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COMMENTARY

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Continuing cereals research for sustainable health and well-being

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ABSTRACT
Cereals research over the past fifty years has led to huge improvements in production, productivity and food security. The current emphasis in agri-nutrition on micronutrients has cast doubt on the need to continue to invest in cereals. However, besides the essential dietary energy content of cereals such as wheat, maize and rice, we argue that there are two important factors to consider. First, the intrinsic micronutrient content of cereals is not often taken into account. As a major dietary component, cereal foods are already an important vehicle for enhanced nutrition, and these characteristics are amenable to further improvement through plant breeding and value chain interventions in processing, manufacturing and distribution. Second, while adverse effects are acknowledged for some people, cereals are a rich source of both dietary fibre and a range of bioactive food components that are also essential for good health and well-being. In particular, the role of the bioactives in combatting non-communicable diseases is becoming more evident. The development community must not assume that the research gains of the last five decades will be sufficient to guarantee future food security. Research into cereals should be implemented as a multi-sectoral and multi-disciplinary activity encompassing whole food systems.

KEYWORDS
Agriculture; cereals; nutrients; dietary fibre (DF); bioactive food components; diet-related non-communicable diseases (NCDs); food systems; multi-disciplinary and integrative research; sustainable development goals (SDGs)

1. Introduction

With success in the increased production of hunger-relieving staple foods in the Global South up to the late 1990s, the focus of agri-nutrition research and development became less about hunger alleviation and more about micronutrient malnutrition. The increasing occurrence of overweight/obesity and non-communicable diseases (NCDs) has since been widely acknowledged (Poole et al., 2021a). Such over-nutrition is associated with the ongoing but unsustainable 'nutrition transition' (Popkin, 2021). This NCD pandemic is partly a result of insufficiencies, imbalances and excesses of nutrients and bioactive compounds in human diets. Progress in reducing diet-related NCDs has been slow and health systems are said to have failed to purposefully anticipate the shift in morbidity and mortality attributable to NCDs in the global population (Murray et al., 2020).

Staple cereals such as wheat, rice and maize, which, for long, have been major components of global diets, are now sometimes considered to contribute to the malnutrition problem because they are rich in energy and not major sources of 'nutrient-rich' foods. Some researchers consider there to have been an imbalance in agricultural research in favour of cereals (originating from the earlier hunger alleviation focus), and that resources should now be directed to other food categories to address micronutrient malnutrition (Pingali, 2015). Others have argued for enhancing the nutrient content of cereal foods (Lenaerts & Demont, 2021). And it is incontestable that we need more micronutrient rich foods.

We have argued elsewhere at length that the multiple qualities of cereals and the appreciable quantities in which they are widely consumed means that even marginal improvements in the nutrition

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and health attributes will impact positively and significantly on the global burdens of malnutrition (Poole et al., 2021a, 2021b).

This commentary provides a 'synthetic' rather than 'systematic' review: it draws on and synthesizes key themes from diverse literatures to provide a coherent account of current knowledge on cereals and nutrition. In the next section, we summarize the complex and evolving science on the dietary role of staple cereals. This is followed by a discussion of key themes, and then a final section which will guide those concerned with agriculture, food security, nutrition and health. We conclude that plant breeders and research funding organizations must adopt a multi-disciplinary perspective on cereals research, because improvements to global health and nutrition derived from high-quality cereals-based foods depend on many food system scientists and other stakeholders, from within agro-industry, political economics, and consumer science. In summary, cereals continue to count in addressing the challenges of hunger and malnutrition framed in both Sustainable Development Goals, 'Zero hunger', (SDG 2) and the 'Good health and well-being' (envisaged in SDG 3), specifically reductions in NCDs.

Given our links to the International Maize and Wheat Improvement Center (CIMMYT), much of the literature we reference concerns maize and wheat. In varying degrees, similar considerations apply to rice, the third global cereal in terms of production and consumption, recent research into which has been reviewed elsewhere in this journal (Zhuang et al., 2020), and the so-called 'minor' cereals. Indeed, the sustainability and resilience challenges in rice production may be more acute than for maize and wheat (Mishra et al., 2021).

2. What have cereals ever done for us?

2.1. Cereals provide more than energy

Cereals have been major foodstuffs for millennia and fuel 50–70% of the dietary energy requirements of much of the world's population. Archaeological evidence from the Middle East recently published in *Nature* suggests that bread was baked from wild cereal species before the Neolithic 'revolution' and the domestication of grain and animal production: 'even before farming took hold, cereals were a daily staple, not just part of an occasional fermented treat' (Curry, 2021, p. 491). It seems that the original 'paleo' diet was not at all cereal-free.

Carbohydrates are rightly considered to be the principal component of cereals, contributing the dietary energy that is necessary for satisfying hunger and enabling human function. The structure and composition of dietary carbohydrates have important impacts on the gut microbiome. Besides energy, the nutrient content of cereals varies but overall is significant (Fukagawa & Ziska, 2019; Palacios-Rojas et al., 2020; Shewry & Hey, 2015). Wheat alone contributes 19% of proteins consumed, although cereals generally are not rich in some essential amino acids. The lipid fraction of cereals contain essential fatty acids such as palmitic and linoleic acids, fat-soluble vitamins and phytosterols. There are also significant amounts of B vitamins thiamine, riboflavin, niacin and pyridoxine, some biotin and folic acid, and tocol derivatives which are vitamin E precursors. There are appreciable amounts of phosphorous and potassium, calcium, zinc, manganese, magnesium, selenium and copper. Polar lipids present in cereals may contribute to reducing cholesterol absorption and improving the gastrointestinal microbiome. Antioxidant and phytochemical components protect against some cancers and cardiovascular diseases, cataracts, impaired immune systems, and brain damage.

2.2. Importance of dietary fibre and other bioactives

There are many bioactive components of food which are not usually considered to be nutrients, but which are known to contribute to nutrition and health. Cereals are an important source of these bioactives. Over the last five or more decades (Burkitt, 1979), we have gained a good understanding of what dietary fibre (DF) is, of the physiology and biochemistry, and of its role in metabolism and disease prevention (Cummings & Engineer, 2018).

DF is the prebiotic substrate for the gut microbiota which act on undigested polysaccharides and oligosaccharides as well as proteins, peptides, and glycoproteins (Machate et al., 2020). Short-chain fatty acids (SCFAs) are essential products of microbial fermentation and are major components in the maintenance of healthy gut integrity and physiology, promoting immune and metabolic homeostasis, and have important anti-inflammatory and antitumorigenic effects (Francino, 2016). De la Cuesta-Zuluaga et al. (2019) highlight the interrelationships between gut microbiota richness and the intake of DF. They note the potential for modifying SCFA production from DF through diet, pre- and pro-biotic interventions. New research on the gut microbiome continues to illuminate the interactions between gut microbial flora, auto-immunity and health (Donkersley et al., 2020). The latest evidence illustrates the complexity of individual metabolic responses to diet, and evidently much more is yet to be learnt (Wyatt et al., 2021).

The DF contribution of cereal grains is well-recognized among food scientists, nutritionists, and food manufacturers. DF has become a major segment of the functional foods market (Mudgil & Barak, 2019), and is a recurrent element in industry marketing efforts to health-conscious consumers. On the most beneficial types of fibre and foods, Stephen et al. note that

> … although there are benefits from consumption of all sources of fibre, associations and degree of protection conferred are generally greater for grains. Grain sources of fibre are not all equivalent, however, and there are marked differences in composition between wheat, rye, oat and rice … (2017, p. 150)

More remains to be discovered about DF in different cereal grains, and the precise linkages from plant breeding to human metabolism and the resulting health (dis-)benefits (SACN, 2015; Stephen et al., 2017). Likewise, a better understanding of the physical and chemical properties of carbohydrates on satiation and satiety may suggest ways to improve laxation and reduce overconsumption of obesogenic foods (Elia & Cummings, 2007; Ferriday et al., 2016; Warrilow et al., 2019).

Evidence from cereal chemistry, food science and metabolic studies shows that in addition to DF, cereals provide a rich complex of other bioactives such as carotenoids, flavonoids, and polyphenols, and a wide variety of phytochemicals. Many of the beneficial effects of the consumption of wholegrain cereals on NCDs are currently attributed to these bioactive components (Bach Knudsen et al., 2017): 'greater consumption of whole grains is associated with a lower incidence of cardiovascular disease, hypertension, type 2 diabetes mellitus and colon cancer' (SACN, 2015, p. 186). Evidence from a meta-analysis by Zong et al. (2016) of prospective cohort studies showed inverse associations between whole-grain intake with mortality from all causes, cardiovascular disease, and cancer, with findings particularly robust for cardiovascular mortality.

One feature of the nutrition transition in many countries is that dietary guidelines often lack clear and comprehensible recommendations. Lockyer et al. (2016) noted that high prices, limited availability and convenience, rapid spoilage of fresh food sources of DF, the attractiveness of competing foods and unwillingness to change consumption behaviour are significant factors affecting consumption. Nevertheless, consumption of wholegrain foods is widely recommended. A study by Springmann et al. (2020) found that in all FAO-defined geographical regions, with the exception of North America, current intakes of whole-grain foods should at least double compared with national dietary guidelines, and in the cases of United Nations FAO/WHO (FAO and WHO, 2019) and EAT Lancet guidelines (Willett et al., 2019), they should be increased by 241 and 362 per cent respectively. Proposals for the UK National Food Strategy include a 30% increase in consumption of fruits and vegetables and a 50% increase in consumption of fibre (nationalfoodstrategy.org, 2021).

Much recent research has been conducted in advanced economies and more studies should be undertaken elsewhere, with a particular focus on local diets and consumption behaviour. More also remains to be discovered about diet-related health inequalities, within the Global North, within the Global South, and between North and South, in order to formulate local and regional food systems strategies which leverage the nutritional benefits of whole-grain cereal foods, and DF in particular.

Formulation of dietary guidelines that are more precise and better adapted to local food systems has implications for local agriculture and pathways of adaptation of food systems towards environmental and economic sustainability. Together with consumer education and 'nudging' approaches to behavioural change, new food policies that embrace the multiple attributes of cereals could lead to major reductions in the burden from diet-related NCDs (Poole et al., 2021a).

2.3. Upstream innovation for nutritional enhancement

Crop breeding is a proven means to biofortify cereal cultivars (Palacios-Rojas et al., 2020). Several components including proteins, amylose, essential amino acids, vitamin A, and zinc have been successfully enhanced in selected cereals. There is large genetic diversity that could help expand efforts further to enhance resistant starch or other sources of DF which improve digestibility, reduce glycaemic index and contribute to prevent NCDs. Also, breeding for reducing anti-nutrient compounds like phytates could enhance bioavailability of minerals like iron and zinc, which in turn will contribute to stronger immune systems and prevention of anaemia. Genetic diversity can also be explored in respect of antioxidant compounds, given their role in preventing cell aging and maintaining the glycaemic index. Genomic prediction has been found to be a cost-effective method for ascertaining wheat quality (Ibba et al., 2020). There are ongoing opportunities for cereal biofortification through gene stacking, using a combination of conventional breeding and metabolic engineering strategies (Van Der Straeten et al., 2020).

Lantican et al. (2016) summarized the impacts of international wheat improvement research for the period 1994–2014, noting extensive adoption on a global scale of high-yielding varieties. However, crop breeding is not the only upstream method to enhance nutrition. Nutritional quality is also affected by crop growing conditions such as soil quality, weather, and the interactions of genotypes with the environment. Increasing levels of atmospheric CO_2 also seem to affect the quality and availability of plant nutrients (Fukagawa & Ziska, 2019), and this is increasingly important under current conditions. Fertilization technologies and different production systems can also lead to higher nutritional value of the kernels.

In many situations, agriculture, natural resources management, food security and nutrition are threatened by global warming, erratic precipitation, pests and diseases and extreme climate events (FAO et al., 2020; IPCC, 2019; Lloyd et al., 2018). The need for contextual research into evolving agri-food system challenges is essential. Besides plant breeding and crop production, upstream research issues for maximizing the benefits from the cereals sector, and more widely, include input distribution, and, recognizing the role of women in agriculture, gender-specific technologies and extension methods.

2.4. Processing: for and against nutritional quality

Processing and other downstream research demands are no less significant. Maize processing methods like fermentation or thermo-alkaline-cooking (nixtamalization) have long been used to enhance nutritional content (Rosales et al., 2016; Suri & Tanumihardjo, 2016). Similarly, there are methods that can enhance the nutritional content of other cereals during cooking (Adeloye et al., 2020; Sowa et al., 2017). However, the most common cereal processing methods typically separate and remove the outer layer of nutrient-rich bran and germ from the starchy endosperm, thereby tending to reduce or remove protein, fat, fibre, vitamins and minerals (Heshe et al., 2015; Oghbaei & Prakash, 2016). The main reasons are cooking ease, to extend the shelf life of the flours and to improve palatability (Fukagawa & Ziska, 2019). Levels of bioactive compounds are also affected by processing such as milling and breadmaking (Dewettinck et al., 2008). Protein and starch qualities are affected by both milling temperature and mill types (Jones et al., 2015). Storage technologies are also implicated in nutritional losses (Suri & Tanumihardjo, 2016).

Nutrient content can be preserved or enhanced by reducing the extraction flour rates, thereby retaining more of the bran (Heshe et al., 2015; Pedersen et al., 1989). Nanotechnology is thought to have potential in the food industry for designing delivery systems for bioactive compounds (Mahfoudhi et al., 2016). A search for more stable flours (derived from kernels that might have different fat composition or higher antioxidant content) could be beneficial to increase the use of whole-kernel flours. These choices of technology and process are usually a function of commercial viability, and the role of the food processing industry is central to obtaining nutrition and health benefits from cereals.

The prevalence of inexpensive, energy-dense, highly processed cereal-based foods on supermarket shelves is often considered to be the cause of the excess energy intake implicated in obesogenic dietary patterns. The persistence of this view in popular and academic publications has not been successfully addressed by a nuanced understanding of the complex dietary contribution of cereal foodstuffs (Brouns et al., 2019; Poti et al., 2017). However, the concern about 'ultra-processed' cereals-based foods and associated noxious dietary components is well-founded (Vandevijvere et al., 2019). Extreme ultra-processed foods (UPFs) are industrial formulations combining dietary energy and nutrients plus diverse additives, which typically are relatively cheap, energy-dense, high in fat, sugars and salt, and make little contribution to intakes of valuable nutrients (Monteiro et al., 2018). Dietary patterns trending towards higher consumption of (ultra-)processed foods are linked to increasing incidences of NCDs. Vandevijvere et al. (2019) found that in five out of eight global regions, baked goods such as cakes, pastries and bread were an important contributor to UPF volume sales. Recent research into (ultra-)processed maize and wheat products in Mexico City found the majority of products were of poor nutritional quality and that promotion and sales were significantly concentrated in low socioeconomic localities (Marrón-Ponce et al., 2020). Such evidence on food quality, promotion and distribution presents a major health challenge, not least the unequal incidence of NCDs prevalence within and between countries and regions.

2.5. Adverse effects of cereals

Adverse reactions to specific cereal components have been well documented (Brouns et al., 2017; Jones et al., 2020). Wheat and derived products are associated with a range of rare effects on human health and well-being, notably irritable bowel syndrome, a generalized dietary condition of the digestive system, and coeliac disease, a more specific immunological response to gluten, and possibly non-coeliac wheat sensitivity. Some sufferers may need to cut back on cereal foods containing certain non-digestible, rapidly fermentable carbohydrates (FODMAPs), or other cereal constituents (Brouns et al., 2017).

Various attempts have been made to overcome non-coeliac wheat sensitivity, including the use of crop genetic diversity. At the breeding stage, genetic engineering techniques have been used to try to develop coeliac-safe wheat genotypes through detoxification or elimination of gluten proteins, and through the silencing of the genes which regulate the accumulation of most gluten proteins (Rustgi et al., 2019). Microwave treatments have also been used to remove antigenic properties (Landriscina et al., 2017). Springer and Schmitz (2017) expected that epigenome engineering can be used for such crop improvements. Due to the structure of the grain, gliadins and glutenins are expressed only in starchy endosperm cells, while the distribution of different proteins is found in the aleurone and transfer cell layers. It may be possible to produce flour with reduced immunogenicity from regular wheat genotypes by applying specific procedures such as differential milling and twin-screw extrusion techniques but retaining nutrient content (Juhász et al., 2018; Rustgi et al., 2019).

There are still uncertainties concerning the adverse effects of cereals. This has fed spurious unscientific knowledge, including widespread misunderstandings on the probability and prevalence of adverse reactions. There is much pseudoscience communicated through social and celebrity media and popular health publications, and there is importance in the epistemological considerations of cereals research for nutrition and health education: as noted above, the Bronze Age 'paleo' diet included cereals. It is important that the majority people, who are not susceptible to adverse reactions, do not pursue 'free-from' diets that deny themselves foods that are by and large inherently healthy in terms of nutrients and bioactives.

2.6. Public policies and food regulation

The role of the food industry is undermining public health demands for open-minded engagement between researchers and industry (Fanzo et al., 2020). The political economy of food has much to do with current nutritional challenges, through lobbying and advocacy of the food industry, civil society, and public regulation and policies. Collectively, the food industry has market reach, and financial and human resources beyond the aspirations of academic researchers and national governments. While private firms face constraints from managers and shareholders in aligning with public health objectives, these are not insurmountable, given clear, stable, and supportive pro-nutrition public policies and food regulatory frameworks (Poole et al., 2020).

Public policy can shape the food environment through research and investment in public infrastructure for the food sector, taxation, subsidies, regulatory incentives, and controls on advertising, labelling and distribution, where there is also a particular role for civil society. Indirect intervention also can facilitate firm efficiency and benefit poor consumers by mitigating food chain costs of contracting, of regulatory compliance, and of financial services. There are many opportunities for improving food system innovation given incentives, regulations and social licence, plus constructive stakeholder dialogue (Herrero et al., 2020).

3. Discussion

3.1. Addressing hunger and the transition towards good health and wellbeing

Agricultural research needs to be linked to downstream activities and the related disciplines. However, there are multiple disciplinary disarticulations in discussing agriculture, sustainability, nutrition and health. In the Sustainable Development Goals, agriculture, hunger and undernutrition are core to SDG2 ‘Zero hunger’, but overweight and obesity are addressed SDG3 ‘Good health and well-being’, in which the NCD targets are nested. This ‘medicalization’ of NCDs, without reference to agriculture, food security and nutrition, is also reflected in the World Health Organization (WHO) being the institutional ‘home’ of SDG3. Political economy analysis is required of (a) the level of resources the private sector spends on influencing consumer purchases and shaping food policies, and (b) the public sector expenditure on understanding why people consume the foods they do and public health policies (Haddad, 2020). Consideration of public policy leads to further research on consumption patterns and public health communications.

3.2. Integrative research

One of the principal challenges remains to integrate the efforts of cereal plant breeders, food scientists, agribusiness, nutritionists, and behavioural scientists in the preservation of whole-grain qualities in the food system: how to link cereal varietal selection with the development of nutritious products that are profitable for processors and acceptable and accessible to consumers? Researchers and policymakers must recognize the problems and break down the institutional and disciplinary ‘siloes’ from plant genetics and agricultural input technologies through food systems to human metabolism. Hazard et al. (2020) have recently reset the scientific agenda to improve the quality of wheat for human health, but more integrative research is needed.

Fanzo et al. are optimistic: ‘Perhaps the most welcome and vital trend in research related to food security and nutrition is the breaking down of disciplinary silos and the shift to more multi-disciplinary, multisectoral research’ (2020, p. 6). This requires an unaccustomed breadth of human skills and organizational collaboration among researchers at the individual and organizational levels, and an integrated approach among research funders and policy-makers. These are summarized in Figure 1, which links the disciplines required to develop new knowledge in areas leading to balanced diets and improved health and well-being.

3.3. Contextual research

Although there are trends towards convergence in global diets, the harmful changes identified in the nutrition transition are still of lesser importance for the 2 billion poor individuals experiencing hunger and undernutrition than for richer populations. These include hundreds of millions of small-scale farmers for whom own-production still supplies a large part of household food needs, and for whom nutrition-sensitive interventions such as new seeds and industrial fortification and ecological resilience must be addressed by locally contextualized initiatives (Porcuna-Ferrer et al., 2020). For example, research into, and development of, improved technologies for land tillage and post-harvest crop management, such as the use of the ‘Happy Seeder’ are critically important for enhanced wheat production and for reducing the major seasonal health externality of air pollution affecting many millions of people in the Indo-Gangetic Plains (Keil et al., 2021).

An increasing majority of the global population depends for basic foods on value chains that are diverse in structure and performance. New diagnostics for sustainable and health-sensitive food value chain development can suggest improvements in the delivery of nutrient-rich or enriched foods to poor consumers (Gelli et al., 2020; Maestre et al., 2017).

Working with industry, research to assess the nutrition-sensitivity of myriad local and global cereal value chains is essential for the nutritional quality of traded and processed foods and improving global health. The results of the value chain and consumer behaviour studies should provide valuable input for further food system development. This agenda includes plant breeders, farmers, and value chain intermediaries through integrated research systems that link supply and demand for nutritional quality; but the agenda also affects public nutrition policy, public health, and consumer behaviour.

3.4. Rebalancing resources

An integrative agri-food research approach calls for some rebalancing and additional resources for the expanding agenda. ‘There are still many areas that require more research, evidence, and knowledge’

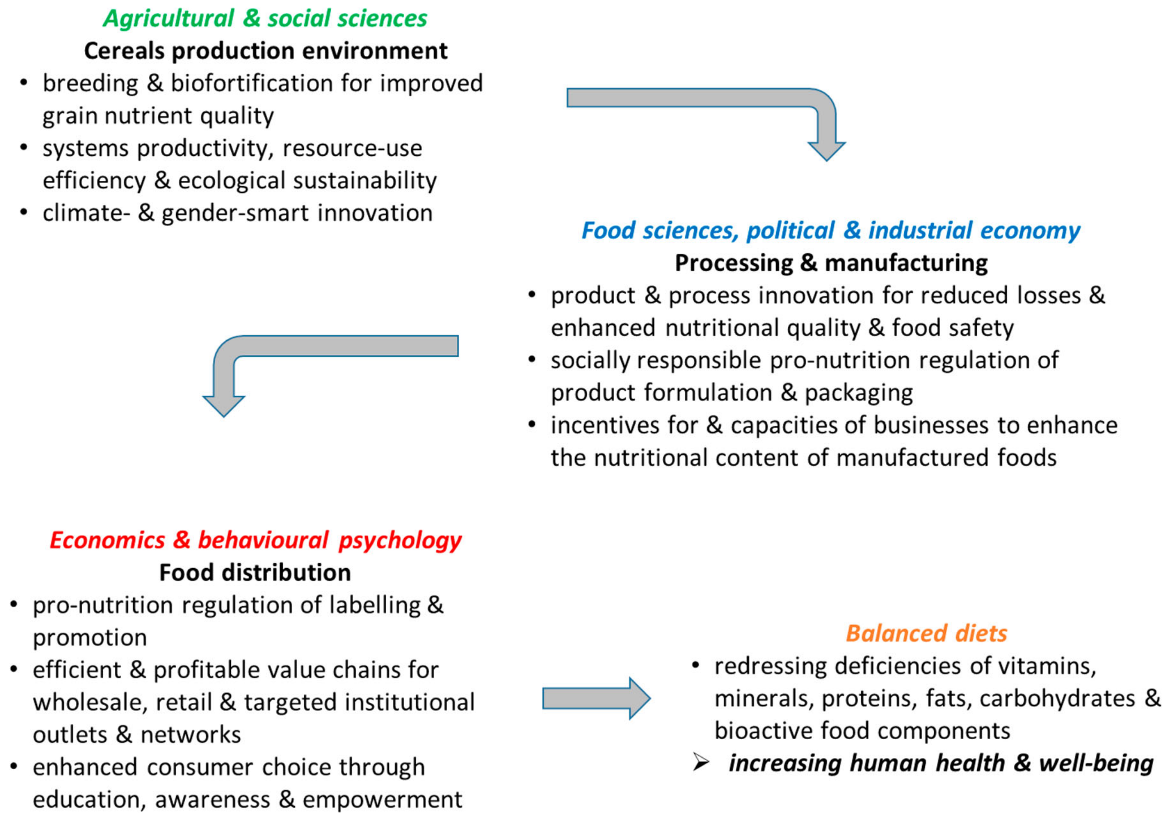

Figure 1. A multi-disciplinary systems research agenda for cereal foods.

(Fanzo et al., 2020, p. 6). Hitherto less-researched nutrient-dense crops and other foods may be a case in point. But this does not mean de-emphasizing cereal-based foods. These remain essential constituents of nutritious diets beyond the significant macronutrient contribution and the modest micronutrient content. The nutritional contribution of cereals in respect of bioactives complements the consumption of micronutrient-rich foods in diverse diets. Even marginal increments in cereal nutrient and bioactives contents can improve diets and health because of the quantities in which they are consumed. Cereal-based foods can be nutritious and are set to remain staples for much of the Global South. Integrative research of the consumption 'transition' will thereby be critical to better address the triple burden of malnutrition and help keep food systems within planetary boundaries.

4. Conclusions

Staple cereals by themselves are not a panacea for diverse diets, but it should be recognized that staple grains are genuinely 'fundamental'. 'Staple grain fundamentalism' (Pingali, 2015, p. 583) misrepresents the case for nutrition and health. We endorse Haddad's argument for research on both staples and 'foods like vegetables, fruits, fish, pulses, nuts, eggs, dairy, and meat' (Haddad, 2020, p. 4), that is, a balance that recognizes that cereals are more than 'not-nutrient-rich' foods and contribute to nutrition and health in ways that are complex and hitherto understated by the agricultural research community.

We have considered some of the adverse health impacts of wheat that genuinely affect a minor proportion of the global population. Many other health challenges attributed to cereals are due to overrefinement of the raw materials in cereals-based foods. There is potential for enhancing positive dietary impacts through novel cereals genomics technologies. Staple grains are immensely important in global diets, being foods consumed frequently and in sufficient quantities, as to constitute the dominant part of the diet and supply a substantial proportion of energy and nutrient needs (Mattei et al., 2015, p. 2).

Rather than shifting away from grains, a broad research agenda is needed to develop healthy food products that are commercially viable, acceptable to the billions of consumers, and meet the growing demand for global food production from increasingly fragile ecosystems at least until the year 2050 (Young, 2020).

4.1. Reconceptualizing cereal systems

The agricultural research community and national and international organizations need to adopt a systems approach to cereals research, just like other agri-food systems from the supply industry to consumers. Some examples of research needs are the following:

- production environments are already changing significantly due to climate change and there is no time to lose in adapting plant breeding to higher temperatures and variable rainfall and irrigation regimes in order to avoid major regional crop failures. Hence it is essential to persist in crop productivity and sustainability research in diverse natural environments, not least under the resource-constrained conditions of smallholder farmers (Kihara et al., 2020; Ritzema et al., 2017);
- accelerate plant breeding for nutritional quality and biofortified crop varieties, and scale up seed production and distribution systems to reach more remote and risk-prone regions through innovative institutional arrangements (Simtowe et al., 2021; Tahir et al., 2020);
- challenges to agricultural sustainability from conditions of climate change demand integration of natural sciences and social sciences research perspectives (González-Esquivel et al., 2020; Keil et al., 2020; Manalo et al., 2020);
- industrial fortification is a proven strategy for enhancing the nutrient-intensity of major cereals among other crops, with considerable prospects for further advances (HarvestPlus, 2020; Prasanna et al., 2020). Integrating fortification practices into small-scale and numerous local milling has proven challenging but is important beyond the industrialized processing sector (Ansari et al., 2018; Maestre & Poole, 2018);
- identify the opportunities for value chain actors to communicate commercial incentives to cereal farmers (Yadav et al., 2021), and enhance practices for the processing, manufacturing, storage, and distribution of natural, bio- and industrially enriched cereal foods for consumers in order to reduce losses and promote nutritional benefits (Ekpa et al., 2019; Sharma et al., 2020);
- understand consumer behaviour at a disaggregated level, including livelihood patterns and access to different foods among vulnerable groups, in different cultures, and in different production and marketing systems (Marrón-Ponce et al., 2020);
- identify the inherent contradictions and resolve the trade-offs within cereal food systems concerning environmental sustainability, poverty reduction, profitability for actors and firms throughout the value chain, and improved nutrition and health of vulnerable populations.

4.2. Integrative working modality

These objectives can be achieved through new working modalities. Working with the processing industry and food scientists will enable the development of crops to improve both the nutritional and the industrial qualities of whole-grain products. Working similarly with the food industry can serve to reduce quality losses during food processing and manufacturing. Consulting with the processing sector and consumers, plant breeders and agronomists can discover production practices that guarantee the best nutritional quality. Collaborating with food scientists and biomedical researchers will create new knowledge to consolidate and verify the evidence on the adverse effects of cereals, and promote an informed engagement with policy-makers, popular media, and wider nutrition education initiatives in order to present clear dietary guidance.

In collaboration with local researchers, the agricultural research community can create a more comprehensive understanding of the socioeconomics of local and specific value chains for cereal foods thereby helping to identify opportunities for increased efficiency in food transformations such as storage and transport, as well as processing. Similarly, multidisciplinary natural and social science approaches to cereal food systems are necessary to address food safety challenges and to minimize food waste.

Finally, there is a need for consumer-focused economic and social behavioural research that will inform policy-makers on the appropriate regulation of food systems, behavioural change ('nudge') programmes and policies (Vecchio & Cavallo, 2019), and provide education for all socioeconomic levels and age groups about healthy food choices and food utilization at the (intra-)household level.

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