Global Journal of Medical Research: L
Nutrition & Food Science
Volume 21 Issue 1 Version 1.0 Year 2021
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4618 & Print ISSN: 0975-5888

Prioritizing Achievable Goals for Food Security in the Developing World

By Sanjaya Rajaram & Maarten van Ginkel

Abstract- Many solutions have been proposed to address food security. We present here a prioritized set of actions achievable within the next 2–10 years. By taking a systems approach we follow the impact pathway backwards starting from the needs and desires of the end-users to eventually define the research agenda that will exactly address those targeted solutions with positive impacts. The following actions emerge as high-priority and achievable in the near future: new research tools to study food systems; dis-aggregated intra-household surveys to reveal within-family inequalities in food access; increased scientific consensus on climate change impacts in sub-Saharan Africa; rapid response measures to address sudden emergencies, such as capturing excess rainfall water; financial tools to enable rapid responses with recovery measures afterwards; consideration of restrictions that excess heat and humidity impose on human productivity; secure land ownership and tenure rights to encourage long-term agricultural investment; mechanization at all stages along the food system.

GJMR-L Classification: NLMC Code: WA 695

PRIORITIZINGACHIEVABLEGOALSFORFOODSECURITYINTHEDEVELOPINGWORLD

Strictly as per the compliance and regulations of:

Prioritizing Achievable Goals for Food Security in the Developing World

Sanjaya Rajaram [α] & Maarten van Ginkel [σ]

Abstract- Many solutions have been proposed to address food security. We present here a prioritized set of actions achievable within the next 2–10 years. By taking a systems approach we follow the impact pathway backwards starting from the needs and desires of the end-users to eventually define the research agenda that will exactly address those targeted solutions with positive impacts. The following actions emerge as high-priority and achievable in the near future: new research tools to study food systems; dis-aggregated intra-household surveys to reveal within-family inequalities in food access; increased scientific consensus on climate change impacts in sub-Saharan Africa; rapid response measures to address sudden emergencies, such as capturing excess rainfall water; financial tools to enable rapid responses with recovery measures afterwards; consideration of restrictions that excess heat and humidity impose on human productivity; secure land ownership and tenure rights to encourage long-term agricultural investment; mechanization at all stages along the food system; improved human capacity to innovate; encouragement for farms able to become more commercial, with support for those not (yet) able to transition; balanced mixed plant and animal diets to address nutrition, with more research on vegetables and fruits to improve human health; facilitation for somewhat larger medium-size farms that produce more efficiently; temporary safety nets for those transitioning out of agriculture; sustainable intensification focused where there is lowest risk of biodiversity loss for greatest production gain; encouragement for private sector to create more food system jobs in rural areas, especially for youth; research on soil biota that facilitate availability of nutrients such as phosphorus or benefit crop growth; attention on root systems; reconsideration of transgenic, hybrid and gene-editing approaches to crop improvement; increased use of the rich genetic diversity in crop and animal wild relatives and landraces in breeding programs.

I. Introduction

Food security, which encompasses food availability, access, utilization and stability (Van den Broeck & Maertens, 2016; Frels et al., 2019), is a key element in Sustainable Development Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture. We set out to identify actions that would enable full food security that are both high-priority and achievable within the next 2–10 years, coinciding with the SDG target of 2030. Our focus is on agriculture in the developing world, where food security is most needed. Our approach is to identify the most important drivers of food systems and then to look at ongoing processes in these food systems in search of achievable goals with a high return. In so doing, we present a big-picture overview of the current status for each area and then offer some recommendations, based on a much wider review that draws also on the authors' long combined experience working in these areas in public-sector agricultural research and development for the developing world.

A crucial point is to recognize that we are dealing with a complex, multi-faceted set of problems. Food systems include soil, water, air, crops, livestock, fish, natural vegetation, pollinators, soil-borne organisms, environmental sustainability, dietary sustainability, food security, food distribution, food demand, consumption, waste, livelihoods, justice and stakeholders from farmers to consumers; such complexity requires interdisciplinary, transdisciplinary and systems thinking (Dawson et al., 2019).

II. Major Drivers

a) Population growth

Norman E. Borlaug, awarded the Nobel Peace Prize 50 years ago for the plant breeding work that ushered in the Green Revolution, emphasized the "population monster". He noted that humankind "is not yet using adequately his potential for decreasing the rate of human reproduction" (Borlaug, 1972).

Nevertheless, global population growth has slowed considerably, to 2.3 births per woman. In almost half of the world's roughly 200 countries, mostly in Asia, Europe and North America, fertility rates have dropped below the replacement rate of 2.1 births per woman. However, in the least developed countries, covering more than 1 billion people, average birth rate is 4.1 per woman, with an average household size of 5. In Africa, the fertility rate is 4.4 births per woman. Death rates too are dropping, although not as fast as birth rates, so that for 25 countries around the world population size will still double between now and 2050 (Population Reference Bureau, 2020). About 90% of global population growth will occur in Africa and Asia. Many of those people–80%–will be in medium-sized cities of fewer than 500,000 inhabitants (Hazell, 2018).

b) Climate change

Agriculture occupies 40% of all global land area (Clapp, Newell, & Brent, 2018). Technological innovation in agri-food systems will have to accelerate in order to mitigate and adapt to climate change (IPCC, 2018). With

Author σ: e-mail: maartenvanginkel1951@gmail.com

[1] Dr. Rajaram passed away on February 17, 2021; [2] corresponding author

climate change, dry regions will become drier, and wet regions wetter (Ruane & Rosenzweig, 2018). Predictions of extreme temperature point in one direction: more frequent heat. Heat extremes will hasten decomposition of soil organic matter (SOM) and decrease soil water availability, requiring crop irrigation with waste water or sewage and resulting in soil pollution (Fayiga & Saha, 2017). The effects on crop species will differ. As is well known, C3 plants are more vulnerable to elevated temperature and CO_2 levels than C4 plants (Lamboll, Stathers, & Morton, 2017). Damage due to crop diseases, pests and weeds extending their range under climate change is already vast, although to some extent predictable based on their presently known environmental adaptation (Hertel & de Lima, 2020). Other impacts on crop physiology, such as pollen maturation and survival, are complex. The agriculture and food sectors are not only victims of climate change but, according to most estimates, are also themselves responsible for about 25% of all greenhouse gas (GHG) emissions, complicating mitigation and adaptation in agriculture considerably (Clapp et al., 2018; Ruane & Rosenzweig, 2018).

Extreme rainfall events will include both lack and excess of precipitation, and be less predictable. Inland flooding and associated water logging of crops are expected, for example in East Africa (Lamboll, Stathers, & Morton, 2017; Ruane & Rosenzweig, 2018). Water logging leaches nutrients from the soil, resulting in negative nutrient imbalances on farmland and downstream (Fayiga & Saha, 2017). Sea-level has risen 20 cm from 1900 to 2020, faster than at any time in the past 2000 years (Lamboll, Stathers, & Morton, 2017). Sea level rises will increase coastal soil salinity levels, reducing crop yields (Fayiga & Saha, 2017; IPCC, 2018). Snow-fed river systems will receive less water, as less snow will fall in their watersheds (Ruane & Rosenzweig, 2018). By 2040, major productive, arable lands will find groundwater depleted or unreachable, with 28% of all cropland under high water stress, (Van der Elst & Williams, 2018). While most studies of agriculture and climate change focus on temperature and precipitation, a 30-year study in China indicates that other weather-related factors may also have large effects; for example, increased wind speed results in lower rice, wheat and maize yields, but increased humidity enhanced crop development (Zhang, Zhang, & Chen, 2017).

Fish stocks in tropical areas may decrease by up to 40% in 2050 compared to 2000, as a result of many factors ultimately linked to climate change (IPCC, 2018; Lam et al., 2020). African countries are most vulnerable to fisheries-related food insecurity although some may be able to compensate with aquaculture (Ding, Chen, Hilborn, & Chen, 2017).

Most models predict that lower latitudes, where most developing countries are located, will experience more severe changes and fluctuations in climate than higher latitudes (Ruane & Rosenzweig, 2018). Many developing countries, especially in Africa, are highly exposed and vulnerable, and with low adaptive capacity compared to developed countries (Sarkodie & Strezov, 2019). In addition, while climate predictions for many regions are in agreement, those for sub-Saharan Africa (SSA) are surprisingly unclear. Different analyses arrive at distinct, even sometimes opposing, conclusions about changes in temperature and precipitation, and even the frequent conclusion that the Horn of Africa and East Africa will see an increase in precipitation is not uniformly agreed upon (Serdeczny et al., 2017).

Climate change will disproportionately hit remote, marginalized semi-arid lands, which already experience scarce, unreliable rainfall and often have degraded soils. Populations there rely on rain fed agriculture, mixed crop and livestock farming or pastoralism, with restricted access to markets, infrastructure and services (Gannon, Crick, Rouhaud, Conway, & Fankhauser, 2018).

Crucially, the impact of relatively small absolute changes varies considerably according to the relative status of different sectors of the population, an effect masked by high-level aggregated approaches to modeling. (Hallegatte & Rozenberg, 2017), for example, show that although the poorest quintile of the population represents only a few percent of total GDP, much of their work is in the informal sector so that impacts will barely be reflected in GDP. Precarious living conditions add to vulnerability to extreme weather events, while rising food prices have a disproportionately large effect when total household income is low. Women in developing countries will be particularly affected, as they often work in the most marginalized activities with restricted access to resources. This is especially true in Africa, but also a factor in Asia (Gannon, Crick, Rouhaud, Conway, & Fankhauser, 2018; Chanana-Nag & Aggarwal, 2020). Many work on land owned by others for a wage, often less than that of men, with increased exposure to higher financial risk and instability.

Livestock, as the rest of agriculture, contributes to climate change – 14.5% of global GHG emissions – and will be negatively affected, resulting in increased competition for water and feed, and reduced production of milk, meat and eggs (Rojas-Downing, Nejadhashemi, Harrigan, & Woznicki, 2017; IPCC, 2018). Ruminant livestock are the greatest source of methane (Reay, Smith, Christensen, James, & Clark, 2018), while manure and fertilizer use in feed production account for almost half the GHG production in livestock management (Rojas-Downing et al., 2017).

As a result of the complexities of food systems, supposedly climate-smart policies could exacerbate rather than mitigate the challenges. Hasegawa et al., (2018) show that carbon taxes on GHG emissions would increase food prices, by increasing the costs of crop production, and demand for biofuel leads to elevated land rents. This mitigation approach resulted in extra risk of hunger over no mitigation and a larger negative impact than climate change itself. The negative effects are more severe on livestock than on food crop prices, especially in low-income regions in SSA and South Asia. The authors stress that they do not argue against climate change mitigation or adaptation measures, but emphasize that study of trade-offs and the implementation of corrective measures on prices, and hence food security, is also important (Hasegawa et al., 2018).

The impact of climate change on labor is likely to be high. Capacity for work by people laboring outside in the sun is known to suffer, especially when humidity is high, as in agriculture and construction. Draft animals are likely to have similar declines in productivity as temperatures rise. And yet, these effects of climate change on agricultural labor productivity in many low-income countries are rarely taken into consideration, while already part of legislature in industrialized countries (Hertel & de Lima, 2020).

In order to address sudden challenges, one of the fundamental requirements is the capacity to innovate. This ability can be learned and upgraded (Leeuwis et al., 2014), indicating a need for capacity building not just in specific disciplines such as agronomy, but in developing the ability, willingness and confidence to successfully experiment with new approaches at short time intervals, thus creating resilience by systems thinking. With increased capacity to innovate, farmers are better prepared to respond, moving from "teaching a person how to fish" to "experimenting oneself on how to fish even better".

c) Recommendations for Climate Change

A very high priority must be for scientists to combine their efforts in a focus on sub-Saharan Africa. Absolute numbers and relative rates of poverty are very high, and most food production is reliant on rainfed agriculture. However, consensus on the impact of climate change is not high. It is urgent that more reliable predictions be produced quickly, to guide other research.

Raising preparedness to cope with and recover from sudden extreme weather events must be a priority. A set of scenarios for a range of events at different scales will indicate levels of resilience and specific areas in which resilience can be improved. For example, prepare to direct run-off of large amounts of rainfall water to storage facilities from where it later can easily be extracted.

Data from the poorest segments of society are absent from most aggregate assessments of the impacts of climate change. Disaggregated, large-scale household surveys are needed to ensure that impacts on these, which are likely to be most severe, can inform higher-level analyses.

Extreme weather events are likely to find expression in greater fluctuation in agricultural production that will affect farmers, consumers and the economy as a whole. New financial tools will be needed that can inject support very quickly when needed, reaping returns in agricultural boom years, when prices are generally lower.

The social costs of climate change on human productivity need to be better understood so that appropriate adaptation measures can be put in place.

d) Decline in research and development budgets

Cuts in agricultural research and development (R&D) budgets by high-income, public, mostly government budgets are increasingly common (Frels et al., 2019), as support is demanded elsewhere. Cutting R&D budgets in any sector sooner or later will result in fewer innovations that are able to address existing and new problems. In the developed world the private sector increasingly pays for much of agricultural R&D, often behind securely patented walls. In the developing world the low return on investment is a drag on private-sector agricultural R&D. In addition, "agricultural research is slow magic," with many of its returns accruing only after decades (Alston et al., 2020).

The importance of agricultural R&D is especially pronounced in developing countries, where increases in agricultural productivity reduced poverty more than productivity gains in industry or services (Ivanic & Martin, 2018). In those countries, public R&D remains crucial. The UN and the African Union Commission recommend that developing countries invest 1% of GDP in agricultural research, but in 2016 the vast majority of these countries reached at most only 0.3% of GDP (Beintema, Pratt, & Stads, 2020). R&D should not just aim to increase calories from a few staple crops, but also nutrients from other food groups, including fruits, vegetables, meat, eggs, and milk (Pingali & Aiyar, 2018; Hertel & de Lima, 2020).

Overseas Development Aid (ODA) provided an average of $11 billion per year for agricultural development between 1975 and 2013. ODA specifically for agricultural research grew from 2.9% to 7.7% of total ODA and was associated with high rates of return (Abler, 2017). Sub-Saharan Africa and South Asia were the major recipient regions. However, SSA consistently had the lowest score in development projects rated satisfactory by the World Bank. Abler (2017) attributes this to a lack of appreciation for SSA's diversity and complexity, lack of local human and infrastructure base to develop agriculture, and fruitless efforts to apply approaches that worked in Asia but are not suited for SSA. ODA investments in agriculture remain important, especially in SSA (Mason-D'Croz et al., 2019).

Reduced ODA inflows may also reflect positive developments, for example when a country exceeds donor limits on income per capita. For example, the

Organisation for Economic Co-operation and Development (OECD) sets a threshold of $12,000 per capita for three years consecutively (Calleja & Prizzon, 2019). Between 2004 and 2019, 35 low-income countries became middle-income countries (Jalles d'Orey & Prizzon, 2019) and the OECD expects an additional 29 countries to "graduate" before 2030 (Calleja & Prizzon, 2019). However, exceeding a threshold for mean per capita income does not guarantee that such countries will now themselves fund a healthy agricultural R&D sector. Furthermore, after transitioning to middle-income, countries receive outside investments as loans rather than grants. As a result, governments invest these loans in money-making sectors, such as infrastructure projects, rather than sectors such as agricultural R&D, under the impression that these latter sectors do not create financial returns in the short term (Engen and Prizzon, 2019). However, a meta-analysis of 492 studies showed that present-day return on investment in agricultural R&D continues to be high, above 50% per year (Rao, Hurley, & Pardey, 2019). At the same time many of the poorest countries stagnate in agricultural production and R&D, while their economic dependency on agriculture continues (Alston and Pardey, 2017).

Another relatively new and positive development is that medium-income countries, such as Brazil, China and India, increasingly define their own agricultural R&D agenda and are responsible for significant technology innovations for the developing world and beyond. While in high-income countries agricultural scientific publications doubled between 1996 and 2016, in newly middle-income countries a 4-to 30-fold increase was reported (Heisey & Fuglie, 2018). The growing role in agricultural R&D of these newly medium-income countries is not restricted to their government sector, but also their emergent private sector. As their success grows, these are likely to spread their influence regionally and even globally. For example, Seed Co, one of the largest homegrown private seed sector companies in SSA, was founded in Zimbabwe and now operates in more than 20 African countries.

e) Recommendation on R&D budgets

As low-income countries reduce investments in agricultural R&D, despite high internal rates of return on agricultural development, we advise governments to create incentives for private sector investment in agri-food systems. One approach might be lower taxes on such investments, especially in rural areas.

III. High-Priority and Achievable Goals

a) Restore resource-base degradation

Land degradation–measurable loss of the "biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands…arising from human activities and habitation patterns" (Barbier & Hochard, 2018)– now affects 25% of all global land, more than 90% of which is in developing countries (Barbier & Hochard, 2018; Tittonell, 2018). Increasing the amount of agriculture through changes in land use is increasingly difficult, even in Africa, where the arable land limit has already been reached in 45 of the 54 African countries and 65% of the land has degraded through unsustainable intensification (Kwame Yeboah, Jayne, Muyanga, & Chamberlin, 2019). Where expansion of agricultural land is still possible, it will be largely into low productivity land, resulting in further land degradation (Barbier & Hochard, 2018). This challenges Sustainable Development Goal 15, land degradation neutrality, defined as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (UNCCD, 2016).

Innovations that increase returns to land and labor can motivate farmers to engage in more sustainable food systems, mitigating land degradation and thus further increasing returns. In addition, rural infrastructure and education have been shown to contribute most to increasing productivity for people on degraded land (Barbier & Hochard, 2018). Restoring their soils requires the mitigation of degrading factors, introducing biomass and nutrients, and producing new biomass from rotationally synergistic plants that are partially sequestered in the soil to increase soil organic matter (Tittonell, 2018). Depleted soils with reduced SOM and greater acidity may no longer respond to inorganic fertilizer, preventing new crop varieties delivering their potential yield (Kwame Yeboah, Jayne, Muyanga, & Chamberlin, 2019).

The provision of phosphate is particularly urgent. Phosphate fertilizer precipitates into complexes and becomes fixed in soils, with 75–90% becoming inaccessible to plants. As a result, phosphate is the second most applied fertilizer after nitrogen (Aloo, Makumba, & Mbega, 2020). Unlike nitrogen, however, rock phosphate is a finite resource, expected to be depleted in the next 100 to 500 years (Cottrell et al., 2018; Aloo et al., 2020). Methods are needed to allow plants to access the phosphorus tied up in soils. Some rhizobacteria can solubilize and liberate phosphorus from soil complexes and make it available to plants, and while they have been commercially available for about 15 years, the mechanisms of action are often unknown (Aloo et al., 2020). Other soil-borne organisms and micro-organisms can potentially restore degraded soils and have been little studied in that context. New methods allow the study of root systems in natural conditions (e.g., (El Hassouni et al., 2018)), enabling a better understanding of the hidden half of crop plants.

Organic farming has been proposed as a sustainable agri-food system that conserves biodiversity, improves soil health and reduces GHG emission, with lower inputs and higher prices as potential incentives for producers, at least in more developed countries. While there remains considerable discussion on both yields and environmental benefits (Jouzi et al., 2017), an extensive literature review indicates that per unit output, organic farming is more polluting than conventional farming because of its lower average productivity for crops and livestock (Meemken & Qaim, 2018). Only 11% of the land devoted to organic systems is currently in Africa and Asia, and more than 80% of purchases take place in Europe and North America (Anderberg, 2020). We conclude that while organic agriculture may make a small contribution to food security in very special circumstances, it does not seem suited for developing country households, and certainly not in the next 2–10 years.

b) Recommendations on degraded resources

The study of micro-organisms that can make bound phosphorus available to plants is urgently needed, along with greater research into the role of other soil biota in promoting plant health.

The study of roots to enhance their role in yield and yield stability can be hugely expanded, with new approaches available to efficiently phenotype, genetically define and improve root systems in natural cropping conditions.

The treatment of crop seeds with microbial solutions deserves further research, as a way to promote their ability to restore degraded lands. The use of microbial solutions has a checkered history that spans centuries, but is now beginning to gain a measure of scientific respect. A better understanding of the mechanisms involved, which might include stimulating the development of the root system, could unlock the potential of microbial solutions to sustainably raise crop yields.

Policies that offer access to land and secure tenancy rights will be essential to encourage youth to make long-term investments in agriculture and sustainable intensification.

c) Reversing biodiversity loss

Dynamic changes in biodiversity are part of the planet's past and present evolution, with new species continuously arising and others declining, hitherto with little impact on humans. More recently, agriculture, and especially changes in land use, have been identified as major drivers of biodiversity loss (Tilman et al., 2017; Almond, Grooten, & Petersen, 2020)}.

To reach global food security by 2030, expansion of croplands and intensification of farming are options additional to crop yield increases, but both risk biodiversity loss by way of loss and fragmentation of natural habitat and adverse water and soil management. Trade-offs are inevitable. Globally, the negative effects of expansion have been worse than those of intensification (Kehoe et al., 2017). Integrated modeling of agro-ecological and economic factors indicate that biodiversity was most severely affected in the tropics (Zabel et al., 2019), with cropland expansion most critical, relative to intensification, in Central and South America and Central Africa, and intensification most important in SSA, India and China (Kehoe et al., 2017; Zabel et al., 2019).

Even when sustainable intensification is deemed preferable to cropland expansion, which involves habitat conversion, biodiversity within agricultural landscapes is threatened (Egli, Meyer, Scherber, Kreft, & Tscharntke, 2018). Increased production through intensification should be focused on those areas where yield gaps are relatively high but risks to biodiversity are relatively low. According to Egli et al., (2018), spatial land-use optimization scenarios can help to avoid 88% of projected biodiversity losses, reconciling trade-offs.

Despite a general trend towards reduced biodiversity in farming systems, over time and in terms of on-farm genetic diversity, mixed and relay cropping are still widely practiced, especially on smallholdings in the developing world. Considering yields from all such crops in a farm by area and by time can show total harvest increases. Mixtures of several crop species and of genetic diversity within a crop have been shown to reduce losses to pests and diseases. Mixtures may also contain species that provide beneficial or synergistic complementary services, which in combination can result in ecosystem productivity and stability and thus increased product yields, quality and profitability insurance for risk-averse farmers (Baumgärtner, 2007). Such services include penetrating soil pans, soil regeneration, increasing water infiltration, preventing excess water evaporation and improving water retention, offering shade, providing protection against wind and habitats for natural enemies and biocontrol agents, greater carbon sequestration, enhanced nitrogen fixation, and greater ability to cope with disturbance. Urban agriculture and home gardens with mixed systems, due to their small scale and personal inputs, can promote production of many traditional, non-staple niche and "orphan" crops that address specific tastes and needs, and hence contribute to biodiversity (Taylor & Lovell, 2014).

d) Recommendations on reversing biodiversity loss

There is an urgent need now to protect and encourage biodiversity that serves both humankind and the planet's resource base. Focusing intensification of production only there where the expected productivity gain is largest and potential biodiversity loss is smallest can facilitate that.

Crop wild relatives, landraces, and neglected and underutilized crops, representing biodiversity, should be used more in modern crop breeding. (See Innovation in crops and animals, below).

e) Facilitating market access

Infrastructure constraints, such as a lack of roads to markets and longer-term (cooled) storage continue to restrict opportunities to earn income from excess crop production in much of the developing world. Investments in transport infrastructure have particularly lagged, despite being the largest portion in many infrastructure budgets, as the start from a low base (Gurara et al., 2017). Food transport and marketing will be sectors particularly affected when extreme rainfall leads to widespread flooding, which will particularly impact high-density cities (Vajjarapu, Verma, & Gulzar, 2019). In addition, an excess of intervening “middlemen” reduces the benefits that flow back to the original crop producers.

Traditionally, smallholder farmers sell excess production to passing traders or at the local market (Ferreira, Goh, & Valavi, 2017). In the past ten years, ODA has started to fund projects that explore digital mobile technologies to provide farmers with broader marketing channels (Ferreira, Goh, & Valavi, 2017; Qiang, Kuek, Dymond, & Esselaar, 2012). While mobile technologies are a promising area for farmers (and for providers of digital technology), regulations are needed and farmers may benefit from uniting in common groups to increase negotiation power with e-intermediaries, because beyond a minimum level of access, market power is more important than market access (Ferreira, Goh, & Valavi, 2017). Despite a checkered history, especially in Africa, producer organizations can facilitate access to input and output markets (Shiferaw, Hellin, & Muricho, 2016). There is some indication that membership of producer organizations is most popular with the middle class of farmers, with very low-income and high-income farmers choosing not to join. Key to future success for producer organizations is to take an expressed agribusiness orientation with strict business principles (Shiferaw, Hellin, & Muricho, 2011).

Despite some positive developments in agricultural production, Africa’s food imports have quadrupled in the past two decades. However, countries differ considerably, providing opportunities for cross-border trade in Africa, which also creates salaried jobs for surplus labor. Hence, investment in the production of local staple crops, to offset growing imports, closely followed by mixed crop-livestock food systems, remains a priority, along with diversification and with an eye to potential exports (Christiaensen & Vandercasteelen, 2019). Since 2000, donors and funders increasingly support value chain development approaches with multiple stakeholders, aimed at food security, poverty reduction and gender equity (Donovan, Stoian, & Hellin, 2020).

In a study of 235 Regional Trade Agreements (RTA) involving 45 developing country exporters from among the countries most active in international trade, and 60 export destinations, north-north agreements were the majority until 1991. However, during 1991–2015, 86% of the RTAs involved north-south and south-south product movements. On average, developing countries clearly benefitted from RTAs, but while Asia doubled its share of world trade to 36%, Africa stagnated at 2–3% (Stender, 2019).

An increase in open international trade would create new opportunities for agricultural goods from developing countries. During much of the previous century, border restrictions limited global trade of food products. At the end of the 20th century globalization bloomed, but the 2008 financial crisis interrupted this expansion (Frels et al., 2019). Nevertheless, since 2000 exports of horticultural products have tripled in Latin America and quadrupled in Africa and Asia (Van den Broeck & Maertens, 2016). Horticulture products represent the single largest category of agri-food exports, making up 24–33% of all agri-food exports from Africa, developing Asia and Latin America. Horticulture diversifies exports and increases food security, because its value chain is very labor-intensive but at a relatively low skill level, thus providing an income for many, including women and youth in food processing, while at the same time the products represent high-value exports (Van den Broeck & Maertens, 2016). Opening up trade will not only increase food diversity, quality and safety, but also raise national income, thus contributing to food availability, access, utilization and market stability (Frels et al., 2019).

There does not appear to be any trade-off between horticulture production for export and domestic food production; both actually increase. Increased household income enables improved access to food, especially for contract farmers, but less significantly so for wage workers, although in the latter case female workers appear to benefit most (Van den Broeck & Maertens, 2016)

Increased export to the developed world requires food safety regulations and sanitary and phytosanitary measures of importing countries to be implemented. Faour-Klingbeil and Todd (2018) studied the West Asia and North Africa (WANA) region and noted that Morocco, Tunisia, Egypt and Jordan adapted their food safety regulations and saw their food exports grow over the long-term. Most countries in WANA were not able to reach international standards, because of low safety standards on-farm and in local markets, and a lack of scientific knowledge and political will. As the value chain upgrades to higher quality markets and upscales export options, food standards and certification become more stringent, with the result that agribusiness increasingly tends to focus on a limited number of large and medium farms, rather than on many smallholdings (Qaim, 2017).

The inclusion of non-farm income sources by farming families when discussing agri-food systems is a dramatic transition from the past, and it requires recognition. Production systems diversify, diets diversify, livelihoods diversify and income sources diversify. Levels of analysis change too, from on-farm analyses, to farming systems analyses, to post farm gate analysis, to value chain analyses, and now to total agri-food systems analyses. This kind of straddling research should be included in future research agendas for them to remain relevant in changing times.

f) Recommendation for market access

We recommend that governments encourage a transition to commercial farming, which offers stronger routes to market access, improves food security, and provides employment and income for a diversified workforce, including women and youth. Those farms not yet able to transition may need other forms of facilitation and support.

g) Diversification of crops and diets

In the past 10–15 years, attention has begun to shift from the need to feed the hungry in developing countries, to the need to nourish those with insufficient access to nutritious food. More than two billion individuals are undernourished or malnourished, including those with stunting, wasting, vitamin and mineral deficiencies, anemia and obesity (Haddad et al., 2016).

In low-income, low-yielding subsistence farming, in the absence of trade and markets, families eat largely what their farm produces. Their dietary and nutritional adequacy is determined by what they grow. In true subsistence farming, increased diversity in home-grown crop production directly leads to increased diversity in nutrient intake and better health. But many of even the smallest farmers do purchase some food, thus somewhat diversifying their diets (Sibhatu & Qaim, 2018; Mehraban & Ickowitz, 2021). As farming initially intensifies, cropping diversity itself often decreases because the focus moves to the few most profitable major staples; as a result, diet diversity may decrease (Ickowitz, Powell, Rowland, Jones, & Sunderland, 2019; Mehraban & Ickowitz, 2021). Then, as farming further intensifies and commercializes, incomes rise, poverty falls, global connectedness grows, and information on nutrition, health and new taste experiences becomes available, interest in more diverse diets rises, as seen in newly medium-income countries (Pingali & Aiyar, 2018; Mehraban & Ickowitz, 2021). With rising incomes and standards of living, growth of the middle class and urbanization, there is an increased taste and demand for diversified diets, which progressively include animal-based foods, fruits and vegetables, and processed foods (Rojas-Downing et al., 2017; Allen, Heinrigs, & Heo, 2018; Van der Elst & Williams, 2018; Adesogan, Havelaar, McKune, Eilittä, & Dahl, 2020; Mehraban & Ickowitz, 2021).Overall, both on-farm diversification (within limits) and market access diversification can lead to fairly well diversified and healthy diets (Sibhatu, Krishna, & Qaim, 2015).

Cereals dominate many diets in the developing world as food staples, and have benefitted from a century of science-based crop improvement, as have staple root and tuber crops and several legume food crops. Most climate change research has focused on the major staples, wheat, rice, maize and soybean, but non-staple crops will be increasingly important in providing protein and micro-nutrients (Hertel & de Lima, 2020). Research on fruits and vegetables has lagged, and given the high nutritional value of many fruits and vegetables and the relatively low research base in many cases, very significant gains in nutritional food security can be expected when modern scientific improvement tools are applied. Furthermore, an entire class of edible plants has been labelled neglected and underutilized species (Padulosi et al., 2018). These NUS crops are often extremely rich in important micronutrients. Researchers have reduced the neglect to some extent, and consumers are being encouraged to use them more frequently and more widely, with large potential impacts on nutritional security particularly in developing countries, where NUS are often well adapted to low-input systems (Hunter et al., 2019; Siddique, Li, & Gruber, 2021)}.

Animal-source food (including milk and dairy products, meat, fish, and eggs) is a hotly discussed topic, with some noting that for the poor it provides crucial nutrients, while others point to its negative environmental impacts (Willett et al., 2019; Adesogan et al., 2020). The SDGs specifically refer to the importance of domesticated animal and fish production (UN General Assembly, 2015), in part because in diets with an excess of cereals the lack of micronutrients (e.g., bio-available vitamin A, vitamin D3, iron, iodine, zinc, calcium, folic acid) may lead to stunting in children and impaired cognitive development. Animal-based foods also provide high-quality proteins and essential fatty acids and may also enhance absorption of nutrients such as iron and vitamin A from plant-based food eaten at the same time. Animal-source foods contain the only natural source of vitamin B12; the lack of which may result in developmental disorders, anemia, and poor motor and cognitive functions. Micronutrient supplements may help to correct this, but are not an available option for many low-income households (Pingali & Sunder, 2017). Some animals also give traction power and all provide manure, both essential in low-income households. In developing countries, animals barely compete with humans for plant food, as animal feed contains only 14% products that humans could also consume. Most animal feed comes from pastures and crop residues (Adesogan et al., 2020).

In this debate on nutrition and balanced diets it is important to avoid becoming unrealistically restrictive in prescribing what others should eat. There may be a need to look beyond country-wide, highly aggregated mean figures, because meal content is largely chosen by individuals, driven at the time by their own appetite and taste as well as access, availability and affordability. At the same time, social norms may mean that women and girls are malnourished even though the household appears to have adequate food quantity and quality (Pingali & Sunder, 2017). Innumerable combinations of food products can constitute a balanced meal. There should also be space in the debate for allowing for that kind of self-determining diversity.

h) Recommendations on diet and nutrition

Diversifying farm production should be a priority focus, moving towards commercial models with good market access. These farms can sell healthy food locally and regionally, while high-quality products are placed on national and international markets. Such products would include fruits, vegetables, livestock and aquatic foods.

Treatment of malnutrition, especially of hidden hunger, should shift to diversified, complementary plant and animal diets, possibly including biofortified crops, rather than direct micronutrient supplementation.

Research is needed on fruits and vegetables at a scale comparable with past investment in starchy staples, to increase production, transportability, shelf life and nutritional value, among others. Progress from the existing low research base is expected to be rapid.

Information about within-household inequity should be gathered as a priority, in order to inform the kinds of gender-transformational changes in social norms and high-level policies that will improve the access of women and girls to more nutritious diets.

i) Innovation in crops and animals

Innovations in crop improvement are not always actually that new, but their adoption on-farm has lagged, and not just in the developing world. Hybrid crop solutions have been applied in cross-pollinating crops, such as maize, for 100 years in both the developed and developing world. But hybrids and hybrid-enabled approaches in self-pollinating crops, harvesting hybrid vigor, remain far behind, while 10–15% yield boosts on top of conventional increases are possible by capturing the additive gene action component underpinning hybrid vigor (van Ginkel & Ortiz, 2018). Transgenic approaches have been widely adopted in many countries, although some, such as the EU members, continue to oppose them. Gene editing with CRISPR-Cas9 is proving very promising in a rapidly increasing range of organisms, including crops and livestock, although it too is currently blocked in the EU. We hope that all three approaches will be more widely adopted, with expected large yield and nutrition gains for each. Governments that set an example by enthusiastically promoting GM food crops, as the Bangladesh government did when it approved a GM eggplant variety with insect resistance for release to its farmers in 2013 (Shelton et al., 2018), could also boost adoption of new technologies.

Wild relatives and landraces have been used in a limited way in scientific breeding over the past 100 years or more, but there is a new and growing appreciation that they often contain traits, such as resistance and tolerance to biotic and abiotic stresses, that are highly desirable in response to climate change. New technologies are making it easier to identify and incorporate these traits into advanced varieties, and the value of wild relatives and landraces should be experimented with in many more crops (Kilian et al., 2021). Increasing photosynthetic efficiency and conferring nitrogen-fixing ability on cereals are two approaches that have so far failed to deliver on their initial promises, but new technologies such as high-throughput phenotyping of wild relatives and landraces may change that record (Langridge, 2018)

j) Recommendations for crop and animal innovation

The positive potential of transgenic, hybrid and hybrid-enabled, and gene-edited crops to achieve food security should be reconsidered, taking food safety requirements fully into consideration.

New technologies should be tested for crop and animal breeding, including the use of wild relatives and landraces to introduce novel genetic diversity for traits underpinning yield, quality, tolerance to biotic and abiotic stresses, and other challenges that climate change may bring.

k) Sustainable intensification of agriculture

Sustainable intensification, encompassing the multiple dimensions of food systems, as a foundation for food security can be traced back at least to the "Borlaug Hypothesis", adding a sustainability requirement to agricultural production (Borlaug, 1994). Later formulations have expanded the idea of ecological intensification to improve agricultural systems (Tittonell, 2018), not least to limit land conversion under climate change as a primary mitigation approach (IPCC, 2018). In practical terms, sustainable intensification aims to obtain higher yields per unit area and time, while applying a sustainable use of (natural) resources.

Mechanization offers considerable advantage, especially to young girls and women, by reducing some the drudgery that prevents them exploring other opportunities. "Retiring the hoe to the museum" is an African Union initiative to promote mechanization among women farmers in Africa that captures this notion well. Mechanization, high and low tech, has made great strides in Asia, but has lagged badly in Africa (Christiaensen, Rutledge, & Taylor, 2021) for well-

Global Journal of Medical Research (L) Volume XXI Issue I Version I Year 2021

understood reasons, including degraded soils that require rehabilitation before agriculture can be intensified (Pingali & Aiyar, 2018; Tittonell, 2018).

Sustainable intensification can deliver greater resource efficiency, including less labor and reduced environmental damage, at the same time as it brings global food security within reach (Saiz-Rubio & Rovira-Más, 2020). A low-hanging fruit would be to reduce post-harvest food losses. Globally, one third of food produced is lost; for staple cereals, which make up the bulk of the losses on a calorie basis, losses average 50–60% (Kumar & Kalita, 2017). Minimizing loss and waste translates directly into greater value, so we would expect the private sector to be interested in addressing loss and waste to maintain or improve their profits. The ongoing trend to larger farms and increasing commercialization, including participation in high-value export markets with strict food standards, will reduce losses earlier in the agri-food system chain.

The global average age of farmers, including those in developing countries, is presently around 60 years. These farmers represent high levels of accumulated knowledge based on years of field experience. For eager, young but less experienced farmers to take over, data-enhanced decision-making tools will enable them to be more effective in sustainably intensifying farming with approaches that are more knowledge- and skill-intensive (Saiz-Rubio & Rovira-Más, 2020). Dozens of farm management information systems are already commercially available to expedite multi-stage decision-making and interest is growing rapidly in such cash crop sectors as coffee production (Sott et al., 2020). While this type of farming has not reached food production in the developing world, we expect that once it is adopted by the cash crop sector there, it will spawn adaptations that are realistic for use also in food production.

An important drag on sustainable intensification is the small size of agricultural holdings, especially in developing countries (Hazell, 2018). These small farms may become even smaller as a result of inheritance customs and in rural Africa, as life expectancies increase, young people inherit land later in life, and holding size will be smaller than in past generations (Kwame Yeboah, Jayne, Muyanga, & Chamberlin, 2019). Consolidation into larger units may provide a solution, with productivity per unit area increasing once farms reach a critical size (Savastano & Scandizzo, 2017). Net value, efficiency and total factor productivity indicators increase with farm size (Garzón Delvaux, Riesgo, & Gomez y Paloma, 2020) due to mechanization and increased input use efficiency (Kwame Yeboah, Jayne, Muyanga, & Chamberlin, 2019). The notion that small farms produce more efficiently per hectare than larger farms, known as the inverse relationship (IR) between land area and output or productivity, is thus a limited interpretation when total factor productivity of integrated farming is taken into account (Savastano & Scandizzo, 2017; Kwame Yeboah, Jayne, Muyanga, & Chamberlin, 2019; Dourandish, Saghaian, Shahnoushi Forushani, Mohammadrezazadeh, & Kuhestani, 2020; Garzón Delvaux et al., 2020). While support for small farms seems well justified for social development reasons, for longer-term national development, poverty alleviation and food security somewhat larger, medium-sized farms should also be supported (Garzón Delvaux et al., 2020). The fashionable opinion among some consumers and opinion-makers in certain high-income countries, which favors regional, low-tech food from “small is beautiful” farms, would leave the poorest farmers in developing countries at high risk for food and nutrition insecurity (Qaim, 2017).

As urbanization grows, city dwellers influence food product choice and processing aspects, so that post-farm links in the food system value chain must adjust to changing demand. This transition to upgraded diets in cities could create new employment opportunities for youth, and result in some small farms being able to cater to these new urban needs, for example by providing specialty crops at higher prices (Hazell, 2018). At the same time, urban agriculture has seen increased interest, although most of the harvested food from urban agriculture is for self-consumption, with the remainder sold in the market (Armanda, Guinée, & Tukker, 2019). Some people also doubt whether the small harvests of urban agriculture will actually make a significant difference to food security (Specht, Schimichowski, & Fox-Kämper, 2021).

An important priority is for transdisciplinary, agro-ecological research into food systems to understand, model, predict and guide future farming systems from a multi-dimensional standpoint (van Ginkel et al., 2013; Pingali & Sunder, 2017; Niles et al., 2018; Ingram & Zurek, 2018). Biophysical, technological, processing, market, social, and policy environments and drivers are all involved (Ingram & Zurek, 2018). While the National Academies of Sciences, Engineering, and Medicine in the USA list “transdisciplinary science and systems approaches” as their first breakthrough and recommendation in their report “Science Breakthroughs to Advance Food and Agricultural Research by 2030” (National Academies of Sciences, Engineering, and Medicine, 2019), full acceptance of the benefits of adopting a systems approach has been lacking. Not only are systems-wide analyses essential, but most important now is to develop new transdisciplinary concepts, methods, tools and metrics to study such complex systems holistically (Ditzler et al., 2018).

l) Recommendations for sustainable intensification

Investment is needed into research and development on mechanization and labor-saving precision-agriculture equipment. Topics might include local weather prediction, early warning systems for natural hazards, knowledge-intensive breeding, automated farming, product transport, food processing and consumer service, among others.

The education and training of eager young potential farmers must become a priority. It should focus on modern farming methods and enhance their personal capacity to experiment and innovate, resulting in a cadre of young people who are both more informed and more enthusiastic about modern farming.

Technology and policy research is needed to facilitate the transition from unviable small farms to larger holdings with a more commercial orientation. Policies will have to include safety nets for those transitioning out of agriculture, and there should also be improved opportunities for rural jobs and income.

Medium-sized towns and cities rather than mega-cities should receive the bulk of investment in areas such as sustainable intensification, rural diversification, and access to technology and infrastructure. The goal is to provide local employment that is intellectually challenging and financially rewarding in order to encourage youth to stay in those areas and contribute directly and indirectly to greater food security.

New transdisciplinary concepts, methods, tools and metrics need to be developed to enable the holistic study of complex, biophysical and socio-economic aspects of food systems.

IV. Conclusions

In our efforts to propose a research and development agenda for food systems in the near future, we follow the impact pathway backwards in order to avoid the trap of developing a science-based solution that is looking for a problem (van Ginkel et al., 2013). First, determine the food system-related needs and constraints of farmer and consumer families and the wider society, directly with these stakeholders. Then decide which biophysical and policy outcomes will positively address and satisfy those needs and constraints, and have impact. Having identified desirable outcomes, we then propose agriculture-related value chain and on-farm outputs that can result in those outcomes. Finally, the outputs we have identified determine the R&D needed to produce them, taking us back to the start of the impact pathway. If the process is rigorous, science-based, transdisciplinary and inclusive, following the impact pathway backwards near guarantees that R&D is precisely focused on the final target population, and will resolve the most urgent social issues.

Using this approach, we recommend the following actions and goals for the coming decade.

Entire integrated food systems require new tools to study systems holistically. Dis-aggregated intra-household surveys will indicate, down to the individual level, where food needs are most acute. We need better predictions of climate change impacts in SSA. Measures to harvest excess water during sudden rain events and retrieve it when needed are essential. Financial tools are needed that can inject funding rapidly to address sudden events, and later retrieve income when economies recover and grow. Better understanding of the effects of excess heat and humidity on human productivity will allow more complete planning and preparation. Secure land tenure rights and rental agreements will encourage long-term sustainable intensification and related investment, especially by rural youth. Mechanization is needed at all stages along the food system. Human capacity to innovate needs to be improved through education, which will also attract rural youth. Facilitation, for example through market access and infrastructure, is needed for farms to transition to commercial farming, which will also create jobs, while farms not (yet) able should receive support to enhance and stabilize production. Balanced plant and animal diets, including valuable neglected and underutilized species, should have priority in addressing nutritional needs. Diversification of farm production and food provision by research to improve vegetables and fruits will improve health and create jobs. Somewhat larger medium-size farms produce crops and food products more efficiently and should be encouraged by supporting related R&D and capacity development, along with temporary safety nets for those transitioning out of agriculture, with new job creation in rural areas. Intensification should focus on those lands that have the lowest potential of biodiversity loss, and the greatest potential gain in production. Facilitating the private sector to create more interesting jobs in rural areas, especially for youth, will also upgrade services to local communities. Investment in smaller rural towns and cities to bring modern food system technologies will provide new jobs. Research on soil biota will help to make nutrients available that are now tied up in the soil, such as phosphorus, while the positive effects of microbial solutions need a concerted effort to understand how they can benefit plant growth. Roots remain understudied, but with new breakthroughs need attention that could make rapid progress in optimizing plant development. Transgenic, hybrid and gene-editing approaches to crop improvement should be explored, where they can help reach food and nutrition security. Breeding new crop and animal types will benefit from the rich genetic diversity in their wild relatives and landraces, for which tools are becoming available.

Acknowledgement

We thank Jeremy Cherfas for help with preparing the paper for publication.

References Références Referencias

1. Abler, D. (2017). The International Role in Agricultural Development. in D. Blandford & K. Hassapoyannes (Eds.), Global Challenges for Future Food and Agricultural Policies World Scientific Series in Grand Public Policy Challenges of the 21st Century Volume 1 (pp. 39-60). World Scientific. doi:10.1142/9789813235403_0003
2. Adesogan, A. T., Havelaar, A. H., McKune, S. L., Eilittä, M., & Dahl, G. E. (2020). Animal source foods: Sustainability problem or malnutrition and sustainability solution? Perspective matters. Global Food Security, 25, 100325. https://doi.org/10.1016/j.gfs.2019.100325
3. Allen, T., Heinrigs, P., & Heo, I. (2018). Agriculture, Food and Jobs in West Africa. Paris: OECD Publishing. https://doi.org/10.1787/dc152bc0-en
4. Almond, R. E. A., Grooten, M., & Petersen, T. (Eds.). (2020). Living Planet Report 2020 - Bending the curve of biodiversity loss. Gland: WWF.
5. Aloo, B. N., Makumba, B. A., & Mbega, E. R. (2020). Phosphate-solubilizing rhizobacteria: Diversity, mechanisms, and prospects in sustainable agriculture. Preprints. Retrieved from https://www.preprints.org/manuscript/202009.0681
6. Alston, J. M., Pardey, P. G., & Rao, X. (2020). The Payoff to Investing in CGIAR Research. Arlington: SoAR Foundation. Retrieved from https://supportagresearch.org/assets/pdf/soar_cgiar_key_findings_final.pdf
7. Anderberg, S. (2020). The Contribution of Organic Agriculture to Poverty Reduction. in M. Breiling & V. Anbumozhi (Eds.), Vulnerability of Agricultural Production Networks and Global Food Value Chains Due to Natural Disasters (pp. 41-71). Jakarta: Economic Research Institute for ASEAN and East Asia.
8. Armanda, D. T., Guinée, J. B., & Tukker, A. (2019). The second green revolution: Innovative urban agriculture's contribution to food security and sustainability–a review. Global Food Security, 22, 13-24. https://doi.org/10.1016/j.gfs.2019.08.002
9. Barbier, E. B., & Hochard, J. P. (2018). Land degradation and poverty. Nature Sustainability, 1(11), 623-631. doi:10.1038/s41893-018-0155-4
10. Baumgärtner, S. (2007). The insurance value of biodiversity in the provision of ecosystem services. Natural Resource Modeling, 20, 87-127. doi:10.1111/j.1939-7445.2007.tb00202.x
11. Beintema, N., Pratt, A. N., & Stads, G.-J. (2020). Key Trends in Global Agricultural Research Investment. Washington, DC: International Food Policy Research Institute. Retrieved from https://www.asti.cgiar.org/sites/default/files/pdf/Global-update-ASTI-note.pdf
12. Borlaug, N. E. (1994). Agricultural research for sustainable development. Testimony of Dr. Norman Borlaug before the U.S. House of Representatives Committee on Agriculture, Subcommittee on Foreign Agriculture and Hunger March 1, 1994.
13. Borlaug, N. E. (1972). The Green Revolution. Peace and Humanity. Mexico City: CIMMYT.
14. Calleja, R., & Prizzon, A. (2019). Moving away from aid: Lessons from country studies. London: ODI. Retrieved from https://cdn.odi.org/media/documents/191128_summary_report_final_v1.pdf
15. Chanana-Nag, N., & Aggarwal, P. K. (2020). Woman in agriculture, and climate risks: Hotspots for development. Climatic Change, 158(1), 13-27. doi:10.1007/s10584-018-2233-z
16. Christiaensen, L. J., & Vandercasteelen, J. (2019). Earning more on the farm. In K. Beegle & L. J. Christiaensen (Eds.), Accelerating Poverty Reduction in Africa. Washington DC: World Bank.
17. Christiaensen, L., Rutledge, Z., & Taylor, J. E. (2021). Viewpoint: The future of work in agri-food. Food Policy, 99, 101963. https://doi.org/10.1016/j.foodpol.2020.101963
18. Clapp, J., Newell, P., & Brent, Z. W. (2018). The global political economy of climate change, agriculture and food systems. The Journal of Peasant Studies, 45(1), 80-88. doi:10.1080/03066150.2017.1381602
19. Cottrell, R. S., Fleming, A., Fulton, E. A., Nash, K. L., Watson, R. A., & Blanchard, J. L. (2018). Considering land–sea interactions and trade-offs for food and biodiversity. Global Change Biology, 24(2), 580-596. https://doi.org/10.1111/gcb.13873
20. Dawson, I. K., Park, S. E., Attwood, S. J., Jamnadass, R., Powell, W., Sunderland, T., & Carsan, S. (2019). Contributions of biodiversity to the sustainable intensification of food production. Global Food Security, 21, 23-37. https://doi.org/10.1016/j.gfs.2019.07.002
21. Ding, Q., Chen, X., Hilborn, R., & Chen, Y. (2017). Vulnerability to impacts of climate change on marine fisheries and food security. Marine Policy, 83, 55-61. https://doi.org/10.1016/j.marpol.2017.05.011
22. Ditzler, L., Klerkx, L., Chan-Dentoni, J., Posthumus, H., Krupnik, T. J., Ridaura, S. L., … Groot, J. C. J. (2018). Affordances of agricultural systems analysis tools: A review and framework to enhance tool design and implementation. Agricultural Systems, 164, 20-30. https://doi.org/10.1016/j.agsy.2018.03.006
23. Donovan, J., Stoian, D., & Hellin, J. (2020). Value chain development and the poor: Promise, delivery and opportunities for impact at scale. Rugby: Practical Action Publishing. doi:10.3362/9781788530576

Global Journal of Medical Research (L) Volume XXI Issue I Version I Year 2021
21

24. Dourandish, A., Saghaian, S., Shahnoushi Forushani, N., Mohammadrezazadeh, N., & Kuhestani, S. (2020). The relation between property rights, farm size and technical efficiency for the developing countries' agricultural sector. Journal of International Development, 32(5), 749-762. https://doi.org/10.1002/jid.3476
25. Egli, L., Meyer, C., Scherber, C., Kreft, H., & Tscharntke, T. (2018). Winners and losers of national and global efforts to reconcile agricultural intensification and biodiversity conservation. Global Change Biology, 24(5), 2212-2228. https://doi.org/10.1111/gcb.14076
26. El Hassouni, K., Alahmad, S., Belkadi, B., Filali-Maltouf, A., Hickey, L. T., & Bassi, F. M. (2018). Root system architecture and its association with yield under different water regimes in durum wheat. Crop Science, 58(6), 2331-2346. https://doi.org/10.2135/cropsci2018.01.0076
27. Engen, L., & Prizzon, A. (2019). Exit from aid: An analysis of donor experiences. London: ODI. Retrieved from http://hdl.handle.net/10419/206743
28. Fayiga, O. A., & Saha, K. U. (2017). Effect of climate change on soil productivity in developing countries. Asian Journal of Environment & Ecology, 4(1), 1-22. Retrieved from doi: 10.9734/AJEE/2017/35485
29. Ferreira, K. J., Goh, J., & Valavi, E. (2017). Intermediation in the Supply of Agricultural Products in Developing Economies. Working Paper 18-033. Cambridge: Harvard Business School. Retrieved from https://www.hbs.edu/ris/Publication%20Files/18-033_8fcdda05-0410-4a43-b329-4e30d790cea b.pdf
30. Frels, K., Chopra, R., Dorn, M. K., Wyse, L. D., Marks, D. M., & Anderson, A. J. (2019). Genetic diversity of field pennycress (Thlaspi arvense) reveals untapped variability and paths toward selection for domestication. Agronomy, 9(6). doi:10.3390/agronomy9060302
31. Gannon, K. E., Crick, F., Rouhaud, E., Conway, D., & Fankhauser, S. (2018). Supporting private adaptation to climate change in semi-arid lands in developing countries. London: Grantham Research Institute on Climate Change and the Environment.
32. Garzón Delvaux, P. A., Riesgo, L., & Gomez y Paloma, S. (2020). Are small farms more performant than larger ones in developing countries. Science Advances, 6(41), eabb8235. doi:10.1126/sciadv.abb8235
33. Gurara, D., Klyuev, V., Mwase, N., Presbitero, A., Xin, C., Xu, G., & Bannister, G. (2017). Trends and challenges in infrastructure investment in low income developing countries. Strategy, policy, and review department IMF Working Paper WP/17/233.
34. Haddad, L., Hawkes, C., Waage, J., Webb, P., Godfray, C., & Toulmin, C. (2016). Food systems and diets: Facing the challenges of the 21st century. London: Global Panel on Agriculture and Food Systems for Nutrition. Retrieved from http://glopan.org/sites/default/files/ForesightReport.pdf
35. Hallegatte, S., & Rozenberg, J. (2017). Climate change through a poverty lens. Nature Climate Change, 7(4), 250-256. doi:10.1038/nclimate3253
36. Hasegawa, T., Fujimori, S., Havlík, P., Valin, H., Bodirsky, B. L., Doelman, J. C., … Witzke, P. (2018). Risk of increased food insecurity under stringent global climate change mitigation policy. Nature Climate Change, 8, 699-703. doi:10.1038/s41558-018-0230-x
37. Hazell, P. B. R. (2018). Urbanization, Agriculture, and Smallholder Farming. In R. Serraj & P. Pingali (Eds.), Agriculture & Food Systems to 2050 World Scientific Series in Grand Public Policy Challenges of the 21st Century (pp. 137-160). World Scientific. doi:10.1142/9789813278356_0004
38. Heisey, P. W., & Fuglie, K. O. (2018). Public agricultural R&D in high-income countries: Old and new roles in a new funding environment. Global Food Security, 17, 92-102. https://doi.org/10.1016/j.gfs.2018.03.008
39. Hertel, T. W., & de Lima, C. Z. (2020). Viewpoint: Climate impacts on agriculture: Searching for keys under the streetlight. Food Policy, 95, 101954. https://doi.org/10.1016/j.foodpol.2020.101954
40. Hunter, D., Borelli, T., Beltrame, D. M. O., Oliveira, C. N. S., Coradin, L., Wasike, V. W., … Tartanac, F. (2019). The potential of neglected and underutilized species for improving diets and nutrition. Planta, 250(3), 709-729. doi:10.1007/s00425-019-03169-4
41. Ickowitz, A., Powell, B., Rowland, D., Jones, A., & Sunderland, T. (2019). Agricultural intensification, dietary diversity, and markets in the global food security narrative. Global Food Security, 20, 9-16. https://doi.org/10.1016/j.gfs.2018.11.002
42. Ingram, J., & Zurek, M. (2018). Food Systems Approaches for the Future. In R. Serraj & P. Pingali (Eds.), Agriculture & Food Systems to 2050 World Scientific Series in Grand Public Policy Challenges of the 21st Century (pp. 547-567). World Scientific. doi:10.1142/9789813278356_0017
43. IPCC. (2018). Summary for Policymakers. In V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, … T. Waterfield (Eds.), Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of

climate change, sustainable development, and efforts to eradicate poverty.
44. Ivanic, M., & Martin, W. (2018). Sectoral productivity growth and poverty reduction: National and global impacts. World Development, 109, 429-439. https://doi.org/10.1016/j.worlddev.2017.07.004
45. Jalles d'Orey, M. A., & Prizzon, A. (2019). Exit from aid: An analysis of donor experiences. London: ODI. Retrieved from https://cdn.odi.org/media/documents/12661.pdf
46. Jouzi, Z., Azadi, H., Taheri, F., Zarafshani, K., Gebrehiwot, K., Van Passel, S., & Lebailly, P. (2017). Organic farming and small-scale farmers: Main opportunities and challenges. Ecological Economics, 132, 144-154. https://doi.org/10.1016/j.ecolecon.2016.10.016
47. Kehoe, L., Romero-Muñoz, A., Polaina, E., Estes, L., Kreft, H., & Kuemmerle, T. (2017). Biodiversity at risk under future cropland expansion and intensification. Nature Ecology and Evolution, 1. doi:10.1038/s41559-017-0234-3
48. Kilian, B., Dempewolf, H., Guarino, L., Werner, P., Coyne, C., & Warburton, M. L. (2021). Crop science special issue: Adapting agriculture to climate change: A walk on the wild side. Crop Science, 61(1), 32-36. https://doi.org/10.1002/csc2.20418
49. Kumar, D., & Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods, 6(1), 8. doi:10.3390/foods6010008
50. Kwame Yeboah, F., Jayne, T. S., Muyanga, M., & Chamberlin, J. (2019). Youth access to land, migration and employment opportunities: evidence from sub-Saharan Africa. Rome: IFAD.
51. Lam, V. W. Y., Allison, E. H., Bell, J. D., Blythe, J., Cheung, W. W. L., Frölicher, T. L., … Sumaila, U. R. (2020). Climate change, tropical fisheries and prospects for sustainable development. Nature Reviews Earth & Environment, 1(9), 440-454. doi:10.1038/s43017-020-0071-9
52. Lamboll, R., Stathers, T., & Morton, J. (2017). Climate Change and Agricultural Systems. In S. Snapp & B. Pound (Eds.), Agricultural Systems: Agroecology and Rural Innovation for Development (pp. 441-490). San Diego: Academic Press. https://doi.org/10.1016/B978-0-12-802070-8.00013-x
53. Langridge, P. (2018). Innovation in Breeding and Biotechnology. In R. Serraj & P. Pingali (Eds.), Agriculture & Food Systems to 2050 World Scientific Series in Grand Public Policy Challenges of the 21st Century (pp. 245-284). World Scientific. doi:10.1142/9789813278356_0008
54. Leeuwis, C., Schut, M., Waters-Bayer, A., Mur, R., Atta-Krah, K., & Douthwaite, B. (2014). Capacity to innovate from a system CGIAR research program perspective. Penang: CGIAR Research Program on Aquatic Agricultural Systems. Retrieved from https://cgspace.cgiar.org/handle/10568/87913
55. Mason-D'Croz, D., Sulser, T. B., Wiebe, K., Rosegrant, M. W., Lowder, S. K., Nin-Pratt, A., … Robertson, R. D. (2019). Agricultural investments and hunger in Africa: Modeling potential contributions to SDG2–zero hunger. World Development, 116, 38-53. https://doi.org/10.1016/j.worlddev.2018.12.006
56. Meemken, E.-M., & Qaim, M. (2018). Organic agriculture, food security, and the environment. Annual Review of Resource Economics, 10(1), 39-63. doi:10.1146/annurev-resource-100517-023252
57. Mehraban, N., & Ickowitz, A. (2021). Dietary diversity of rural Indonesian households declines over time with agricultural production diversity even as incomes rise. Global Food Security, 28, 100502. doi:https://doi.org/10.1016/j.gfs.2021.100502
58. National Academies of Sciences, Engineering, and Medicine. (2019). Science Breakthroughs to Advance Food and Agricultural Research by 2030. Washington, DC: The National Academies Press. doi:10.17226/25059
59. Niles, M. T., Ahuja, R., Barker, T., Esquivel, J., Gutterman, S., Heller, M. C., … Vermeulen, S. (2018). Climate change mitigation beyond agriculture: A review of food system opportunities and implications. Renewable Agriculture and Food Systems, 33(3), 297-308. doi: 10.1017/S1742170518000029
60. Padulosi, S., Cawthorn, D.-M., Meldrum, G., Flore, R., Halloran, A., & Mattei, F. (2018). Leveraging Neglected and Underutilized Plant, Fungi, and Animal Species for More Nutrition Sensitive and Sustainable Food Systems. In P. Ferrante, E. Berry, & J. Anderson (Eds.), Encyclopedia of Food Security and Sustainability. Elsevier. doi:10.1016/B978-0-08-100596-5.21552-7
61. Pingali, P., & Aiyar, A. (2018). Food, Agriculture, and Nutrition Policy: Looking Ahead to 2050. In R. Serraj & P. Pingali (Eds.), Agriculture & Food Systems to 2050 World Scientific Series in Grand Public Policy Challenges of the 21st Century (pp. 609-653). World Scientific. doi:10.1142/9789813278356_0017
62. Pingali, P., & Sunder, N. (2017). Transitioning toward nutrition-sensitive food systems in developing countries. Annual Review of Resource Economics, 9(1), 439-459. doi:10.1146/annurev-resource-100516-053552
63. Population Reference Bureau. (2020). World Population Data Sheet. Retrieved 2021-03-24, from https://www.prb.org/2020-world-population-data-sheet/
64. Qaim, M. (2017). Globalisation of agrifood systems and sustainable nutrition. Proceedings of the

Nutrition Society, 76(1), 12-21. doi: 10.1017/S0029665116000598

65. Qiang, C., Kuek, S., Dymond, A., & Esselaar, S. (2012). Report No. 96226-GLB Mobile Applications for Agriculture and Rural Development. Washington DC: ICT Sector Unit, World Bank. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/21892/Mobile0applica0nd0rural0development.pdf
66. Rao, X., Hurley, T. M., & Pardey, P. G. (2019). Are agricultural R &D returns declining and development dependent? World Development, 122, 27-37. https://doi.org/10.1016/j.worlddev.2019.05.009
67. Reay, D. S., Smith, P., Christensen, T. R., James, R. H., & Clark, H. (2018). Methane and global environmental change. Annual Review of Environment and Resources, 43(1), 165-192. doi:10.1146/annurev-environ-102017-030154
68. Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. Climate Risk Management, 16, 145-163. https://doi.org/10.1016/j.crm.2017.02.001
69. Ruane, A. C., & Rosenzweig, C. (2018). Climate Change Impacts on Agriculture. In R. Serraj & P. Pingali (Eds.), Agriculture & Food Systems to 2050 World Scientific Series in Grand Public Policy Challenges of the 21st Century (pp. 161-191). World Scientific. doi:10.1142/9789813278356_0017
70. Saiz-Rubio, V., & Rovira-Más, F. (2020). From smart farming towards agriculture 5.0: A review on crop data management. Agronomy, 10(2). doi:10.3390/agronomy10020207
71. Sarkodie, S. A., & Strezov, V. (2019). Economic, social and governance adaptation readiness for mitigation of climate change vulnerability: Evidence from 192 countries. Science of the Total Environment, 656, 150-164. https://doi.org/10.1016/j.scitotenv.2018.11.349
72. Savastano, S., & Scandizzo, P. L. (2017). Revisiting the farm size–productivity relationship: New evidence from sub-Saharan African countries. In P. Pingali & G. Feder (Eds.), Agriculture and Rural Development in a Globalizing World: Challenges and Opportunities. Routledge. Retrieved from https://doi.org/10.4324/9781315314051
73. Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., … Reinhardt, J. (2017). Climate change impacts in sub-Saharan Africa: From physical changes to their social repercussions. Regional Environmental Change, 17(6), 1585-1600. doi:10.1007/s10113-015-0910-2
74. Shelton, A. M., Hossain, M. J., Paranjape, V., Azad, A. K., Rahman, M. L., Khan, A. S. M. M. R., … Mc Candless, L. (2018). Bt eggplant project in Bangladesh: History, present status, and future direction. Frontiers in Bioengineering and Biotechnology, 6, 106. doi:10.3389/fbioe.2018.00106
75. Shiferaw, B., Hellin, J., & Muricho, G. (2011). Improving market access and agricultural productivity growth in Africa: What role for producer organizations and collective action institutions. Food Security, 3(4), 475-489. doi:10.1007/s12571-011-0153-0
76. Shiferaw, B., Hellin, J., & Muricho, G. (2016). Markets Access and Agricultural Productivity Growth in Developing Countries: Challenges and Opportunities for Producer Organizations. In J. Bijman, R. Muradian, & J. Schuurman (Eds.), Cooperatives, Economic Democratization and Rural Development (pp. 103-124). Cheltenham: Edward Elgar Publishing. doi:10.4337/9781784719388.00013
77. Sibhatu, K. T., Krishna, V. V., & Qaim, M. (2015). Production diversity and dietary diversity in smallholder farm households. Proceedings of the National Academy of Sciences USA, 112(34), 10657. doi:10.1073/pnas.1510982112
78. Sibhatu, K. T., & Qaim, M. (2018). Review: Meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. Food Policy, 77, 1-18. https://doi.org/10.1016/j.foodpol.2018.04.013
79. Siddique, K. H. M., Li, X., & Gruber, K. (2021). Rediscovering Asia's forgotten crops to fight chronic and hidden hunger. Nature Plants, 7(2), 116-122. doi:10.1038/s41477-021-00850-z
80. Sott, M. K., Furstenau, L. B., Kipper, L. M., Giraldo, F. D., López-Robles, J. R., Cobo, M. J., … Imran, M. A. (2020). Precision techniques and agriculture 4.0 technologies to promote sustainability in the coffee sector: State of the art, challenges and future trends. IEEE Access, 8, 149854-149867. doi:10.1109/ACCESS.2020.3016325
81. Specht, K., Schimichowski, J., & Fox-Kämper, R. (2021). Multifunctional Urban Landscapes: The Potential Role of Urban Agriculture as an Element of Sustainable Land Management. In T. Weith, T. Barkmann, N. Gaasch, S. Rogga, C. Strauß, & J. Zscheischler (Eds.), Sustainable Land Management in a European Context (pp. 291-303). Cham: Springer International Publishing. doi:10.1007/978-3-030-50841-8_15
82. Stender, F. (2019). Sign here, please! On developing countries' market access conditions in regional trade agreements. Review of Development Economics, 23(3), 1347-1367. https://doi.org/10.1111/rode.12591

83. Taylor, J. R., & Lovell, S. T. (2014). Urban home food gardens in the global north: Research traditions and future directions. Agriculture and Human Values, 31(2), 285-305. doi:10.1007/s10460-013-9475-1
84. Tilman, D., Clark, M., Williams, D. R., Kimmel, K., Polasky, S., & Packer, C. (2017). Future threats to biodiversity and pathways to their prevention. Nature, 546(7656), 73-81. doi:10.1038/nature22900
85. Tittonell, P. (2018). Ecological Intensification of Agriculture. In R. Serraj & P. Pingali (Eds.), Agriculture & Food Systems to 2050 World Scientific Series in Grand Public Policy Challenges of the 21st Century (pp. 437-472). World Scientific. doi:10.1 42/9789813278356_0017
86. UN General Assembly. (2015). Transforming our world: the 2030 Agenda for Sustainable Development, A/RES/70/1. Retrieved from https://www.refworld.org/docid/57b6e3e44.html [accessed 30 March 2021]
87. UNCCD. (2016). Report of the Conference of the Parties on its twelfth session, held in Ankara from 12 to 23 October 2015. Part two: action taken. Bonn: United Nations Convention to Combat Desertification (UNCCD). Retrieved from https://www.unccd.int/official-documents/cop-12-ankara-2015/iccdcop1220add1
88. Vajjarapu, H., Verma, A., & Gulzar, S. (2019). Adaptation policy framework for climate change impacts on transportation sector in developing countries. Transportation in Developing Economies, 5(1), 3. doi:10.1007/s40890-019-0071-y
89. Van den Broeck, G., & Maertens, M. (2016). Horticultural exports and food security in developing countries. Global Food Security, 10, 11-20. https://doi.org/10.1016/j.gfs.2016.07.007
90. Van der Elst, K., & Williams, A. (2018). Environment and Natural Resources. In R. Serraj & P. Pingali (Eds.), Agriculture & Food Systems to 2050 World Scientific Series in Grand Public Policy Challenges of the 21st Century (pp. 193-214). World Scientific. doi:10.1142/9789813278356_0017
91. van Ginkel, M., & Ortiz, R. (2018). Cross the best with the best, and select the best: Help in breeding selfing crops. Crop Science, 58(1), 17-30. https://doi.org/10.2135/cropsci2017.05.0270
92. van Ginkel, M., Sayer, J., Sinclair, F., Aw-Hassan, A., Bossio, D., Craufurd, P.,… Ortiz, R. (2013). An integrated agro-ecosystem and livelihood systems approach for the poor and vulnerable in dry areas. Food Security, 5(6), 751-767. doi:10.1007/s12571-013-0305-5
93. Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., … Murray, C. J. L. (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
94. Zabel, F., Delzeit, R., Schneider, J. M., Seppelt, R., Mauser, W., & Václavík, T. (2019). Global impacts of future cropland expansion and intensification on agricultural markets and biodiversity. Nature Communications, 10(1), 2844. doi:10.1038/s41467-019-10775-z
95. Zhang, P., Zhang, J., & Chen, M. (2017). Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation. Journal of Environmental Economics and Management, 83, 8-31. https://doi.org/10.1016/j.jeem.2016.12.001