Chapter 6

The Role of Vegetables in Asia's Food and Nutrition Security

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1. Introduction

There are an estimated 150 species of vegetables cultivated in Asia [Ma *et al*., 2009]. Major vegetables (e.g. tomato, chili and pepper, onion, cabbage, and cucumber) and vegetables of sub-regional importance (e.g. pumpkin, bitter gourd, mungbean, vegetable soybean, okra, kangkong, amaranth) are terrestrial herbaceous plants, whereas other vegetables include aquatic plants (e.g. water bamboo, watercress, lotus); lower-vascular plants (ferns); ocean algae (e.g. kelps, seaweeds); and saprophytic fungi (mushrooms). Edible plant parts include sprouts, seedlings, leaves, petioles, heads, fronds, stems, pseudo-stems, non-starchy roots, rhizomes, corms, non-starchy tubers, bulbs, flowers, fruits, seeds, and fungal fruiting bodies that contain diverse types and different concentrations of beneficial compounds. This enormous diversity of vegetables in Asia is a great asset; it provides many opportunities to adapt to local growing conditions, adding color, flavor, nutrients and health qualities to people's diets [Rubatzky and Yamaguchi, 1999].

Vegetables have tremendous nutritional value. They provide important sources of essential micronutrients (vitamins and minerals), plant-based proteins, edible fibers and antioxidants, all of which are vital to healthy development, disease prevention, and wellbeing. For instance, the antioxidant properties of phytochemicals inherent in various vegetables have protective functions against the oxidation of omega-3 oils, essential for good health [Cheng *et al*., 2022]. An adequate vegetable intake therefore helps to protect against malnutrition in all its forms, as well as against chronic and non-communicable diseases. The World Health Organization (WHO) recommends a daily minimum fruit and vegetable (F&V) intake of 5 portions or 400 g per adult per day, including at least 3 portions of vegetables (~240 g) [WHO/FAO, 2003]. The EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems and the Global Burden of Disease study [Afshin *et al*., 2019] even recommended daily mean intakes of fruit and vegetables of 300 g and 360 g, respectively.

Globally, dietary risks are among the top-5 global health risk factors, with over 3.5 million deaths and 99 million Disability-Adjusted Life Years (DALYs). Each DALY represents the loss of the equivalent of one year of full health attributable to poor quality diet [Afshin *et al*., 2019]. However, the reality is that 3 billion people on our planet are unable to afford a healthy diet. More than half of them (1.9 billion people) live in Asia - the majority in South Asia (1.3 billion people, 57% of the South Asia population), followed by Southeast Asia (0.32 billion, 46% of the Southeast Asia population) and East Asia (0.23 billion, 16% of the East Asia population). This is strongly related to the cost of food with dairy, F&V and protein-rich foods accounting for more than 79% of the cost of diets across Asia [FAO *et al*., 2021].

Asia's population is affected by multiple forms of malnutrition - hunger, hidden hunger (lack of micronutrients) and overweight and obesity. Half of the world's undernourished people are living in the Asia and Pacific region (about 351M people): South Asia counts the largest number (257M), followed by Southeast Asia (65M) while the numbers in East Asia are very small [FAO *et al*., 2021]. These numbers have fallen rapidly since the 1990s and the burden of hidden hunger, measured in DALYs, has surpassed that of chronic hunger across Asia. South Asia has the highest burden of hidden hunger of all regions in the world [Lenaerts and Demont, 2021]. For example, 56M children under five years of age affected by stunting (one dimension of hidden hunger) are living in South Asia [FAO *et al*., 2021].

Because of the rapidly increasing consumption of highly processed food and consumption of salt, sugar and sugar-sweetened drinks, malnutrition has increased in all Asian countries over the last 20 years. Overweight and obesity now affect between 20% and 55% of adult populations in Asia. This has become an enormous public health issue. Diabetes alone is associated with US$ 321 billion of economic loss in East Asia and the Pacific in 2015 and is projected to reach US$ 800 billion by 2030. Comparative figures in South Asia are US$ 26 billion, projected to reach US$ 84 billion by 2030 [Bommer *et al*., 2018].

Besides their importance for healthy lives, vegetables are also important to raise the living standards and resilience of smallholder farmers and other actors along the vegetable value chain. Vegetables can be grown on small spaces and profits per hectare are 3-14 times higher in vegetable production than in rice production [Schreinemachers *et al*., 2018]. However, Asia's agriculture remains strongly rice-based (and based on wheat in parts of South Asia). While rice production is key to national food security, most rice farmers have remained poor and food insecure as productivity growth has been accompanied by price declines benefiting consumers rather than producers [Timmer, 2009]. Given that vegetables can be grown on relatively small areas of land and are labor intensive, opportunities for jobs and income generation are important considerations in particular in low- and middle-income countries.

The objective of this chapter is to: (*i*) describe the diverse and colourful world of vegetables in terms of varieties, production systems and diets in Asia and the drivers of change; (*ii*) analyze how to reduce the vegetable dietary gap across Asia, enabling healthier lives, with maximum benefits to people's livelihoods and with minimal environmental footprint; (*iii*) highlight enablers and constraints related to the policy and decision-making environment; and (*iv*) reflect on future prospects related to the role of vegetables to boost food and nutrition security in Asia. While the chapter focuses on vegetables, many of the issues equally apply to fruit.

2. Status of Vegetables in Asia

2.1 Production

The total value of vegetables produced worldwide, measured at farmgate prices, was 568 billion US dollars in 2020 according to FAO estimates [FAOSTAT, 2022]. Asia accounted for 78% of this value (Figure 1), or a total of 441 billion US dollars from a harvested area of 19.5 million hectares and a production volume of 332.3 million tons. However, mainland China dominates production in Asia as well as globally. Mainland China accounted for 57.4% of global vegetable production by value, 37.3% by area, and 45.5% by volume, although the country only accounts for 20.0% of global population.

The rise of China's vegetable production, as documented by FAO data, has been phenomenal (Figure 2A). China's vegetable production expanded at a mean growth rate of 5.7% per annum over the period 1990-2020, while this was 2.8% for the rest of Asia, and 1.5% for the rest of the world. Factoring in population growth (Figure 2B), China's growth in vegetable production remains impressive while there is hardly any increase for the rest of Asia or for the rest of the world. While China exports vegetables to other countries in Asia, FAO Food Balance data suggest that only about 2% is exported.

2.2 Diversity in varieties

Asia has an incredible range of vegetable species and varieties grown in diverse production systems and climates, resulting in a vast diversity of local dishes. Asia is an extremely rich source of vegetable origin and diversity. Central Asia and West Asia are the centers of origin for carrot, garlic, onion, peas, broad bean, and spinach; East and Southeast Asia for Asian types of amaranth, bamboo shoot, various subspecies of *Brassica rapa* (Chinese cabbage), kangkong, radish and vegetable soybean; and South Asia for bitter gourd, cucumber, eggplant, Malabar spinach, sponge gourd, wax gourd, and yardlong bean [Siemonsma and Piluek, 1993]. However, some of the most widely grown vegetables in Asia find their

origin in other regions of the world, such as green bean, pepper, tomato, okra, pumpkin, and various sub-species of cabbages (*B. oleracea*).

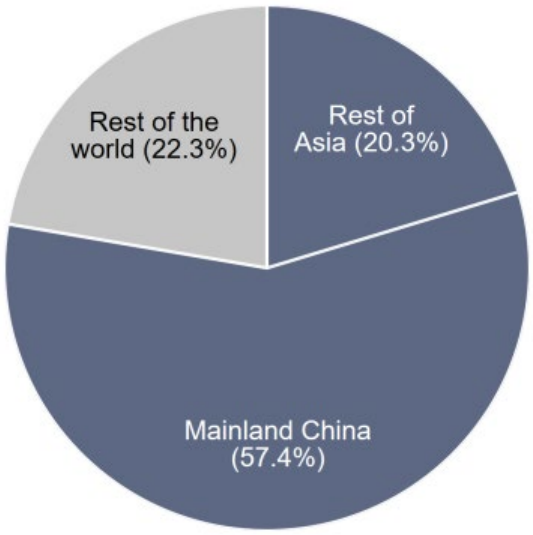

Figure 1. Share of Asia in global vegetable production

Note: Based on Gross Production Value (current thousand US$) for 2020. Vegetables in FAOSTAT include melons and mushrooms. Source: FAOSTAT [2022]

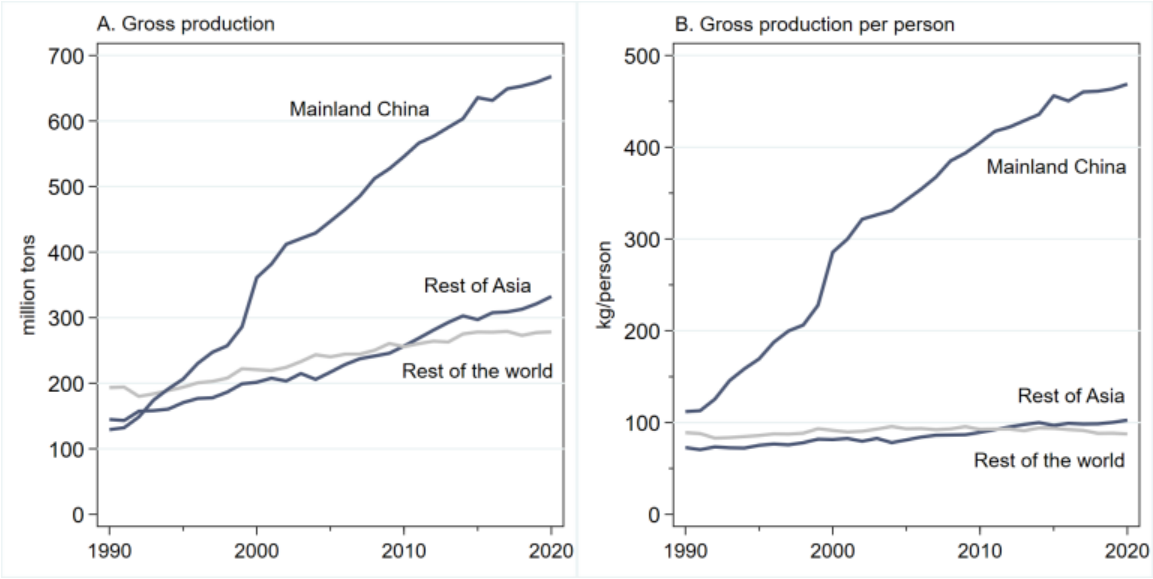

Figure 2. The role of Asia in global vegetable production by volume from 1990-2020: gross production (A) and gross production per person (B)

Note: Based on production volume (tons). Vegetables in FAOSTAT include melons and mushrooms. Source: FAOSTAT [2022]

Vegetables are an attractive food group for farmers to diversify food production systems at farm and landscape level to make food supply more climate-resilient and nutritious because they require little space, have short rotations, and offer high-value products [van Zonneveld *et al*., 2020]. However, little research has been carried out on climate stress tolerance in vegetable species compared with species from other food groups such as grain legumes, cereals, and fruit trees [van Zonneveld *et al*., 2020]. A meta-analysis of experimental studies calculated a one-third yield reduction in vegetable crops if water availability dropped by 50% or if temperature increased by 4 degrees Celsius while the combined effects of heat and water scarcity likely leads to even more severe reductions in vegetable yield [Scheelbeek *et al*., 2018]. At the same time, preliminary results from environmental niche modeling show that many commercial and traditional vegetables have been grown in a wide range of environments; this diversity provides a wealth of vegetable crop choices for tailored adaptation of local food production to changing climates [van Zonneveld *et al*., 2023]. This diversity can be further evaluated in different environments to better understand the agronomic and physiological responses of vegetable crops to different climate stresses [van Zonneveld *et al*., 2020]. These evaluations allow to select crops that are best-bet options for diversification and to identify germplasm that is promising to develop more climate-resilient varieties [van Zonneveld *et al*., 2023].

The World Vegetable Center (WorldVeg) holds the largest international and public collection of vegetable germplasm in its genebank in Taiwan. Of its total collection of close to 65,000 accessions (November 2022), 37,092 accessions come from Asia, covering 280 species, and representing 38 countries. Of these, 9,023 accessions of 226 species representing 16 countries were collected directly by WorldVeg and partners in these countries. Many of these may no longer be found in their places of origin. Vegetable biodiversity in Asia is rapidly declining in farmers' fields and natural ecosystems [Pilling *et al*., 2022; Schunko *et al*., 2022] while it is poorly conserved *ex-situ* and therefore at risk to be lost [van Zonneveld *et al*., 2021]. The decline is a result of multiple factors, which include overexploitation of local food plants, natural and diversified farm land being taken out of production because of urbanization and industrialization, and because of a gradual homogenization of consumer preferences and diets leading to reduced emphasis on a diversity of vegetable crops [Pingali, 2007; Khoury *et al*., 2022; Schunko *et al*., 2022], although this is not seen in all Asian countries (see below). In specific countries and in local societal settings, people continue to eat a diverse set of vegetables [e.g. Xu *et al*., 2004; Sthapit *et al*., 2008].

This reduction in diversity is narrowing the range of options to select new vegetable crops or breed new varieties providing resilience to climate change (e.g. tolerance to heat, resistance to pests and diseases, enhanced shelf life) or providing better health and nutrition benefits for different segments of

the Asian population. This is a major concern that requires concerted action at country and regional level, to rescue, safeguard and use vegetable biodiversity, either directly or in breeding programs.

Many farmers in Asia nowadays buy vegetable seed supplied by seed companies, in particular improved varieties of global vegetables. For instance, it is estimated that in India, F_1 hybrids now occupy about 70% of the vegetable market by value [Schreinemachers *et al*., 2021]. Asia counts a large number of seed companies. The Asia and Pacific Seed Association is the largest association of private seed companies in the world with over 500 members. Vegetable seed is the most important business for most of these companies.

With climate change, heat tolerance and resistance to increasing and newly emerging pest and disease pressure is becoming increasingly important. WorldVeg monitoring data show that its vegetable collection is used as a source for climate resilience by at least 43 seed companies, members of the WorldVeg-Asia & Pacific Seed Association consortium [Schreinemachers and Lin, 2022]. Informal seed systems, such as farmer to farmer exchange are also important in particular for more traditional Asian varieties and their complementarity to formal vegetable seed systems needs further study.

2.3 Diversity in systems

Commercial vegetable production systems in Asia range from rainfed open field cultivation to plant factories, resulting in vastly different performance in terms of productivity, product quality, length of growing season and environmental footprint. Vegetable production in Asia is mostly from open field production; however, there are enormous differences between countries. Open field production in tropical Asia is often subject to climate variability and change of elevated temperature, storms, heavy rainfall, flooding, drought, etc. that impact vegetable growth and development, and increase biotic stresses such as diseases and pests on the vegetable value chain. To overcome these stresses, protected cultivation such as greenhouses is often used for growing vegetables.

Taking tomato as a proxy, compared to open-field production, high-tech greenhouses resulted in 6.4 times more yield per unit area [Maureira *et al*., 2022]. Scarcity of water and land, and abundant capital drives a country like Singapore towards vertical farming, and plant factories. For a country like India, capital is most limiting, therefore expansion of vegetable production will have to come from field-based production, with the exception of production in urban areas – where vertical farming and plant factories are taking off.

Asia has approximately 0.2M hectares of greenhouses, based on international greenhouse vegetable production figures in 2018 [Hickman, 2019]. Nearly half of the world's greenhouse vegetable

area is located in Asia, most of these can be found in China, Japan, South Korea and Taiwan. Singapore plans to expand vegetable production through indoor farms and rooftop gardening, using hydroponics and aeroponics cultivation techniques [Klein-Hessling and Zimmermann-Loessl, 2021].

Plant factories are also increasingly common, currently focusing mostly on leafy vegetables such as lettuce, spinach and other leafy greens. Efforts are being made to popularize the commercial production of head vegetables with plant factories [Kozai *et al*. 2022]. These factories may gain in prominence if they could focus on health promoting vegetable crops, or crops produced for a specific nutrition or health product.

The environmental footprint of vegetable production is a major concern, even for open field systems. Commercial vegetable production is associated with the intensive use of mineral fertilizers and pesticides. For greenhouse production, the construction itself, the media used to grow vegetables, and climate control (cooling or heating) and artificial lighting contribute to greenhouse gas emissions. Agricultural plastics are widely used in horticulture, often for one-time use (e.g. for mulching), and may lead to the accumulation of microplastics in soil and water resources, creating a food hazard [Conti *et al*., 2020].

Life cycle analysis comparing environmental footprint for vegetables, from the production of inputs all the way to the consumer in Asia are rare. Evidence from Australia for tomatoes showed that carbon and water footprint varied considerably depending on the season and the type of production system used. In the case of field-grown tomatoes, transportation to the market contributed most to the carbon footprint, while for greenhouses it was artificial heating [Page *et al*., 2012]. A study by Li *et al*. [2022] showed that 27% of greenhouse gas emissions from total freight miles are related to food miles. Fruit and vegetables (transported at high tonnage and requiring temperature control) contribute more than a third of global food-mile emissions. For nearly all regions, emissions related to food miles of F&V were greater from domestic transport than from international transport.

In many parts of Asia, poor road conditions, lack of refrigerated transport, poorly designed market infrastructure (often without cold storage facilities) and large distances between farmers, processors and consumers lead to high losses. Postharvest losses in the vegetable sector are typically large, ranging from 30 – 50% of farm production [FAO, 2011]. Market gluts may also cause farmers being unable to sell their produce.

Because of rapid urbanization, consumer behavior in Asia is shifting towards convenience food. These trends create opportunities for farmers and other actors in the value chain to supply urban markets and add value through processing and target higher-value market segments, e.g. plant-based substitutes

for animal-sourced products. This may also lead to reduced losses. Cutting back on losses and waste and reducing the distance between producers and consumers will also bring down the environmental footprint as is the use of renewable energy for storage and processing. Processing, and more durable packaging and greater usage of coproducts can reduce food losses and waste. Wastage of processed F&V is 14% lower than that of fresh F&V [Poore and Nemecek, 2019].

A substantial quantity of vegetables comes from home gardens or is collected from the wild. The quantities can be very substantial in some countries but are usually not reflected in official data. The home garden production of vegetables makes a tremendous yet undervalued contribution to food and nutrition security. Evidence is strong that the promotion of home gardens through training in gardening and nutrition increases household production and consumption of vegetables [Schreinemachers *et al*., 2020; Baliki *et al*., 2022; Depenbusch *et al*., 2022]. The COVID-19 pandemic has raised the interest in this type of cultivation, not just for consumption but also because gardening can contribute to relieving stress in people's busy lives.

Although some efforts are made by Asian governments, more needs to be done to promote greater diversity of production systems, using environmentally safe and sustainable practices. More diversified systems can improve soil health, reduce environmental footprint, while increasing the availability of vegetables. They also contribute to increased economic opportunities and have a great potential to enhance resilience against climate change and different types of shocks.

2.4 Diversity in diets

Many Asian dishes traditionally contain a wide variety of vegetables. Preparation methods of vegetables vary depending on the local cuisine. They can enhance or reduce the nutrition quality of vegetables eaten [Fabbrin and Crosby, 2016]. While some Asian cultures eat fresh vegetables as salads, the vast majority of vegetables are cooked. Cooking methods include cooking and blending as a puree, blanching in boiling water or steam, stir-frying with oil or water, battering and deep-frying, sautéing, roasting, broiling, boiling as a soup, etc. Many vegetables are also processed - e.g. pickled, fermented or dried - to transform perishable produce into stable foods with long shelf lives.

Unhealthy diets lacking fruits, vegetables and other nutrient-rich foods are among the major drivers of illness and death globally, underpinning 11 million deaths worldwide each year [Afshin *et al*., 2019]. Low vegetable consumption is a global problem affecting high- and low-income countries: only 5% of people in low-income countries meet WHO fruit and vegetable recommendations of 400g per person per day, and only 27% of people in upper-middle-income countries do [Frank *et al*., 2019].

As incomes rise in Asia, the consumption of meat and ultra-processed food often takes precedence over nutritious foods like vegetables. The expanding market share of large international food companies producing ultra-processed foods and beverages and their aggressive marketing and sales strategies is a key driver of the nutrition transition away from traditional diets. There are also food safety concerns related to pesticide residues that dissuade consumers from buying fresh vegetables [e.g. Ha *et al*., 2020]. However, with rapid urbanization in Asia, a growing middle-class is also becoming more demanding in terms of quality food, which opens up, in principle, economic opportunities for vegetable value chain actors, from seed companies, farmers, to processors and retailers.

3. Boosting Vegetable Supply and Intake

Consumption patterns, climates and socio-economic settings in Asia differ greatly and this has important consequences for pathways to closing dietary gaps. Diets are moving away from vegetables and towards highly processed unhealthy food. In many urban areas in Asia quality and healthy fresh food items are not easily accessible or affordable to all.

3.1 Boosting supply

Asia's population is projected to grow from 4.72 billion in 2022 to 5.29 billion in 2050, with the share of the urban population growing from 52% in 2022 to 66% in 2050[1]. Mason-D'Croz *et al*. [2019] estimated dietary gaps in F&V consumption between 1965 and 2015 for 150 countries by comparing the minimum F&V intake recommended by WHO of 400 g per capita per day and F&V availability based on FAOSTAT commodity balance sheets[2] and the IMPACT simulation model developed by the International Food Policy Research Institute. Only 5 countries (out of 22) in the East Asia and Pacific region had greater F&V availability than 400 g per person per day in 1965. This increased to 12 (out of 23) by 2015, representing 1.9 billion people (out of 2.2 billion, so 86%), for which F&V are available in their countries, although not necessarily accessible and affordable. The situation was very different for South Asia. None of the South Asian countries in 1965 had sufficient F&V availability compared to the 400 g target – and although average F&V intake levels increased substantially to an average of 326 g per person per day, the situation was the same in 2015, representing 1.7 billion people with insufficient F&V availability. There are, therefore, huge differences in terms of dietary gaps when it comes to F&V across Asia, with East Asian

[1] https://ourworldindata.org/ accessed on 13 July 2022.

[2] FAO commodity balance sheets do not include waste from retail to consumer and neglect F&V not commonly traded or grown for home consumption. They also do not account for intra-country variation and production levels of F&V are highly aggregated.

countries generally best positioned. Because the majority of Asia's population growth towards 2050 will occur in South Asia this trend will be amplified in the future. These results underline the need for policies and incentives adapted to local contexts that enhance F&V availability, accessibility and affordability, by enhancing year-round production and reducing losses and waste.

In higher-income countries, vegetables are mostly produced in high-input field systems, often protected with insect-proof nets and/or plastic roofing and use of plastic mulch or produced in polyhouses or greenhouses near cities. Because yield levels are generally high, boosting local production can be achieved through area expansion, either vertically in urban areas or horizontally in peri-urban and rural areas. In high-input field-based systems, the environmental footprint is often of great concern. Agroecological approaches, such as the introduction of biocontrol measures, cover crops, crop rotations and strip cropping (two or more crops grown side by side in narrow strips) increase diversity, enhance soil and plant health and can lead to reduced reliance on chemical pesticides and fertilizers. Introduction of traditional Asian vegetables that are generally more robust and nutritious than global vegetables may further cut back on the need to use external inputs.

In lower-income countries, vegetable yield levels are often far below what would be possible under optimal management conditions. Here, vegetable production can be enhanced by introducing improved varieties, or sturdy traditional Asian vegetables, which are better adapted to local growing and market conditions, and introducing improved management practices, thereby increasing yields per m^2 surface area per day, and/or lengthening the growing season. A study for Bangladesh showed that training farmers in off-season vegetable production increased their seasonal income by 48% [Schreinemachers *et al*., 2016]. Ideally, agroecological approaches should be combined with judicious use of external inputs. There are major opportunities for producing vegetables in the off-season or replacing lower value crops such as cereals with higher-value vegetables. This will often require introducing protected cultivation measures that reduce risk to the farmer and allow to intensify and/or diversify production in space and time. It will also require improvements in market functioning and postharvest practices. The best approach will be very context specific. Protecting crops with polyethylene film and insect-proof nets reduce incoming radiation by about 20% and increase air temperature by 4% and 10% respectively [Nordey *et al*., 2017]. This may open up opportunities to cultivate vegetables in colder climates or growing seasons, but may require varieties that are more tolerant to heat stress. Climate change may also require farmers to adopt heat tolerant and pest and disease resistant varieties or different vegetable crops altogether.

Across Asia, reducing losses and waste from field to fork will have a major positive effect on availability. Moreover, having significant losses and waste of food means that all efforts to produce vegetables are in vain. This represents an unnecessary burden to the environment, and a loss of nutritious food and economic opportunities.

Food safety is a major concern for Asian consumers and is mostly related to fear of pesticide residues [e.g. Ha *et al*., 2019, 2020; Wertheim-Heck *et al*., 2014 for Vietnam]. Overuse of pesticides in vegetable production is common in Asia [Schreinemachers *et al*., 2017], leading to health risks for farmers, consumers and the environment. However, microbial contamination is another and often greater threat that often becomes more prominent moving from the field to storage, wholesale and retail markets. Vegetables produced in urban contexts may also be contaminated with heavy metals, in particular if fields are close to roads or factories. It is critical that vegetables can be traced along the supply chain back to the producer to instill trust in local produce by local consumers. The shorter the supply chain and the distance between producer and consumer the easier this will be.

3.2 Stimulating intake

Focusing solely on increasing the availability of vegetables would not be a wise strategy, given that current dietary trends show little to no increase in vegetable consumption despite income growth, while the consumption of ultra-processed food is increasing rapidly - associated with a range of health risks such as type 2 diabetes, heart disease, and cancer. In general, much work will need to be done in Asia to stimulate the intake of vegetables as a strategy to fight malnutrition. Overweight and obesity affect both urban and rural populations.

While marketing campaigns can influence consumer behavior, there is little evidence that large-scale marketing of vegetables is effective to create long-term changes in food behavior. Besides, investments in the marketing of ultra-processed foods with high profit margins would always dwarf public investments in healthy eating campaigns. While nutrition literacy is important to stimulate healthy eating, it will need to be combined with restrictions on how ultra-processed food is marketed.

Key challenges are to make vegetables more affordable (cheaper without compromising on quality), more widely accessible, and more acceptable and desirable. Food safety concerns (related to microbial contamination and pesticide residues) need to be addressed. Healthy vegetable preferences in children can be developed through taste exposure, sensory learning, food preparation, and nutrition education. WorldVeg and other organizations have shown that home and school gardens are one effective approach to accomplish this. A study in Nepal showed that children’s vegetable intake increased after

setting up vegetable gardens in schools and training both children and their parents in gardening and nutrition [Schreinemachers *et al*., 2020]. Training rural low-income people in gardening has also shown to be effective in various countries such as Bangladesh, Cambodia, and India.

More innovations are needed in food environments so that these enable healthier eating. This may involve stimulating procurement of F&V for schools, canteens, hospitals, and prisons; price subsidies for F&V; or zoning and market regulations, e.g. banning sale of unhealthy food items in a radius of 500 m around schools. Another possibility is to bring vegetables closer to consumers, e.g. by designing new retail options, such as door-to-door delivery, mobile vendors, etc. One can also think of more prominent places for F&V in shops, canteens. It is critical to create and promote more attractive ways to present and prepare vegetables to increase desirability and stimulate demand.

3.3 Enabling policy

Food systems policy decisions shape how vegetables are available, accessible, desirable and affordable over time. Policies in Asia related to vegetables are mostly geared towards facilitating export and generating income. Governments need to be encouraged to design national F&V strategies that focus on the health of local consumers and livelihoods of small-scale farmers rather than export earnings. In Thailand, the government is increasingly interested in food systems approaches to healthy diets, evidenced by multiple events and commitments around the 2021 United Nations Food Systems Summit and national dialogues organized by the Ministry of Agriculture and Cooperatives. This included a debate on the need for Thailand to adopt a sustainable vegetable policy [https://summitdialogues.org/dialogue/15703/].

Thailand is also one of the few Asian countries that introduced a tax on sugar-sweetened beverages in 2019. Yet what is often lacking is evidence through which policy actors can decide on appropriate changes to support vegetable food systems towards healthy diets. It is critical to fill that evidence gap and accompany governments in the development and implementation of concrete action plans. Another priority is to boost investments in vegetable R&D to stimulate supply of and demand for safe locally produced vegetables. For both national and international research, the fraction allocated to vegetables and other nutritious foods, like fruits, nuts and pulses is extremely low [Schreinemachers *et al*., 2018]. There is an urgent need to shift the focus of food policies and research investments from ‘calories’ to ‘diet quality’.

To nourish Asia’s growing urban population with safe locally produced vegetables there will be a need for innovative policies and incentives to protect peri-urban agricultural land as a vital resource for

vegetable production that are free from contaminants from urban waste. The city of Beijing (China) as part of its Urban Master Plan preserves farmland and green spaces and has designated permanent green areas in city fringes and corridors [Dubbeling *et al.,* 2019]. Singapore actively promotes high-tech indoor farming next to leasing out plots of land across the city to encourage people to grow food [https://www.fairplanet.org/story/passion-for-urban-farming-takes-singapore-by-storm/].

Investments are also needed in wholesale and retail market infrastructure to ensure vegetables can be cleaned, sorted and stored safely with renewable energy, as well as applications of new technologies to improve traceability of vegetables for food safety. To boost the availability and affordability of vegetables, policies are needed that promote investments in off-season horticulture, aggregation, processing and storage facilities as much as possible using durable and recyclable materials and green energy sources.

Much more attention is also needed for traditional Asian vegetables, getting them on the policy agenda, on the R&D agenda, on the farm, and ultimately on the plate. Breeding efforts also need to expand for controlled environment conditions to enhance the diversity of vegetables produced through indoor farming.

4. Conclusions

Vegetable production in Asia will need to increase substantially to close dietary intake gaps and cater for population growth. There is a tremendous need for innovation and targeted action at multiple levels. This requires addressing the huge research funding disparity at national and international levels that still focuses largely on the big staples and not on nutritious food and to redirect agricultural subsidies towards healthy food systems.

Transforming food systems towards a healthier and more sustainable diets, requires partnerships among international development organizations, international agricultural research centers like WorldVeg, governments, private sector, national agricultural research systems and civil society to encourage and support innovation, infrastructure development and extension services. These partnerships involve coordination and leveraging private- and public-sector resources toward strengthening the vegetable sector and shortening the time to impact from R&D.

Current production systems carry a heavy environmental footprint and are the cause of food safety issues. Vegetable producers in Asia must be enticed to embrace greener and safer ways of production and investments in market and transport logistics and infrastructure must be made to cut back on losses and waste, and consciously reduce the carbon footprint of vegetable supply chains. Vegetable

waste can be valorized, e.g., by conversion into biofertilizer, animal feed, bioenergy fuels, chemicals and compounds of high value, and for use in soft drinks.

Vegetables are valuable in monetary terms. However, beyond their economic value, these foods are not sufficiently prioritized in people's diets. There is a need to better understand consumers' preferences and behaviors with respect to vegetables and what incentives might increase consumption in different contexts. Governments can make a start to value vegetables more as part of a healthy diet, rather than just focusing on economic value and exports. National horticultural policies and strategies must focus on domestic consumption, and ideally such policies should link with public health policy. Much more attention is also needed for traditional Asian vegetables.

The health and economic burden of unhealthy diets is enormous. The consumption of ultra-processed foods is likely to rise in many countries in Asia and, with it, the burden of many non-communicable diseases. While there is a big need to substantially increase the quantity of vegetables consumed, it will be challenging to even maintain current quantities in some countries. Success in this area will partly depend on governments' ability to restrain the growth in ultra-processed foods.

Last but not least, there is an urgent need to stem the rapid decline in vegetable biodiversity, because much valuable material that current and future generations will need is being lost forever. This diversity must be rescued, conserved and put to good use to transition to healthier lives and a healthier planet.

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