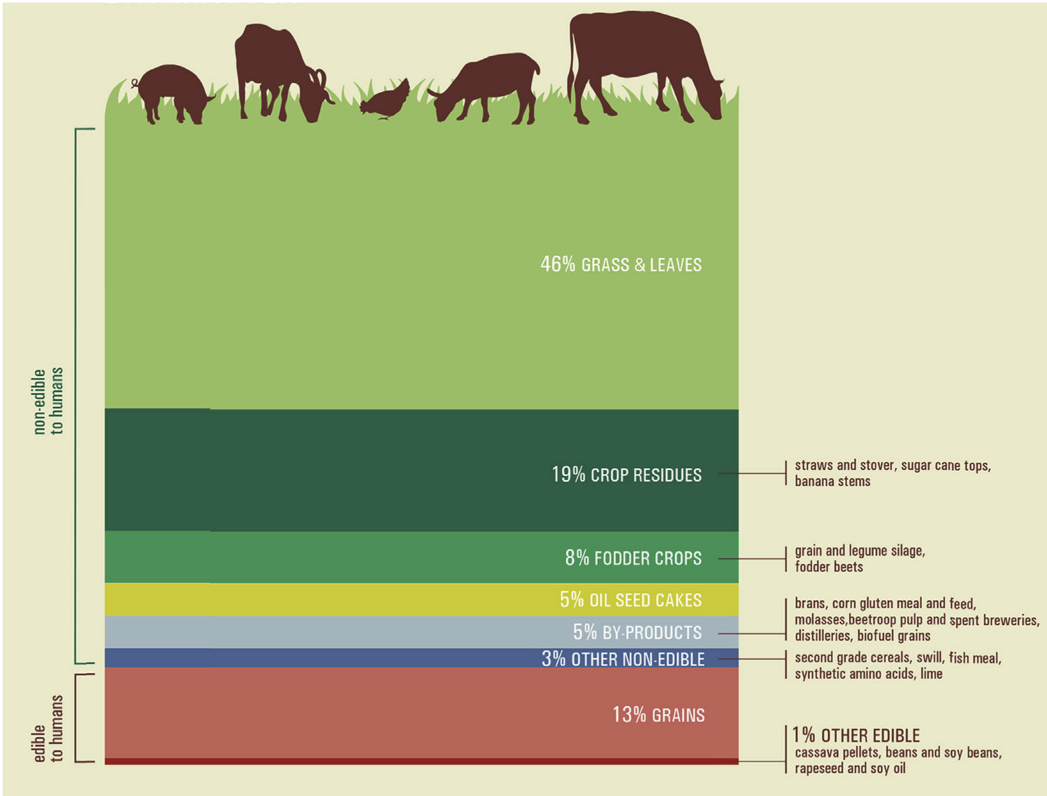

Fig. 2. Global livestock feed dry matter intake [Adapted from FAO, 2017 (Adpated from Mottet et al., 2017)].

an income source when sold for fuel. Achieving the SDG target for gender equality without attention to livestock production would be difficult, as nearly half of the world's farmers are women (Raney et al., 2011), and livestock is especially important for those female smallholder farmers who do not own land (Bravo-Baumann, 2000). Animal source food production contributes meaningfully to goals for a sustainable food system, by converting millions of tons of agroindustrial by-products that cannot be consumed by humans into livestock feeds, concomitantly reducing waste and environmental pollution and increasing human-consumable food. It is critical to note also that globally, only about 14% of the feed dry matter ingested by livestock is edible to humans, based on recent FAO data (Mottet et al., 2017, Fig. 2), and the figure is likely even lower in several developing countries where ruminant livestock subsist mainly on pastures or crop residues. These aspects are often overlooked in discussions about livestock and sustainability, such as in the recent Science article (Poore and Nemecek, 2018) that received global attention and unfortunately catalyzed widely-circulated non-scientific media calling for less ASF consumption in order to save the planet (Monbiot, 2018).

Though less pronounced in developed countries, the current increasing global demand for ASF is widespread in LMICs (WHO, 2013; Livestock Dialogue, 2014; Turk, 2016; LGA, 2016). With increasing urbanisation, education levels, and affluence in LMICs, the demand for ASF rises and this is likely to continue (Bruinsma, 2003; WHO, 2013; Zhang et al., 2017). This partly because as populations develop economically, they and their families become more food and nutritionally secure, including having increased dietary diversity from fruits and vegetable consumption (Mayen et al., 2014), as well as ASF (Agrawal et al., 2019). Sustainable intensification of livestock production, which involves improved resource use efficiency with environmental stewardship, can foster a reduction of greenhouse gas emissions while meeting this growing global demand for livestock products, which is expected to increase by 70% by 2050 (FAO, 2019). Several reviews have described how adverse environmental impacts of livestock production can be significantly curtailed using strategies such as improving herd efficiency and health and genetics; improving feed production and feeding practices including grazing management; heat abatement, fertility management, and facility design; reducing herd sizes to retain only productive and efficient animals; ensuring attainement of market size or weight earlier, and manure management to recover and recycle nutrients and energy, etc. (Hristov et al., 2013a, b, c; Knapp et al., 2014; FAO, 2018b). These approaches can reduce greenhouse gas emissions by up to 30% (FAO, 2013; Knapp et al., 2014; LGA, 2016) and they have reduced greenhouse gas emissions in intensive dairy farms to as low as 1 kg of CO_2 equivalents (CO2e)/kg of energy-corrected milk (ECM), compared with > 7 kg of CO_2e/kg of ECM in extensive systems. Further, strategic integration of other operations into livestock production can severely curtail greenhouse gas emissions, and even result in net sequestration of carbon. For instance, a recent meta-analysis of 86 studies concluded that silvo-pastoral systems, which involve livestock production in forests, resulted in the greatest net accumulation of soil carbon or net sink of greenhouse gases among agroforestry systems studied (Feliciano et al., 2018). In addition, widespread adoption of anaerobic digestion of manure to produce biogas in the US and the resultant reductions in coal and manure greenhouse gas emissions, could reduce greenhouse gas emissions by 99 + 59 metric tons and produce 0.6% of the annual electricity consumption (D'Cuéllar and Webber, 2008).

Like other agricultural systems, all livestock systems contribute to environmental pollution in different ways and to varying degrees. Each livestock system should critically examine which of the above practices it should adopt to improve environmental stewardship.

The current low productivity of livestock relative to their greenhouse gas emissions in Sub-Saharan Africa and South Asia results in higher greenhouse gas emission intensities. For example, to produce as much milk as the average US dairy cow in a year (10,000 L), about 8 Indian dairy cows (producing an average of 1200 L annually) would be required, generating *nine times* as much methane from gastrointestinal sources (Mitloehner, 2016). In LMICs, where emissions of greenhouse gases per unit of food produced, are generally higher, sustainable intensification will require practices such as feeding energy dense, nutritionally balanced rations, culling unproductive animals, fertility management, improving genetics, decreasing herd size to retain only productive animals, using appropriate mechanization, heat abatement and improving herd health.

Sustainable intensification of livestock production contributes to achievement of the SDG goals of responsible consumption and production; sustainable cities and communities; and climate action. Indeed, among agricultural strategies to achieve the climate action goal of reducing greenhouse gas emissions, sustainably intensifying livestock production may be the strategy with the greatest potential (FAO, 2018a). This emphasizes the need for significant additional investments in research and development to curtail greenhouse gas emissions from livestock systems, particularly from the ruminant production systems that contribute the most emissions. Such investments are greatly needed to increase sustainably productivity and production efficiency and thereby reduce emissions per unit of food produced from such systems.

In addition to consideration of agricultural strategies to minimize negative environmental impacts of livestock production, attempts to increase ASF consumption must also reduce the risks from acute and chronic human diseases associated with their production and consumption, especially in smallholder livestock systems in developing countries. Infectious diseases at the animal-human interface are highly dynamic and livestock are an important reservoir of zoonotic diseases. To date, control of these infectious diseases has had limited success in low- and middle-income countries, resulting in a high burden of human gastrointestinal disease (Havelaar et al., 2015). Environmental enteric dysfunction (EED) – an important risk factor for stunting – is associated with chronic inflammation in the intestines of young children and asymptomatic infections by diverse enteric pathogens including those present in livestock manure (Platts-Mills et al., 2017). In developed and developing countries alike, antimicrobial-resistant pathogens, often associated with intensification of production systems, are commonly found in animals, animal food products, and agro-food environments (Schwarz et al., 2018). These risks highlight the need for improved management practices to increase food safety and mitigate disease risks from livestock. Finally, overconsumption of certain ASF may increase the risk of developing of chronic diseases such as cancer and diabetes (Battaglia et al., 2015). Thus, while efforts should be made to increase consumption of ASF among the poorest, the general goal needs to emphasize moderation in ASF consumption and adherence to recommended daily intakes (Buttriss, 2016; USHHS & USDA, 2015).

Sustainable development strives to meet "the needs of the present without compromising the ability of future generations to meet their own needs" (Bruntland Commission, 1987). The current rate of ASF consumption among the world's poorest people meets neither their nutritional needs—present or future—nor those of their children and children's children; rather it results in poor nutrition and health, poor educational achievements, and lifelong restrictions of economic productivity, with all the attendant intergenerational harms these can cause. Conversely, evidence suggests that well-timed, *modest* increases in the amounts of milk, fish, meat, and egg consumption among the poorest people could significantly improve their nutritional status, as well as their educational and economic successes. This highlights the fundamental problem of advocating dietary change towards less ASF consumption (Willet et al., 2019): it is an unbalanced view of sustainability that does not adequately address the needs of the most vulnerable. While vegetarianism or veganism may be nutritionally feasible in the very places where ASF is overconsumed, the recommendation overlooks the risk of a vegetarian or vegan diet to those on whom it is unwillingly imposed and where micronutrient supplements are unavailable. Without doubt, increases in ASF consumption among the global poor needs to be achieved while safeguarding the health and wellbeing of people, animals, and the environment. This will require smart, intentional, and enduring collaborations among livestock and human nutrition and health practitioners, as well as policymakers and environmentalists. It will also necessitate a nuanced understanding of and attention to the disparate needs and perspectives of a global population. Only with effective multidisciplinary partnerships will we improve the accessibility and affordability of nutrient-dense ASF in low-income countries while maximizing the benefits and minimizing the adverse effects – environmental and otherwise – of ASF production globally.

Declaration of competing interest

Authors acknowledge no conflict of interest to report.

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The contents are the responsibility of the authors and do not necessarily reflect the views of [REMOVED FOR BLIND REVIEW]. We thank those who provided comments on the manuscript including [REMOVED FOR BLIND REVIEW] for assistance with the data collation. Authors contributed equally to this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2019.100325.

References

Balehegn, M., Mekuriaw, Z., Miller, L., McKune, S., Adesogan, A., 2019. Animal source foods for improved cognitive development. Front. Anim. Sci. 9 (4), 50–57. https://doi.org/10.1093/af/vfz039.

Agrawal, S., Kim, R., Gausman, J., Sharma, S., Sankar, R., Joe, W., Subramanian, S.V., 2019. Socio-economic patterning of food consumption and dietary diversity among Indian children: evidence from NFHS-4. Eur. J. Clin. Nutr. 73, 1361–1372.

American Society of Animal Science, 24 February 2019. Eat-Lancet report ignores nutrition research and food security needs. Retrieved from. https://www.asas.org/taking-stock/blog-post/taking-stock/2019/02/24/eat-lancet-report-ignores-nutrition-research-and-food-security-needs.

Bailey, R.L., West, K.P., Black, R.E., 2015. The epidemiology of global micronutrient deficiencies. Ann. Nutr. Metabol. 66 (S2), 23–33. https://doi.org/10.1159/000371618.

Battaglia, R., Baumer, B., Conrad, B., Darioli, R., Schmind, A., Keller, U., 2015. Health risks associated with meat consumption: a review of epidemiological studies. Int. J. Vitam. Nutr. Res. 85 (1–2), 70–78. https://doi.org/10.1024/0300-9831/a000224.

Black, R., Allen, L., Bhutta, Z., Caulfield, L., De Onis, M., Ezzati, M., Mathers, C., Rivera, J., Maternal and Child Undernutrition Study Group, 2008. Maternal and child undernutrition: global and regional exposures and health consequences. The Lancet 371 (9608), 243–260. https://doi.org/10.1016/S0140-6736(07)61690-0.

Black, R., Victora, C., Walker, S., Bhutta, Z., Christian, P., De Onis, M., Ezzati, M., Grantham-McGregor, S., Katz, J., Martorell, R., Uauy, R., 2013. Maternal and child undernutrition and overweight in low-income and middle-income countries. The Lancet 382 (9890), 427–451. https://doi.org/10.1016/S0140-6736(13)60937-X.

Bravo-Baumann, H., 2000. Gender and livestock. Capitalisation of experiences on livestock projects and gender. Working document. Swiss development cooperation, bern. Retrieved from. http://www.fao.org/wairdocs/LEAD/X6106E/x6106e00.HTM.

Bruinsma, J., 2003. World Agriculture: towards 2015/2030. An FAO Perspective. Rome. Food and Agriculture Organization of the United Nations/London, Earthscan Retrieved from. http://www.fao.org/3/a-y4252e.pdf.

Bruntland Commission, 1987. World Commission on Environment and Development: Our Common Future. Oxford University Press.

Buttriss, J., 2016. The Eatwell guide refreshed. Nutr. Bull. 41 (2), 135–141. https://doi.org/10.1111/nbu.12211.

Daniels, J., Longnecker, M., Rowland, A., Golding, J., ALSPAC Study Team, 2004. Fish intake during pregnancy and early cognitive development of offspring. Epidemiology 15 (4), 394–402. https://doi.org/10.1097/01.ede.0000129514.46451.ce.

De Beer, H., 2012. Dairy products and physical stature: a systematic review and meta-analysis of controlled trials. Econ. Hum. Biol. 10 (3), 299–309. https://doi.org/10.

1016/j.ehb.2011.08.003.

De Onis, M., Branca, F., 2016. Childhood stunting: a global perspective. Matern. Child Nutr. 12 (S1), 12–26. https://doi.org/10.1111/mcn.12231.

Development Initiatives, 2018. Global Nutrition Report: Shining a Light to Spur Action Nutrition. Development Initiatives, Bristol, UK Retrieved from. https://globalnutritionreport.org/reports/global-nutrition-report-2018/.

D'Cuéllar, A., Webber, M., 2008. Cow power: the energy and emissions benefits of converting manure to biogas. Environ. Res. Lett. 3 (034002), 1–8. https://doi.org/10.1088/1748-9326/3/3/034002.

Englemann, M.Davidsson, Sandström, L., Walcyzk, T., Hurrell, R., Michaelsen, K., 1998. The influence of meat on nonheme iron absorption in infants. Pediatr. Res. 43 (6), 768–773.

Food and Agricultural Orgniazation of the United Nations [FAO], 2012. Livestock and landscapes. Retrieved from. http://www.fao.org/3/ar591e/ar591e.pdf.

FAO, 2013. By the umbers: GHG emissions by livestock. Key facts and findings. Retrieved from. http://www.fao.org/news/story/en/item/197623/icode/.

FAO, 2017. Global livestock feed intake. Retrieved from. www.fao.org/ag/againfo/home/en/news_archive/photo/2017_Infografica_6billion.jpg.

FAO, 2018a. World Livestock: Transforming the Livestock Sector through the Sustainable Development Goals. FAO, Rome, Italy, pp. 222. Retrieved from. http://www.fao.org/3/CA1201EN/ca1201en.pdf.

FAO, 2018b. Nitrogen inputs to agricultural soils from livestock manure: new statistics. Retrieved from. http://www.fao.org/3/I8153EN/i8153en.pdf.

FAO, 2019. Livestock and the environment. Retrieved from. http://www.fao.org/livestock-environment/en/.

FAOSTAT Statistical database, 2016-2018. Food and Agricultural Organization of the United Nations. FAO Retrieved from. www.fao.org/faostat/en/#home.

Feliciano, D., Ledo, A., Hillier, J., Nayak, D.R., 2018. Which agroforestry options give the greatest soil and above ground carbon benefits in different world regions? Agric. Ecosyst. Environ. 254, 117–129. https://doi.org/10.1016/j.agee.2017.11.032.

Galasso, E.A., Wagstaff, N., Naudeau, S., Shekar, M., 2016. The economic costs of stunting and how to reduce them. World Bank Policy Research Note. Retrieved from. http://pubdocs.worldbank.org/en/536661487971403516/PRN05-March2017-Economic-Costs-of-Stunting.pdf.

Gerber, P., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., Tempio, G., 2013. Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities. FAO Retrieved from. http://www.fao.org/3/a-i3437e.pdf.

Global Livestock Advocacy for Development [GLAD], 2018. Making the case for livestock: economic opportunity. Retrieved from. https://cgspace.cgiar.org/bitstream/handle/10568/99550/Livestock_Economic-Opportunity_GLAD_June2018.pdf?sequence=1&isAllowed=y.

Gupta, S., 2016. Brain food: clever eating. Nature 531, S12–S13.

Gupta, R., Bharti, S., 2019. Healthy diet from sustainable food systems is not affordable: our reminder to the Lancet Commission. RUHS J. Health Sci. 4 (1), 3–4.

Hadaad, L., 18 February 2019. The EAT lancet report: landmarks, signposts and omissions. Global alliance for improved nutrition. Retrieved from. https://www.gainhealth.org/knowledge-centre/the-eat-lancet-report-landmarks-signposts-and-omissions/.

Havelaar, A., Kirk, M.D., Torgerson, P.R., Gibb, H.J., Hald, T., Lake, R.J., Praet, N., Bellinger, D.C., de Silva, N.R., Gargouri, N., Speybroeck, N., Cawthorne, A., Mathers, C., Stein, C., Angulo, F.J., Devleesschauwer, B., 2015. World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. PLoS Med. 12 (12), e1001923. https://doi.org/10.1371/journal.pmed.1001923.

Headey, D., Hirvonen, K., Hoddinott, J., 2018. Animal sourced foods and child stunting. Am. J. Agric. Econ. 100 (5), 1302–1319. https://doi.org/10.1093/ajae/aay053.

Hirvonen, K., Bai, Y., Heady, D., Masters, W.A., 2019. Cost and affordability of the EAT-Lancet diet in 159 countries. Lancet.

Hristov, A.N., Oh, J., Lee, C., Meinen, R., Montes, F., Ott, T., Firkins, J., Rotz, A., Dell, C., Adesogan, A.T., Yang, W.Z., Tricarico, J., Kebreab, E., Waghorn, G., Dijkstra, J., Oosting, S., 2013a. Mitigation of greenhouse gas emissions in livestock production: a review of technical options for non-CO2 emissions. In: In: Gerber, P., Henderson, B., Makkar, H. (Eds.), FAO, Animal Production and Health Division. Paper No. 177. 226 Pp FAO, Italy, Rome Retrieved from. http://www.fao.org/3/i3288e/i3288e.pdf.

Hristov, A.N., Oh, J., Firkins, J., Dijkstra, J., Kebreab, E., Waghorn, G., Makkar, H.P.S., Adesogan, A.T., Yang, W., Lee, C., Gerber, P.J., Henderson, B., Tricarico, J.M., 2013b. Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. J. Anim. Sci. 91, 5045–5069.

Hristov, A.N., Ott, T., Tricarico, J., Rotz, A., Waghorn, G., Adesogan, A.T., Dijkstra, J., Montes, F., Oh, J., Kebreab, E., Oosting, S., Gerber, P.J., Henderson, B., Makkar, H.P.S., Firkins, J., 2013c. Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. J. Anim. Sci. 91, 5095–5113. https://doi.org/10.2527/jas.2013-6583.

Hulett, J.L., Weiss, R.E., Bwibo, N.O., Galal, O.M., Drorbaugh, N., Neumann, C.G., 2014. Animal source foods have a positive impact on the primary school test scores of Kenyan schoolchildren in a cluster-randomised, controlled feeding intervention trial. Br. J. Nutr. 111 (05), 875–886. https://doi.org/10.1017/S0007114513003310.

Iannotti, L.L., Lutter, C.K., Stewart, C.P., Riofrío, A.G., Malo, C., Reinhart, G., Palacios, A., Karp, C., Chapnick, M., Cox, K., Waters, W.F., 2017. Eggs in early complementary feeding and child growth: a randomized controlled trial. Pediatrics 140 (1). https://doi.org/10.1542/peds.2016-3459.

Kawarazuka, N., Béné, C., 2010. Linking small-scale fisheries and aquaculture to household nutritional security: an overview. Food Secur. 2 (4), 343–357. https://doi.org/10.1007/s12571-010-0079-y.

Knapp, J., Laur, G., Vadas, P., Weiss, W., Tricardo, J., 2014. Enteric methane in dairy cattle production: quantifying the opportunities and impact of reducing emissions. J. Dairy Sci. 97 (6), 3231–3261. https://doi.org/10.3168/jds.2013-7234.

Livestock for Data Decisions [LD4D], 2018. Livestock and Economy: does the livestock sector make up 40% of total agricultural GDP globally? Fact Check. Retrieved from. https://www.era.lib.ed.ac.uk/bitstream/handle/1842/30115/Livestock%20Economy%20Fact%20Sheet.pdf?sequence=5&isAllowed=y.

Livestock Global Alliance [LGA], 2016. Livestock for sustainable development in the 21st century 2016. Retrieved from. http://www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2016/LGA-Brochure-revMay13th.pdf.

Livestock Dialogue, 2014. Global agenda for sustainable livestock: towards sustainable livestock- Livestock in development. Retrieved from. http://www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2014_Colombia/2014_Towards_Sustainable_Livestock-dec.pdf.

Mayen, A., Marques-Vidal, P., Paccaud, F., Bovet, P., Stringhini, S., 2014. Socioeconomic determinants of dietary patterns in low-and middle-income countries: a systematic review. Am. J. Clin. Nutr. 100 (6), 1520–1531.

Mitloehner, F., 2016. Livestock and Climate Change: Facts and Fiction. University of California, Davis Retrieved from. https://egghead.ucdavis.edu/2016/04/27/livestock-and-climate-change-facts-and-fiction.

Monbiot, G., 2018. The best way to save the planet? Drop meat and dairy. The Guardian (8 June 2018). Retrieved from. https://www.theguardian.com/commentisfree/2018/jun/08/save-planet-meat-dairy-livestock-food-free-range-steak.

Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C., Gerber, P., 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. Glob. Food Secur. 14https://doi.org/10.1016/j.gfs.2017.01.001. 18-8.

National Academies of Sciences, Engineering and Medicine, 2019. In: Sustainable Diets, Food and Nutrition: Proceedings of a Workshop. The National Academies Press, Washington, DC.

Navas-Carretero, S., Pérez-Granados, A., Sarriá, B., Carbajal, A., Pedrosa, M., Roe, M., Fairweather-Trait, S., Vaquero, M.P., 2008. Oily fish increases iron bioavailability of a phytate rich meal in young iron deficient women. J. Am. Coll. Nutr. 27 (1), 96–101. https://doi.org/10.1080/07315724.2008.10719680.

Neumann, C., Harris, D., Rogers, L., 2002. Contribution of animal source foods in improving diet quality and function in children in the developing world. Nutr. Res. 22 (1–2), 193–220.

Neumann, C., Murphy, S., Gewa, M., Grillenberger, M., Bwibo, N., 2007. Meat supplementation improves growth, cognitive, and behavioral outcomes in Kenyan children. J. Nutr. 137 (4), 1119–1123. https://doi.org/10.1093/jn/137.4.1119.

Organization for Economic Cooperation and Development, 2018. Meat consumption (indicator). Retrieved from. https://data.oecd.org/agroutput/meat-consumption.htm.

Panjwani, A., Heidkamp, R., 2017. Complementary feeding interventions have a small but significant impact on linear and ponderal growth of children in low- and middle-income countries: a systematic review and meta-analysis. J. Nutr. 147 (11). https://doi.org/10.3945/jn.116.243857. 2169S-78S.

Pimpin, L., Kranz, S., Liu, E., Shulkin, M., Karageorgou, D., Miller, V., Fawzi, W., Duggan, C., Webb, P., Mozaffarian, D., 2019. Effects of animal protein supplementation of mothers, preterm infants, and term infants on growth outcomes in childhood: a systematic review and meta-analysis of randomized trials. Am. J. Clin. Nutr. 110 (2), 410–429. https://doi.org/10.1016/j.gfs.2017.01.001.

Platts-Mills, J.A., Taniuchi, M., Uddin, M.J., Sobuz, S.U., Mahfuz, M., Gaffar, S.A., Mondal, D., Hossain, M.I., Islam, M.M., Ahmed, A.S., Petri, W.A., Haque, R., Houpt, E.R., Amed, T., 2017. Association between enteropathogens and malnutrition in children aged 6-23 mo in Bangladesh: a case-control study. Am. J. Clin. Nutr. 105 (5), 1132–1138.

Poore, T., Nemecek, T., 2018. Reducing food's environmental impacts through producers and consumers. Science 360 (6392), 987–992. https://doi.org/10.1126/science.aaq0216.

Prendergast, A.J., Humphrey, J.H., 2014. The stunting syndrome in developing countries. Paediatr. Int. Child Health 34 (4), 250–265. https://doi.org/10.1179/2046905514Y.0000000158.

Raney, T., Gustavo, A., Croppenstedt, A., Gerosa, S., Lowder, S., Matuschke, I., Skoet, J., 2011. The role of women in agriculture. ESA Working Papers, 289018. FAO, Agricultural Development Economics Division Retrieved from. https://ideas.repec.org/p/ags/faoaes/289018.html.

Schwarz, S., Cavaco, L., Shen, J., 2018. Antimicrobial Resistance in Bacteria from Livestock and Companion Animals. American Society of Microbiology Press, Washington, USA.

Shapiro, M., Downs, S., Swartz, H., Parker, M., Quelhas, M., Kreis, K., Kraemer, K., West, K., Fanzo, J., 2019. A systematic review investigating the relation between animal-source food consumption and stunting in children aged 6-60 months in low and middle-income countries. Adv. Nutr. 10 (5), 827–847. https://doi.org/10.1093/advances/nmz018.

Sinha, R.K., Dua, R., Bijalwan, V., Rohatgi, S., Kumar, P., 2018. Determinants of stunting, wasting, and underweight in five high-burden pockets of four Indian states. Indian J. Community Med.: Off. Publ. Indian Assoc. Prev. Soc. Med. 43 (4), 279. https://doi.org/10.4103/ijcm.IJCM_151_18.

Smith, J., 2017, October 5-6. The role of livestock in development countries: misperceptions, facts and consequences. In: Presented at the Workshop on Extinction and Livestock: Moving to a Flourishing Food System for Wildlife, Farm Animals, and Us. London, UK, Retrieved from. https://www.slideshare.net/ILRI/extinction-livestock-smithoct17.

Stabler, S.P., Allen, R.H., 2004. Vitamin B12 deficiency as a worldwide problem. Annu. Rev. Nutr. 24, 299–326. https://doi.org/10.1146/annurev.nutr.24.012003.132440.

Steinfeld, H., Gerber, P., Wassenaar, T.D., Castel, V., Rosales, M., de Hann, C., 2006. Livestock's long shadow: environmental issues and options. Food Agric. Org. U. S.

Stewart, C., Caswell, B., Iannotti, L., Lutter, C., Arnold, C.D., Chipatala, R., Prado, E.L., Maleta, K., 2019. The effect of eggs on early child growth in rural Malawi: the Mazira Project randomized controlled trial. Am. J. Clin. Nutr. (00), 1–8. https://doi.org/10.1093/ajcn/nqz163.

Teicholz, N., 2019, January 29. Eat-Lancet Report Is One-Sided, Not Backed by Rigorous Science. Nutrition Coalition Retrieved from. https://www.nutritioncoalition.us/news/eatlancet-report-one-sided.

Turk, J., 2016. Meeting projected food demands by 2050: understanding and enhancing the role of grazing animals. J. Anim. Sci. *94* 9S6, 53–62.

UN Statistics Division, 2018. The Sustainable Development Goals Report 2018. Retrieved from. https://unstats.un.org/sdgs/report/2018/overview/.

UNICEF WHO & The World Bank Group, 2017. Global database on child growth and malnutrition. Joint child malnutrition estimates- levels and trends. Retrieved from. http://www.who.int/nutgrowthdb/estimates2016/en/.

UNICEF/WHO/World Bank Group, 2018. Joint child malnutrition estimates 2018 edition. Retrieved from. https://www.who.int/nutgrowthdb/2018-jme-brochure.pdf.

US Department of Health and Human Services & US Department of Agriculture, 2015. 2015-2020 *Dietary Guidelines for Americans*, eighth ed. .

Victora, C., De Onis, M., Hallal, P., Blössner, M., Shrimpton, R., 2010. Worldwide timing of growth faltering: revisiting implications for interventions. Pediatrics 125 (3). https://doi.org/10.1542/peds.2009-1519.

Vilain, C., Baran, E., Gallego, G., Samadee, S., 2016. Fish and the nutrition of rural Cambodians. Asian J. Agric. Food Sci. 4 (1), 26–34.

World Health Organization, 2013. Global and regional food consumption patterns and trends. Retrieved from. https://www.who.int/nutrition/topics/3_foodconsumption/en/index1.html.

World Health Organization, 2014. World health assembly global nutrition targets 2025: stunting policy brief. Retrieved from. http://www.who.int/nutrition/topics/globaltargets_stunting_policybrief.pdf.

Willet, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., 2019. Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. The Lancet 393 (10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.

World Bank, 2009. Minding the Stock: Bringing Public Policy to Bear on Livestock Sector Development. The World Bank Agriculture and Rural Development Department Report No. 44010-GLB. Retrieved from. http://documents.worldbank.org/curated/en/573701468329065723/Minding-the-stock-bringing-public-policy-to-bear-on-livestock-sector-development.

Zhang, J., Wang, D., Eldridge, A., Huang, F., Ouyang, Y., Wang, H., Zhang, B., 2017. Urban–rural disparities in energy intake and contribution of fat and animal source foods in Chinese children aged 4–17 years. Nutrients 9 (5), 526.