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Review Article

Tapping the economic and nutritional power of vegetables

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ABSTRACT

Vegetables are increasingly recognized as essential for food and nutrition security. Vegetable production provides a promising economic opportunity for reducing rural poverty and unemployment in developing countries and is a key component of farm diversification strategies. Vegetables are mankind's most affordable source of vitamins and minerals needed for good health. Today, neither the economic nor nutritional power of vegetables is sufficiently realized. To tap the economic power of vegetables, governments will need to increase their investment in farm productivity (including improved varieties, alternatives to chemical pesticides, and the use of protected cultivation), good postharvest management, food safety, and market access. To tap the nutritional power of vegetables, consumers need to know how vegetables contribute to health, and find them at affordable prices or be able to grow them themselves. Vegetable consumption must therefore be nurtured through a combination of supply-side interventions and behavioral change communication emphasizing the importance of eating vegetables for good nutrition and health. To fully tap the economic and nutritional power of vegetables, governments and donors will need to give vegetables much greater priority than they currently receive. Now is the time to prioritize investments in vegetables, providing increased economic opportunities for smallholder farmers and providing healthy diets for all.

1. Introduction

Food security has long been associated with a vision of an abundance of grains, roots, and tubers – the staple crops that provide affordable sources of dietary energy. But this picture is changing as the concept of nutrition security has become embedded in that of food security and the importance of dietary diversity for good health has moved to the fore. Healthy, high-quality diets require the consumption of a wide range of food categories in the right quantities. Globally, the prevalence of hunger has declined to 795 million in 2015 (FAO et al., 2015), indicating progress in ensuring adequate access to staple foods as measured in terms of caloric intake. But an estimated 2 billion people are affected by insufficient intakes of micronutrients (WHO, 2016) and a further 2.1 billion people are overweight or obese (Ng et al., 2014).

Fruits and vegetables are essential sources for the micronutrients needed for healthier diets. Potassium in vegetables helps to maintain healthy blood pressure, their dietary fiber content reduces blood cholesterol levels and may lower the risk of heart disease, folate (folic acid) reduces the risks of birth defects, and vitamin A keeps eyes and skin healthy, while vitamin C not only keeps teeth and gums healthy but also aids in iron absorption. Recognizing the important nutritional benefits of fruits and vegetables, the World Health Organization (WHO) recommends a minimum intake of 400 g per day to prevent chronic diseases (especially heart diseases, cancers and diabetes) and supply needed micronutrients (especially calcium, iron, iodine, vitamin A and zinc) (WHO, 2015; WHO/FAO, 2003). However, consumers today, even those with higher incomes, are believed to be missing this target. More attention to filling this dietary gap and enabling consumers to tap the nutritional power of vegetables is required.

Expansion of fruit and vegetable production is an obvious first step. Growing populations and increased incomes, especially in urban areas, are already creating a rise in market demand as consumers seek to diversify their diets. Increasing vegetable production to respond to this demand creates important economic opportunities, especially for smallholder farmers. Data for Cambodia, Niger, and Vietnam show that profits per hectare are 3–14 times higher in vegetable production than in rice production while profits per labor-day are double (Joosten et al., 2015). Vegetables also typically provide more employment per hectare than cereals. Weinberger and Lumpkin (2007) showed that vegetable production in six Asian countries used on average 297 labor-days per hectare per season against 116 labor-days for cereal production. Particularly for youth, vegetable farming may offer a profitable business opportunity.

Market-oriented vegetable farming not only creates income for

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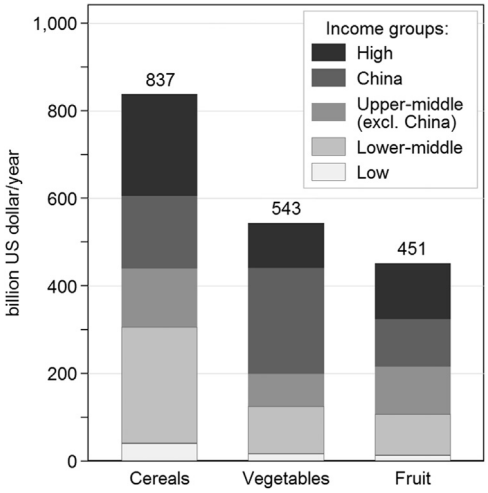

Fig. 1. Farmgate value of the global production of food cereals, vegetables and fruit, average 2012–2013, by national income categories, current US dollars.
Source: FAO (2017): Database on the value of agricultural production. **Notes:** World Bank 2016 classification used to group countries. FAO data on Gross Production Value (current million US$) are incomplete. Missing values were imputed using linear regression models for each crop using the Gross Production Value (constant 2004–2006 1000 I$) as predictor, which is more complete. Feed maize excluded from cereals. Watermelons, melons and avocados classified as fruit.

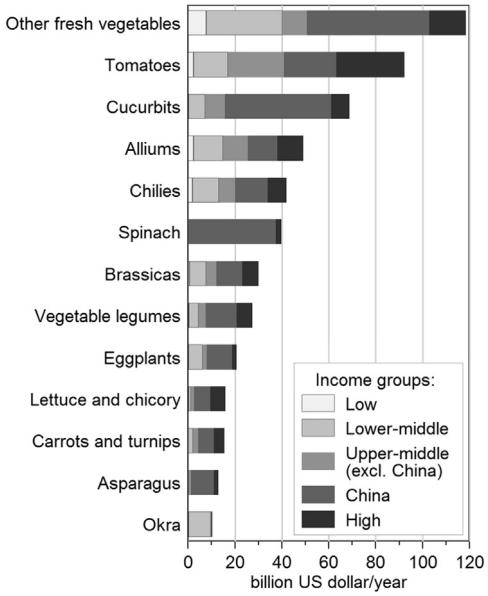

Fig. 2. Farmgate value of global vegetable production by income groups of countries, average 2012–2013, current US dollars.
Source: FAO (2017): Gross Production Value (current million US$). **Notes:** See notes under Fig. 1. Similar crops were added together; for instance, cucurbits include pumpkin, squash, gourds, cucumbers and gherkins. However, cucurbits excludes watermelons and melons. Not all countries report values for each vegetable and instead report an aggregate for "other fresh vegetables".

smallholder farmers but also helps to build their resilience to external risks. Diversity of vegetable crops, short growing cycles, and efficient use of irrigation can reduce farmers' vulnerability to climate change. For economic resilience, farmers may either opt to integrate vegetables into existing staple cropping systems or move into specialized vegetable production.

Vegetable production, processing and marketing offer potential opportunities that can be especially attractive to youth: production requires only small amounts of land, is technology-savvy, and high profits can be obtained in a relatively short period of time. Furthermore, low levels of mechanization in vegetable production and the need for careful handling of produce often create a specific demand for female labor. Public investments in infrastructure, training and subsidies in support of vegetable value chains could advance such employment.

The potential of vegetables to generate positive economic and nutritional impacts, however, has been limited by the relatively low levels of support that national governments and international donors direct to public sector vegetable research and development. Public and private investments in agriculture are still largely focused on staple crops and oil crops, not on commodities rich in micronutrients (Haddad et al., 2016; Pingali, 2015). To the extent that private sector investments in lower income countries are directed at vegetables, these tend to be focused on a narrow range of globally-important vegetables such as tomatoes, onions, green beans, peppers, lettuce and cucumbers.

The World Vegetable Center ("WorldVeg") is an international public research organization focused exclusively on expanding vegetable production and promoting increased consumption of vegetables. Founded in 1971 by several East and Southeast Asian countries, the United States and the Asian Development Bank as the Asian Vegetable Research and Development

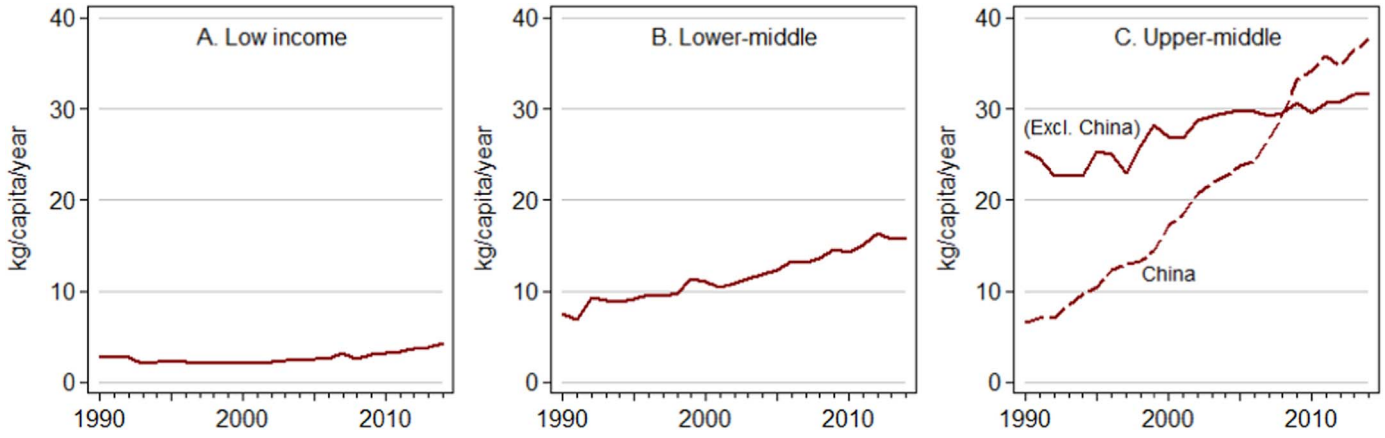

Fig. 3. Per capita tomato production in low-and middle-income countries, 1990–2014.
Sources: FAO (2017): Crop production data. UN (2017): Total Population - Both Sexes. **Notes:** World Bank 2016 classification used to group countries. Averages per group weighted by country populations.

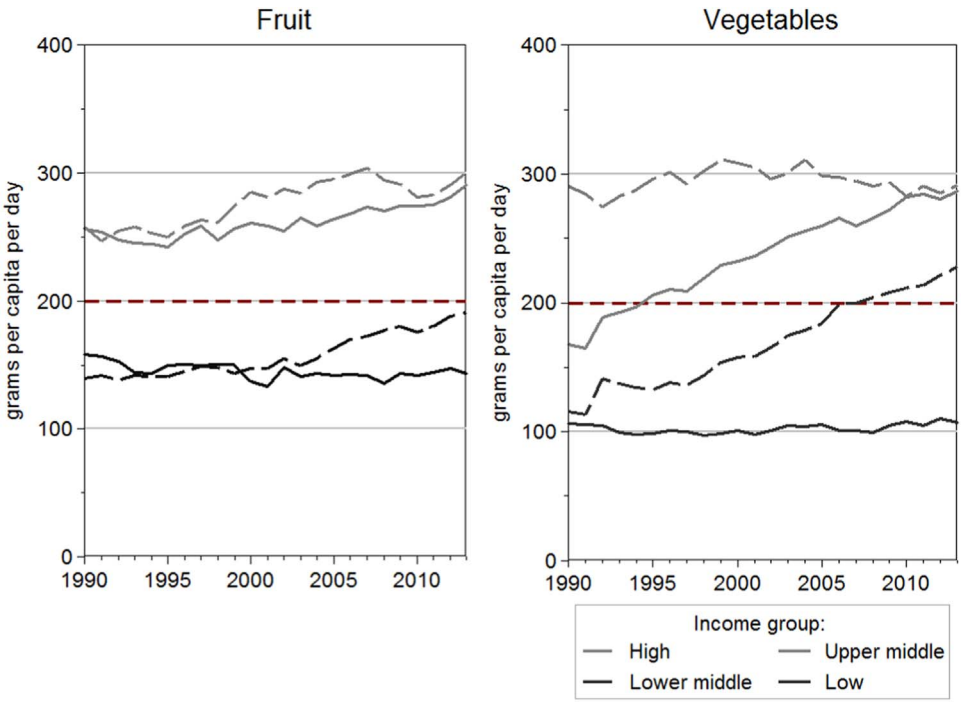

Fig. 4. Per capita availability of fruit and vegetables by income group of countries, 1990–2013.
Source: FAO (2017): Food Balance Sheets. **Notes:** World Bank 2016 classification used to group countries. Averages per group are unweighted by country populations: each country is one observation. China is therefore not shown separately. Watermelons, melons and avocados classified as fruit. Dashed horizontal line shows the FAO/WHO recommended consumption level of 200 g/capita/day.

Center (AVRDC), the Center now works across Asia and Africa. WorldVeg has a long history of conservation of vegetable germplasm, successful breeding of both global and indigenous vegetables, and development of production technologies that support the growth of vegetables on an intensification gradient from home gardens aimed at family nutrition to intensive market-oriented vegetable farming at scale.

This paper explores the potential for vegetables, first, to provide new opportunities for economic growth for smallholder farmers living in low-income tropical and subtropical countries and, second, to advance food and nutrition security–and better health–for billions of consumers in line with the Sustainable Development Goals. Our exploration will draw heavily on the work on the World Vegetable Center, but also references other key studies. Section 2 summarizes the current status of global vegetable supply and demand. Section 3 describes challenges to increasing vegetable supplies and highlights a number of cases where these have been successfully met. Section 4 considers experience in influencing and enabling increased vegetable consumption. Section 5 concludes with recommendations for public policies and interventions to expand the abilities of producers and consumers to tap the economic and nutritional power of vegetables.

2. Vegetables in the global food economy

Few people appreciate the significant economic role already played by vegetables and their close cousins, fruits.[1] The FAO Food Price Index provides no information on the market conditions for fruit or vegetables, although the broader databases maintained by the UN Food and Agriculture Organization (FAO) include data on supply and availability of key vegetables as well as their farmgate value.[2] The FAO data underscore the global importance of these crops (Fig. 1). The estimated farmgate value of annual

[1] There is no universally agreed classification of fruit and vegetables; the difference is based on cultural definitions and culinary use rather than botany. This section therefore discusses both fruit and vegetables.

[2] The data must be interpreted with caution. The data may underestimate the true value of fruit and vegetable production as a substantial share is produced in home gardens or collected from the wild for family consumption (e.g. Beal et al., 2017). At the same time, the data overestimate actual availability as they do not adequately account for waste and loss in the supply chains for fresh, highly-perishable produce. Further, data focus on so-called “global” vegetables and exclude many of the “traditional” or “indigenous” vegetables of importance in local markets.

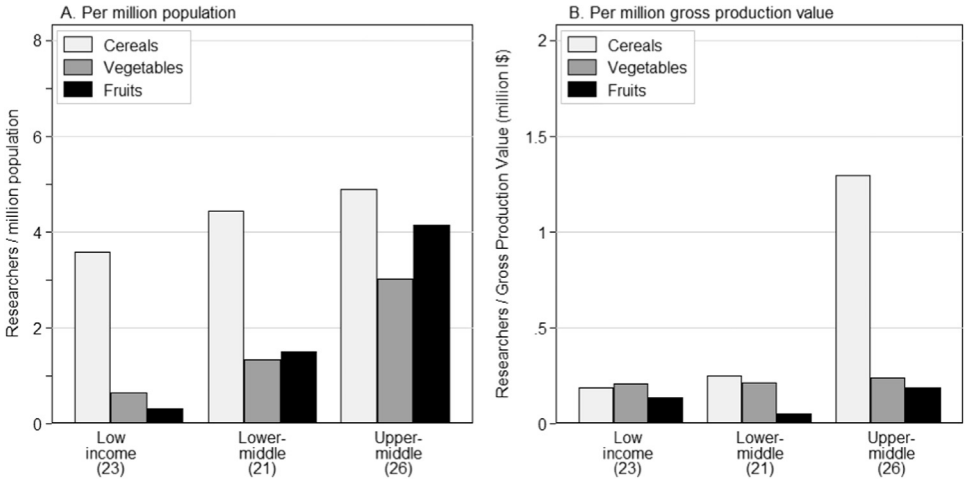

Fig. 5. Public sector researchers in cereals, vegetables and fruits by income group of countries, average 2008–2014.
Sources: IFPRI (2017): Agricultural Science and Technology Indicators (ASTI) "Researchers, total (Full time equivalents)". UN (2017): Population data. FAO (2017): Gross Production Value (constant 2004–2006 1000 I$). **Notes:** World Bank 2016 classification used to group countries. Number of countries in brackets. The group of upper-middle income countries also includes four high income countries (Chile, Oman, Trinidad and Tobago and Uruguay). Means per income group not weighted by country populations or gross production values. Cereals include wheat, rice, maize, barley, sorghum and other cereals. Fruits excludes bananas. Although the ASTI data are available for the period 2008–2014, there is usually only 1 observation per country.

global fruit and vegetable production, at nearly $1 trillion per year, exceeds the farmgate value of all food grains combined (US$ 837 billion).

This section provides more disaggregation of trends relevant to vegetables. Substantial rises in both production and consumption are occurring in middle-income countries, but not in low-income countries. There are indications of underinvestment in vegetable research, especially by the public sector and in improving "indigenous" or "traditional" vegetables that primarily reach local and regional markets.

The most dominant vegetables in the global food economy are tomatoes, cucurbits (pumpkins, squashes, cucumbers, and gherkins), alliums (onions, shallots, garlic) and chilies. These vegetables are consumed in nearly all countries—although with much variation in shapes, sizes, colors and tastes—and are rightly called "global." As shown in Fig. 2, apart from okra, no data on what are often called "indigenous" or "traditional" vegetables (e.g. amaranth, bitter gourd, kangkong, and spiderplant) are reported. While the marketing of global vegetables accounts for significant revenue streams, traditional vegetables often have superior nutritional properties (Yang and Keding, 2009). For instance, 100 g of leaves of amaranth, jute mallow, African nightshade or vegetable cowpea can provide over 100% of the vitamin A needs of pregnant women (World Vegetable Center, 2017).

Tomatoes alone are the fourth most economically-valuable food crop produced in low- and middle-income countries, after rice, sugarcane and wheat. Tomatoes accounted for US$ 63 billion per year in traded value (at farmgate) in 2012–13, with 35% of this value produced in China.[3] Fig. 3 depicts the rapid growth in tomato production in middle-income countries since 1990, with the remarkable six-fold increase in per capita tomato production in China reflecting the country's overall growth in horticultural production and the potential for economic gain associated with tomatoes. These opportunities are foregone in low-income countries as the trend line for tomato production in these countries is nearly flat.

Rising vegetable demand is driven by rising incomes as well as population growth. Globally, a 1% increase in per capita income in developing countries is associated with a 0.5% increase in per capita vegetable availability.[4] It follows that the bulk of the global supply of fruit and vegetables (77% of total value) is produced in populous middle-income countries.[5] China accounts for 45% of the global value of vegetable production and 24% of fruit production (FAO, 2017). India comes second, accounting for 8% and 7% of global vegetable and fruit production, respectively.

FAO data on food balance sheets suggest that the current per capita availability of vegetables in upper-middle income countries has converged to levels observed in high-income countries and that availability in middle income countries is increasing at the same rate (Fig. 4). Middle-income countries, on average, now produce a large enough quantity of fruit and vegetables to meet the FAO/WHO recommended intake levels of 200 g of fruit and 200 g of vegetables per day (WHO/FAO, 2003). Low-income countries, on the other hand, have seen little growth in their average vegetable production, and availability is well below the recommended consumption level, although this may be partly compensated by production and consumption of more traditional vegetables, not captured in the FAO data.[6]

It is also likely that productivity of vegetable farming is not rising as rapidly as it could be. Technological progress relies upon systematic research efforts to develop new varieties, crop management techniques, and innovations in postharvest handling and processing. Even in high income countries like the United States, there is evidence that public funding for vegetable research (as part of the "specialty crops" sector) is lower than expected given its economic value and its contribution to human health (Alston and Pardey, 2008). Public funding for research in low- and middle-income countries is rarely disaggregated enough to assess investments in vegetable research alone (See Pray et al., 2011 for SSA).

Fig. 5 gives a specific point of comparison of the level of priority currently allocated to fruit/vegetable research compared to cereals. It shows data for 70 countries on the number of public sector researchers per million population (panel A) and per million dollars of gross production value (panel B). These data suggest that lower income countries attach greater research priority to increasing productivity of staple food grains than they do to fruit and vegetables. While there are 4–5 publicly-funded cereal researchers per 1 million population in all country groups, in low- and lower-middle income countries, on average, only one researcher is working on fruit or vegetables. Panel B shows that research investment in fruits and vegetables per dollar of production value is about the same for all country groups, but higher income countries invest much more per dollar of cereal output than per dollar

[3] Estimate based on FAO data on the value of agricultural production ("Net Production Value (constant 2004–2006 1000 I$)"). Values averaged over 2012–2013.

[4] Regressing the exponential growth rate for per capita vegetable availability over the period 2003–2013 (from FAOSTAT) on the exponential growth rate for per capita GPD over the same period (from World Bank) while controlling for 2003 levels of per capita vegetable availability (in natural logarithms). Sample includes 113 developing countries.

[5] As classified by the World Bank based on gross national income per capita.

[6] It must be noted, however, that availability does not automatically translate into actual dietary consumption. There is evidence that vegetable demand must be nurtured and requires active policy intervention as part of efforts to promote healthier food choices. Comparing the food balance sheet data to the Global Dietary Database, for example, Del Gobbo et al. (2015) found that these data overestimate individual-based vegetable intakes by 75%. The difference is likely due to measurement error and unaccounted waste from cooking, spoilage and plate waste. Although actual levels may not be accurate, these data nevertheless illustrate strong growth in fruit and vegetable supplies in many middle-income countries over two decades.

of vegetable output. This may be because their production value of fruit and vegetables is increasing faster than that of cereals, or because these countries invest more into cereal research to keep up the income of cereal farmers as compared to other farmers and other sectors of the economy.

Private sector research investment is important, particularly for vegetables. Data on private sector investments in vegetable R & D are difficult to collect. However, the extensive consolidation that has taken place in the global vegetable seed industry and competitiveness within the industry for market share are indicative for its large economic value (Howard, 2009). Yet, even for China and India, which are considered leaders in this regard, the private sector accounts for only about a fifth of the total research investment (Hu et al., 2011; Pray and Nagarajan, 2012). Investments in private sector vegetable research tend to be directed toward hybrid development in a limited range of "global" vegetables that are of high commercial value, e.g., tomatoes, chilies, onions, and cucumbers.

3. Increasing the availability of a diverse range of safe vegetables

To meet the growing market demand for vegetables at affordable prices, production has to increase. This can be achieved through diversification of staple crop systems to include vegetables as well as intensification of existing specialized vegetable systems, particularly in peri-urban areas (e.g. Beed et al., 2015). But ensuring the safety of the vegetable supply is a critical correlate of increasing its availability. This section first addresses the importance of actions to ensure that vegetables are safe to eat and then examines three key challenges for increasing vegetable supply: improving on-farm productivity, reducing postharvest losses, and improving market access.

3.1. Ensuring that vegetables are safe to eat

Most vegetables are highly susceptible to damage from insect pests and plant diseases in the production phase. Certain pests and diseases can cause blemishes or odd shapes as well as reduce yields. Since consumers place a high value on the appearance of fresh produce offered in markets, farm managers often turn to excessive use of pesticides to reduce these economic risks. The use of pesticides is much more intense on high-value crops than on low-value crops and farmers tend to spray preventively to protect their investment (e.g. Riwthong et al., 2015 for Thailand). This practice not only increases potential health hazards and food safety concerns for consumers, but also exposes farm workers and their families to pesticide residues that can affect their own health (Praneetvatakul et al., 2013).

In addition, vegetable supplies can be affected by foodborne pathogens through various routes of contamination such as the use of organic waste in vegetable production, the use unclean water for irrigation or produce washing, and direct contamination by livestock, wild animals or birds (Heaton and Jones, 2008; Ha et al., 2008; Park et al., 2012).

As a result, consumers are increasingly concerned about the safety of vegetables. If vegetables regularly contain pathogens or exceed maximum pesticide residue limits, then consumers will associate fresh vegetables with health risks rather than health benefits and reduce consumption. Modernization of supply chains (e.g., refrigeration and quality control systems provided by supermarkets) only offer a partial solution. Studies have found that vegetables sold in supermarkets have a lower microbial contamination than vegetables sold in wet markets (e.g. Duedu et al., 2014), but both may be equally contaminated with pesticide residues (e.g. Wanwimolruk et al., 2016).

Some middle-income countries have seen the development of innovative market channels aimed at offering consumers a more trusted supply of fresh vegetables, some of which is certified as conforming to safety and quality standards. In Thailand, for example, the Royal Project Foundation links vegetable-producing communities in poor mountainous parts of the country with packing centers and a country-wide cold chain distribution network. This network has high levels of trust among consumers who are willing to pay a substantial price premium. Similar or cheaper initiatives are expanding in other countries, for example, organic farms directly delivering baskets with a variety of vegetables to consumers on a weekly basis. Regular phone-based systems or Internet applications are emerging as other avenues for vegetable farmers and producer groups to connect to consumers to a supply of safe, high-quality vegetables.

Food safety goals require policymakers to define suitable standards for vegetable production and handling and to put in place systems for monitoring compliance, including regular testing for pesticide residues and pathogens at major markets and public dissemination of the test results.

3.2. Improving on-farm productivity

On-farm productivity of vegetables varies widely. For instance, average tomato yields of Nigerian growers are only 4 t/ha (FAO, 2017; average 2012–2014). In comparison, growers in Cameroon attain yields of 13 t/ha, in India 21 t/ha, and in China they attain as much as 51 t/ha (FAO, 2017). Similar yield differences can be found for other vegetables. These differences are due to tremendous variability in growing conditions and input use. This variability indicates the potential to improve on-farm productivity through innovation. We focus here on three key areas of innovation: varietal improvement, pest and disease management, and protected cultivation.

3.2.1. Improved vegetable varieties

The availability of quality vegetable seeds is fundamental to increasing on-farm productivity. The rising supply of global vegetables has been linked to investments in research and development of hybrid varieties, and the marketing of seeds appropriately matched to specific production constraints. Policies that have supported private investments in quality vegetable seed development and production have paid off in terms of vegetable supply volumes.

The story of India's vegetable seed sector is instructive. Until 1988, the Government of India tightly regulated the seed sector, preventing entry of large domestic and foreign companies and restricting the import of seed for research or commercial purposes (Pray et al., 2001). The market for hybrid varieties was largely non-existent, there were only few private seed companies, and most farmers were served by the informal seed sector or recycled their own seed (Kolady et al., 2012; Pray et al., 2001). Subsequent seed sector liberalization and stronger protection of breeders' rights gave an enormous boost to private seed sector development and the vegetable seed sector in particular. Quality vegetable seeds are now available in nearly all parts of India. There is a highly competitive seed sector and hundreds of hybrids are available with different fruit and plant traits, with high yield and widespread resistance to key pest- and diseases (Schreinemachers et al., 2016b). Currently, the Indian vegetable seed sector market is reportedly valued at US$ 580 million per year and growing at a rate of 5% per year (Kapur, 2017). The availability of a diverse range of seeds will also be important for climate change adaptation.

In Africa, there is still little to no local capacity for private sector vegetable breeding and the supply of improved vegetable varieties remains limited (Afari-Sefa et al., 2012; Perez et al., 2017). Limited choice in vegetable seed does not enable farmers to select those varieties best suited to their production conditions. Without further seed development, lack of appropriate varieties will expose farmers to elevated risks associated with climate change – changes in rainfall and temperatures, and changing patterns of pests and diseases. However, there are ample opportunities in sub-Saharan Africa for economic gain through vegetable variety improvement.

In the mid-1990s, for example, the World Vegetable Center and partners in Tanzania tested various tropically-adapted open-pollinated

tomato varieties from Asia and made those that showed promise available to local private seed companies. Two of the introduced varieties now cover about 82% of the planted tomato area in Tanzania. This publicly-funded research had generated US$12.5 of economic benefit by 2014 for every dollar invested since 1987 and have resulted in a total economic gain of US$ 255 million for Tanzania until 2014 (Schreinemachers et al., 2017c).

Farmer demand for better vegetable varieties is encouraging global seed companies to invest in vegetable seed development and production for Africa (Access to Seeds Foundation, 2016; Broek, 2015). However, experience of the World Vegetable Center shows that the private sector in Africa, as well as in Asia, tends to focus on global rather than local vegetables. For example, there are few sources of improved seed of African nightshade or jute mallow in Africa and of Malabar spinach in Asia, despite these vegetables being important locally. Public sector research may need to lead the way to develop better varieties of these crops.

Challenges of ensuring a match between market demand and nutritional quality must be met as new varieties of both global and indigenous vegetables are developed. Data on the nutritional profiles of many traditional vegetables in raw and cooked forms are currently lacking, although many of these appear to be far more nutrient-dense than global vegetables. More insight is needed with respect to how nutrient profiles vary with varietal choice, growing conditions, processing and cooking methods and ultimately to what extent these nutrients are absorbed by the human body, which again depends on a range of other factors, including individuals' health status (Sriwichai et al., 2016). More evidence of the health benefits of traditional vegetable consumption supported by greater availability of improved and/or adapted indigenous seed varieties could create new investment opportunities for vegetable producers, processors and marketers.

3.2.2. Safe and sustainable pest management

Farmers often identify crop pests and diseases as their main sources of risk because they reduce yields and negatively affect the marketability of the produce. Indications are that the intensity of pest and disease pressures may increase due to climate change (Bebber et al., 2013) so methods of mitigation will assume even greater importance going forward. World Vegetable Center experience indicates three key sets of interventions could help: use of biocontrol methods, grafting high-yielding seedlings on to resistant rootstocks, and investing in protected cultivation systems.

Bio-control methods (i.e. the use of living organisms such as predator insects or parasites to control pests) have much potential to replace chemical pesticides, thereby improving food safety and lowering production risks. However, the diffusion of such methods is hampered in many countries by the rapid expansion of global trade in chemical pesticides and the high satisfaction of farmers with the effectiveness of chemical pesticides combined with limited risk awareness and knowledge of biocontrol methods (Schreinemachers et al., 2015). Regulatory frameworks often treat biopesticides (i.e., pesticides derived from natural materials such as of the neem plant) the same as chemical pesticides, which hampers the commercialization of safer methods (Srinivasan, 2012).

Vegetable grafting is also a promising method to control pests and diseases. The practice of grafting is widespread for fruit and vegetable production in high-income countries, but until recently it was uncommon in Southeast Asia or Africa. In the 1990s, the World Vegetable Center developed tomato scions with excellent fruit characteristics that could be grafted to eggplant and tomato rootstocks resistant to soilborne diseases, nematodes and flooding. Introduced to southern Vietnam tomato producers in 1998, this technology was adopted by nearly all producers in Lam Dong province by 2014. The grafted tomato plants gave a yield advantage of about 37% over non-grafted plants (Genova et al., 2013). Grafting also created new economic opportunities for small companies not only to produce grafted seedlings themselves but also to engage in trading and processing the greater supply of tomatoes.

3.2.3. Protected cultivation

The incidence of pests and diseases can also be lowered through the use of protected cultivation systems. Such systems enable producers to gain more control over their production environment. They can also allow farmers to produce vegetables outside the "regular" season (often defined by rainfall and temperature). Production brought to market outside of this season can realize significantly higher prices. Technologies range from simple rain shelters made of bamboo and plastic sheets to fully equipped greenhouses allowing for year-round cultivation. The use of protected cultivation methods is spreading rapidly across Asia (Kang et al., 2013; Nair and Barche, 2014). A study in Bangladesh showed that training farmers to grow tomatoes in the hot-wet season using low-cost rain shelters, heat-resistant varieties and plant hormones to induce flowering increased farmers' seasonal incomes by 48% (Schreinemachers et al., 2016c).

The use of protected cultivation is still limited in Africa, but there is enormous potential near medium- to large-size cities where vegetables find a ready market. However, the required inputs are often simply not available and private and public investment is needed to import materials or produce these locally. The decision to adopt (or to promote) protected cultivation would benefit from public policy support in other areas as well. Farmers may need to seek out sources of credit, upgrade skills in bookkeeping to keep track of cash flows, and use market information to better plan production.

3.3. Reducing postharvest losses

Postharvest losses in vegetable value chains are typically large, estimated in many developing countries to be in the range of 30–50% of farm production volumes (FAO, 2011). Reduction of these losses begins on-farm with appropriate selection of varieties and the use of good agricultural practices. Simple on-farm innovations such as harvesting at the right time of the day and sorting and grading of produce, combined with the use of appropriate packaging near the farmgate, can reduce economic losses.

Post-farmgate investments in logistics, cold storage systems and market information systems are needed to improve market functioning for high-value perishable vegetables. This mid-stream segment of vegetable value chains, what Reardon (2015) coined as the "hidden-middle", is exceedingly important and is undergoing rapid change in many middle-income countries. Postharvest interventions are complex as they require coordinated changes in the entire vegetable value chain from farm input providers to retailers. There is an urgent need to document what works and what doesn't in vegetable value chain interventions.

3.4. Improving market access

Increased access to domestic, regional and international markets for vegetables can provide important income incentives for farmers to enter vegetable production, as for instance shown by Muriithi and Matz (2015) for Kenya. There, as well as in Ghana, producers have successfully broken into the vegetable export business by producing non-traditional vegetables such as fresh French beans and Asian vegetables to exacting market specifications, packaged to retain freshness, and shipped by air or sea directly to supermarkets in Europe. In Kenya, these exports are valued at about US$ 1 billion a year (Fernandez-Stark et al., 2011).

Many developing countries have also seen a transformation of traditional value chains related to the growth of modern retail such as supermarkets (Reardon et al., 2003). If well-managed, this can benefit both consumers and farmers. However, it requires upgrading of farmers' skills to use new technologies, engage in contracting, and

invest in equipment and infrastructure to meet the demands for quality, consistency, and volume of modern retail. For Indonesia, Reardon and Gulati (2008) noted that the net profit of tomato farmers supplying supermarket channels was 33–39% higher than of farmers supplying traditional markets. For Kenya, Chege et al. (2015) showed that supplying supermarkets not only increased incomes, but also households' own micronutrient consumption.

4. Increasing vegetable consumption to improve nutrition

For low-income populations, the dietary priority is often to consume enough energy-rich foods to meet essential intakes of calories. Vegetables are relatively expensive per kilocalorie of energy compared to food staples, so the low priority given to purchasing vegetables seems understandable. Increased availability of vegetables is a necessary but not a sufficient condition to achieve the recommended intake levels of 400 g per day. Nor are rising incomes likely to result in satisfactory intakes of fruits and vegetables. In some countries, vegetable consumption has actually fallen in spite of growth in average incomes (Global Panel, 2016).

Changes in food consumption patterns are complex, reflecting other factors besides availability and price (Kearney, 2010; Traill et al., 2014). Tastes, changing lifestyles, convenience, food habits, low nutritional awareness, and food safety concerns all emerge as potent reasons for why vegetables are not always included in family meals. Certain segments of the population (think about young children) simply don't "like" vegetables. Cultural norms in some areas associate vegetable consumption with low social status or poverty. In other places, consumption of animal-based foods such meat and dairy is perceived as conveying higher social status or providing more nutrition than vegetables. And in some places there are social taboos; for instance, respondents of one study in Cameroon expressed a belief that the consumption of amaranth causes male impotency (Kamga et al., 2013).

Further, in high and low income countries alike, there is a shift toward the consumption of highly processed foods, including increasing quantities of sugars, salts, and edible oils (Popkin et al., 2012). As a result, the gap between recommended and actual consumption of vegetables persists even when vegetables are available and affordable.

To realize the nutritional and health benefits associated with recommended intakes of vegetables, consumer behaviors need to be modified. This section briefly describes three key approaches that have been tested to encourage the inclusion of more vegetables in healthier diets: behavior change communication aimed at nudging people toward healthier food choices including vegetables, vegetable home gardens to simultaneously increase demand and supply at the household level, and the inclusion of vegetables in school meal programs to improve nutrition of young children in poor areas. Still, the scale of the problem of insufficient vegetable consumption requires that the food system as a whole must be retooled to promote healthier diets and, especially, increased intakes of the fruits and vegetables that can deliver needed nutrients.

4.1. Behavior change communication on vegetable consumption

Public campaigns promoting vegetable consumption and nutritional awareness are part of the information landscape in many countries, e.g., the United Kingdom's "Five a Day" campaign.[7] Educational programs in hospitals, schools and markets also encourage dietary diversity and eating behaviors that promote good nutrition. Such campaigns and programs are regularly conducted by nongovernmental organizations in Africa and Asia, although an increased focus on nutrition by both national and regional organizations (e.g., members of the Scaling Up Nutrition movement) has also sparked an increased flow of information about dietary quality. The evidence for impact is still limited, but some show promising results. For example, Ochieng et al. (2017) evaluated the impact of campaigns promoting the use of African traditional vegetables on dietary diversity among rural and urban households in northern Tanzania and found significant increases in the dietary diversity of children under 5 years and of women in reproductive age.

Studies in high-income countries show that simple informational interventions can nudge children toward healthier food choices, including associating vegetables with superhero powers or giving vegetable dishes names attractive to children. Other "nudges" to changing eating behaviors involve simply cutting vegetables into smaller pieces or serving vegetables before serving meat and staples (e.g. Appleton et al., 2016; Wansink et al., 2012). Very little such research has been conducted in or applied to developing countries. There is an urgent need to do this.

The use of financial incentives (either cash or vouchers) to encourage low-income consumers to purchase a greater diversity of foods, including vegetables, has been widely proposed as a means of improving the "nutrition sensitivity" of social protection and food safety net programs and encouraging healthier diets. The Healthy Incentives Pilot in the U.S. found positive results both in terms of behavior and potential nutritional impact from the provision of economic incentives specifically tied to fruit and vegetable purchases (Bartlett et al., 2014). A study of food choices associated with provision of food, cash or vouchers to low-income populations in Ecuador found that vouchers were the most effective in encouraging vegetable consumption (Hidrobo et al., 2014).

More documentation is needed to show "what works" to influence consumers in various countries, with varying cultural preferences, and with different incomes to increase their vegetable intakes to recommended levels.

4.2. Home gardens and rural vegetable consumption

Home garden interventions designed with nutritional quality in mind pair hands-on training in vegetable production with nutrition and health behavioral change communication (e.g. World Vegetable Center, 2016). Such interventions simultaneously address vegetable availability, access, demand and utilization. This multipronged approach is especially effective at increasing vegetable consumption among poor rural households vulnerable to micronutrient deficiencies (DFID, 2014; Galhena et al., 2013; Olney et al., 2009; Schreinemachers et al., 2016a). A study of Helen Keller International's integrated household food production program in Burkina Faso found significant improvements in several child nutrition indicators, including reductions in wasting, diarrhea, and anemia, especially among young children (Olney et al., 2015).

Home garden interventions are often targeted at women as they are typically in control of meal choice and preparation, but sometimes it is also important to involve men and grandmothers in behavioral change communication. There is evidence that home gardens contribute to women's empowerment in Bangladesh (Bushamuka et al., 2005; Patalagsa et al., 2015), but there is need to test this in other countries as well.

4.3. School meals

School meals provide a good entry point for influencing children's diets; recent studies provide sound evidence for their nutritional impact (Global Panel, 2015; Kristjansson et al., 2006). Nutritional benefits can be increased when school meal programs include fresh fruit and vegetables alongside food staples, pulses, vegetable oil, dairy and meat. Brazil has made local procurement of fresh foods a critical element of school meal programs (Sidaner et al., 2012). There is much recent interest in home-grown school feeding to link school meals to procurement of commodities from local farmers (Gelli et al., 2010; World Food

[7] http://www.nhs.uk/Livewell/5ADAY/Pages/5ADAYhome.aspx.

Programme, 2009), but there is still little evidence that this can effectively complement school meals with fresh fruit and vegetables. The opportunity for the education, health and agriculture sectors to effectively work together for the benefit of children and local farmers alike is one that is beginning to be realized.

School garden programs—involving a combination of nutrition and health education with hands-on experience in gardening—is one such integrated approach to influencing children's food behavior toward healthier food choices, including fruit and vegetables. School garden interventions aim to expose children at a young age to fruit and vegetables and to develop eating habits and food attitudes during childhood that may persist through to adulthood. Despite being a popular intervention in high- and low-income countries alike, the evidence basis for achieving these goals is thin. The World Vegetable Center recently evaluated the combined impact of school gardens linked to complementary lessons and promotional activities about gardening and nutrition among 10- to 15-year-old school children in Bhutan and Nepal (Schreinemachers et al., 2017a, 2017b). These studies found a significant increase in children's awareness and knowledge about fruit and vegetables and their stated preferences for eating fruit and vegetables, but no significant improvements in fruit and vegetable consumption or nutritional status. The same has been observed in a recent systematic survey of the impact of school gardens in high-income countries (Ohly et al., 2016). This suggests that school garden interventions alone are unable to achieve better quality diets and in low income countries may require strong linkages to school meals or home garden programs.

4.4. Modifying food systems for better nutrition

There is growing recognition that current food systems are not resulting in increasingly healthy, high-quality diets (Global Panel, 2016). Agricultural policies are strongly biased toward increasing productivity of the food crops (cereals, roots, and tubers) that serve as the primary source of calories, especially for low-income consumers. But, as incomes increase, foods with added sugars, fats, and salt are added to the diet and nutritional quality suffers. Further, the consumption of processed, or even ultra-processed, foods and beverages is increasing fast, even in rural areas (Tschirley et al., 2015). While these foods are convenient and often more affordable than fresh and more nutrient-rich foods, they do not support the kind of diverse, nutritionally-adequate diets that are required for health. Micronutrient malnutrition levels, therefore, remain high and overweight and obesity are increasing in low- and high-income countries alike.

Pingali (2015) and others have noted the growing disconnect between agricultural policies, public funding priorities, and contemporary nutritional challenges. However, a number of nutrition-sensitive policy initiatives that have been launched at various levels provide new opportunities to re-engage, e.g., through the formulation of national dietary guidelines, the Scaling Up Nutrition (SUN) movement founded in 2010, and by partners in Nutrition for Growth. Evidence of insufficient dietary intake of micronutrients, for example, has led to efforts to mandate fortification of processed foods or to biofortify staple foods that are widely consumed by low-income populations as well as to deliver micronutrients as supplements through the healthcare system. Such interventions are important for addressing immediate micronutrient deficiencies, but long-term solutions must be sought in food and agricultural systems that supply people with the diverse range of safe, nutritious foods essential for healthy diets.

5. Conclusion

Vegetables are nutritional powerhouses, key sources of micronutrients needed for good health. Vegetables add diversity, flavor, and nutritional quality to diets. A strengthened focus on vegetables may be the most direct and most affordable way to deliver better nutrition for all. Vegetables are also economic engines for productive, profitable agricultural economies. Intensified vegetable production has the potential to generate more income and employment than other segments of the agricultural economy, making vegetables an important element of any agricultural growth strategy.

Today, however, neither the economic nor the nutritional power of vegetables is sufficiently realized. The longstanding focus on staple food crops must be adjusted to take in a broader view. Governments and donors need to raise the priority given to increasing the productivity of vegetable production systems, reducing postharvest losses, and increasing affordability and market access. Measures to ensure that vegetables are safe are fundamental. With a growing understanding of the linkages between dietary quality and health, policymakers must also be prepared to support additional interventions to promote vegetable consumption. Elimination of the persistent gap between recommended and actual intakes of vegetables would go a long way to achieving the Sustainable Development Goals related to improving food and nutrition security and good health.

Now is the time to direct increased attention to the vegetable sector, providing increased opportunities for generating employment and income, especially for new entry and smallholder farmers, as well as promoting more diverse, healthy, high-quality diets for all.

Conflict of interest

P. Schreinemachers and M.C.S. Wopereis are staff of the World Vegetable Center. E.B. Simmons is a member of the Global Panel on Agriculture and Food Systems for Nutrition and a former member of the Board of Directors of the World Vegetable Center.

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