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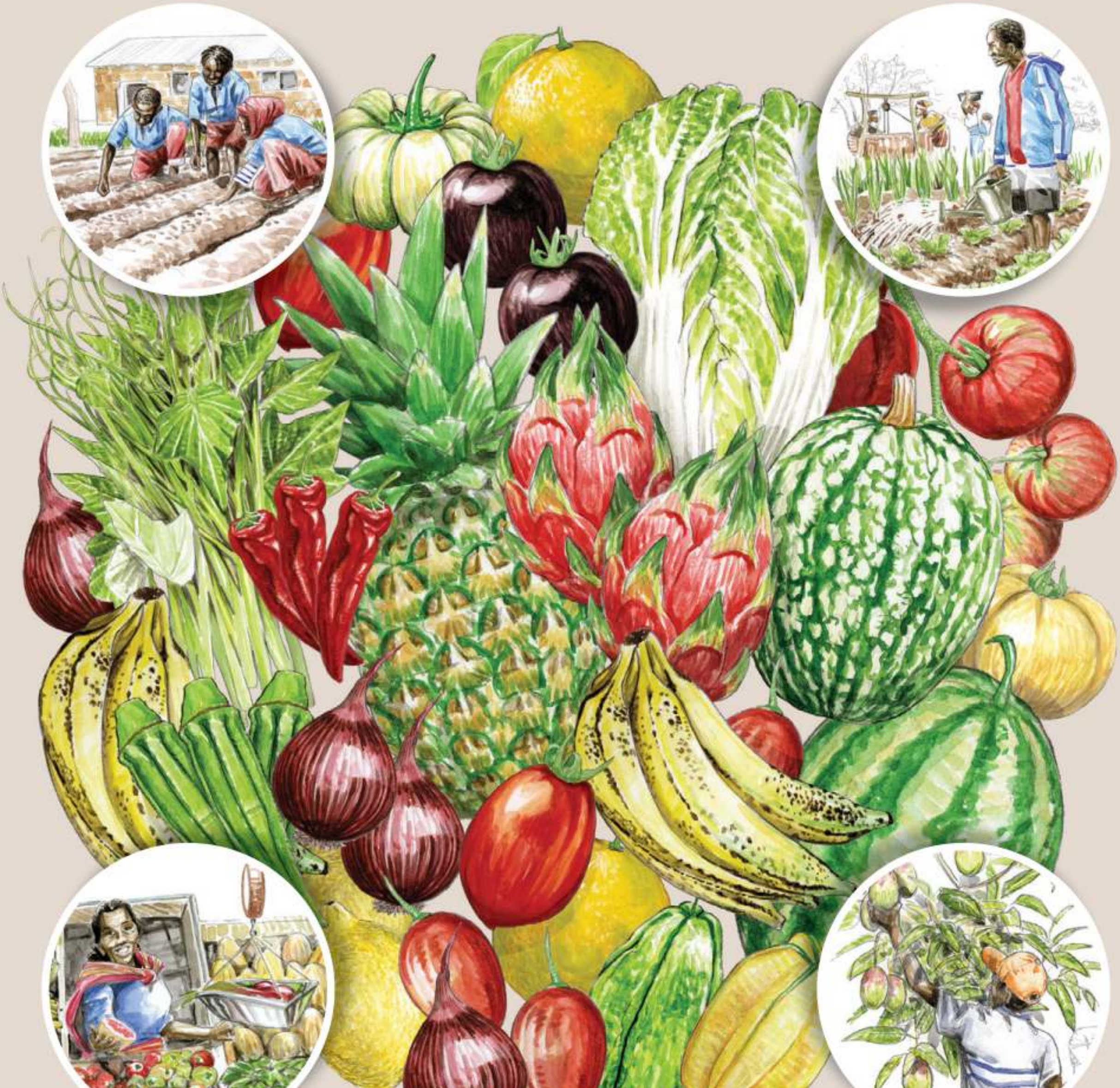

FRUIT AND VEGETABLES

Opportunities and challenges for small-scale sustainable farming

INTERNATIONAL YEAR OF
FRUITS AND VEGETABLES
2021

The UN designated International Year of Fruit and Vegetables 2021, approved in 2019 and formally launched on 15 December 2020 advocates for the importance of healthy diets and lifestyles through sustainable food systems. It also seeks to strengthen the role of small-scale and family farmers in sustainable farming and production practices, accountable for the livelihoods of millions of rural families, and raises awareness of the nutritional benefits of fruit and vegetable, and also of the high levels of food loss and waste in fruit and vegetable supply/value chains. This publication was developed to provide further technical information and policy guidance, with a particular focus on opportunities and challenges for small-scale farmers, for further developing the fruit and vegetable sector towards achieving the SDGs.

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Opportunities and challenges for small-scale sustainable farming

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ACRONYMS

AEAS	Agricultural Extension and Advisory Services
APSA	Asia and Pacific Seed Association
CGIAR	Consultative Group on International Agricultural Research
CIRAD	*Centre de coopération internationale en recherche agronomique pour le développement* (Agricultural Research Centre for International Development)
CRFS	city region food systems
CWR	crop wild relatives
DLT	distributed ledger technologies
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Free database of food and agriculture data
FFS	Farmer Field Schools
GAP	good agricultural practices
GDIC	Green Delta Insurance Company
GMP	good manufacturing practices
ICT	information and communication technologies
IFAD	International Fund for Agricultural Development
IFC	International Finance Corporation
IPM	Integrated Pest Management
IPP	Integrated production and protection
ISHS	International Society of Horticultural Science
MRL	maximum residues levels
NES	not elsewhere specified
NGO	non-governmental organization
NUS	neglected and underutilized species
PAA	Purchase from Africans for Africa
PGS	Participatory Guarantee Systems
QDS	Quality Declared Seed System
SAFTA	*Sistema Agroflorestal de Tomé-Açu* (Agroforestry System of Tomé-Açu)
SDG	Sustainable Development Goals
SOFI	State of Food Insecurity in the World
UN	United Nations
WFP	World Food Programme
WHO	World Health Organization

FOREWORDS

The delicious flavours of fresh seasonal fruit and vegetables are among life's pleasures. Their vitamin, mineral and fibre content keep us well-nourished and healthy.

However, for too many people the availability, affordability and, therefore, the consumption of fruit and vegetables, does not meet recommended daily dietary requirements. The lack of these foods in diets is resulting in widespread malnutrition and is reducing global wellbeing.

Empowering small-scale farmers in low-middle-income countries to increase their production of fresh fruit and vegetables in environmentally, economically and socially sustainable ways is a priority if we are to achieve the Sustainable Development Goals.

Empowering small-scale farmers to sustainably produce more fruit and vegetables is a priority

This mission is supported by the incredible diversity of fruit and vegetables that exist locally, nationally and internationally. Farmers have an array of options when it comes to deciding what to grow, when and where. They can select diversified cropping systems adapted to their environment, pests and diseases, seasons, changes in climate and according to market demands.

Some challenges must be addressed, such as the need for an enabling environment to increase consumer demand for fruit and vegetables. Fruit and vegetables are highly perishable and vulnerable to food loss and waste. To meet demand, farmers must be integrated into stable value chains and city region food systems. This is essential to ensure that harvested produce is kept cool, processed carefully and quickly, and delivered to markets without loss of quality. In addition, since fruit and vegetables are often eaten raw, special attention must be paid to assurances that the food is safe by reducing the risks of chemical (pesticides and mycotoxins) and biological (pest, disease and food-borne pathogen) contamination. Such safety is also important to the regulated markets where fruit and vegetables are traded.

Sustainable fruit and vegetable production is labour, input and knowledge intensive and provides a wealth of opportunities for decent employment opportunities such as for specialized farm inputs, post-harvest services and marketing. Furthermore, the logistics involved in crop calendars, cultivation and harvesting, managing post-harvest facilities, coordinating deliveries, and systems to ensure the traceability of produce, require the expanded use of digitalization data services in both rural and urban areas.

This publication has been prepared to support the United Nations International Year of Fruits and Vegetables, which will encourage the increased consumption of nutritious food to promote a healthy global population and increased wellbeing through thriving food systems with sustainable production practices at their core.

Mrs Beth Bechdol
Deputy Director-General
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Food and Agriculture Organization of the United Nations

CIRAD has a long tradition of research for development in the tropical and Mediterranean fruit and vegetable sector. Its scientific teams are committed to working in partnership with all stakeholders to ensure a sense of ownership of the research results while focusing on the main target, which is to benefit family farming. CIRAD provides a direct response to the issues and concerns of populations, especially agricultural households in the south where they are most vulnerable to climate hazards and to health and economic crises.

Beyond a classical sector approach, mobilizing all its scientific disciplines – from agronomic to human sciences – and its stakeholders – in the public and private sectors and in civil society – CIRAD considers horticulture to be a prime target for studying the agroecological transition, the integration into the concept of "One Health", and the territorial approach.

Fruit and vegetables, and traditional horticultural production systems, encompass an enormous range of cultivated biodiversity, made up of rotations and interrelationships between crops, some of which are known only to farmers. They must be understood and recognized, preserved and improved, together with their creators and farming managers, to contribute to the sustainability of agriculture.

Fruit and vegetables are highly nutritious, and this, among their many benefits, makes them essential for human health. Though people everywhere must be encouraged to eat them, any campaign related to increasing production and consumption must go along with efforts to reduce the health and environmental risks from contamination and pollution as well as efforts to change the poor diets and sedentary lifestyles that often accompany the urbanization of populations.

The perishability of fruit and vegetables has long shaped the technical and spatial organization of food systems in relation to distance to markets. Today, conservation, processing, transportation and packaging technologies, as well as information and communication technologies, are redesigning this structure in view of economic and ecological optimization and food sovereignty.

Even though fruit and vegetables account for the largest share of world trade in value, they make up only a small part of the diets of most women and children, especially in sub-Saharan Africa. These sectors represent the lowest budget for public agricultural research. The International Year of Fruits and Vegetables will be an opportunity for CIRAD and the international community to change this situation and remove the obstacles to developing sustainable horticultural systems.

Fruit and vegetables are highly nutritious, and this, among their many benefits, makes them essential for human health

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PREFACE

There are 690 million undernourished people living in the world today, 750 million people suffering food insecurity, 2 billion people lacking access to safe and nutritious foods and 3 billion people unable to afford a healthy diet. *The State of Food Insecurity in the World* (SOFI) 2020 reports that the burden of malnutrition in all its forms poses a significant challenge to those who suffer it (FAO *et al.,* 2020). According to estimates from 2019, 21.3 percent (144 million) of the world's children under 5 years of age were stunted, 6.9 percent (47 million) were wasted and 5.6 percent (38 million) were overweight. Diets in low-income countries rely more on staple foods and less on fruit, vegetables and animal proteins than in high-income countries. The Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) recommendation of a minimum of 400 g of fruit and vegetables per person per day is only met in parts of Asia and in upper-middle-income countries where sufficient fruit and vegetables are available for human consumption. The global poverty rate is projected to reach 8.8 percent in 2020, rising for the first time since 1998. The impact of COVID-19 is exacerbating these trends and putting vulnerable people even more at risk, which could cause another 132 million people to be added to the global number of undernourished (Kharas, 2020). Restrictions implemented to combat the spread of COVID-19 have reduced the availability of labour for fruit and vegetable production and have limited transport and marketing activities, which has resulted in increased consumer prices for fruit and vegetables. Put simply, the world is not on track to achieve Zero Hunger by 2030 (FAO *et al.,* 2020)!

In order to achieve the 2030 Agenda for Sustainable Development, all United Nations (UN) Members adopted the 17 Sustainable Development Goals (SDGs) in 2015 (**https://www.un.org/sustainabledevelopment/sustainable-development-goals/**) as a universal call to action to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere.

Promoting sustainable crop production is a critical part of FAO's work with partners to contribute to global efforts to achieve the SDGs and is central to realizing FAO's strategic objectives. In particular, the sustainable production of fruit and vegetables requires attention because the current supply does not meet global nutrition requirements (SDGs 2 and 3). Fruit and vegetables are highly perishable, making them a "hot spot" in the fight to reduce food loss and waste (SDGs 2 and 12). The vast diversity of fruit and vegetable crops provides small-scale farmers with greater options for adapting to climate shocks and stresses and mitigating climate change (SDG 13) and environmental and market shocks across different production settings (SDGs 1 and 15). Fruit and vegetables are high-value crops that can be grown on small areas of land, creating economic opportunities for small-scale farmers in rural, peri-urban and urban settings as well as in conflict zones and in fragile contexts (SDGs 1, 3, 11 and 16). Since fruit and vegetables are often eaten fresh or raw, food safety is a critical issue. Promoting good practices in producing, harvesting and post-harvest handling of fresh produce lowers the risk of food contamination (FAO and WHO, 2003) and helps maintain quality, thereby reducing losses (SDGs 2 and 12). Since fruit and vegetable value chains are high value and are labour and knowledge intensive, they can generate on-farm and off-farm employment opportunities and create decent work that is attractive to youth and other vulnerable populations, such as migrants (SDGs 4 and 8). Initiatives to make fruit and vegetable production and supply chains more sustainable can be particularly strategic points of entry for empowering women (SDG 5), since it is traditionally women who produce and handle fruit and vegetables while men focus more on staple crops.

This is a key contribution to the International Year of Fruits and Vegetables

One impetus for the timing of this publication is the designation by the UN of 2021 as the International Year of Fruits and Vegetables. This provides an opportunity to emphasize the important role played by fruit and vegetables in efforts to reduce poverty and malnutrition in all its forms, including: undernutrition (wasting, stunting, underweight), inadequate minerals or vitamins, overweight and obesity resulting in metabolic-related non-communicable diseases. This publication has been prepared as a key contribution to this International Year and in recognition of the critical role played by the sustainable production of fruit and vegetables in achieving the SDGs.

This publication is intended to provide guidance to practitioners and policy makers on sustainable fruit and vegetable production, and value chain management, that is resilient to changes in the climate or in market demand. Such resilience can be achieved by balancing economic, social and environmental objectives to achieve development that meets the needs of the present without compromising the ability of future generations to meet their own needs. FAO's report *Building a Common Vision for Sustainable Food and Agriculture* (FAO, 2014a) describes sustainability in terms of the following five principles:

1. Improving efficiency in the use of resources, including reducing loss and waste, is crucial to sustainable agriculture.
2. Sustainability requires direct action to conserve, protect and enhance natural resources.
3. Agriculture that fails to protect and improve rural livelihoods, equity and social wellbeing is unsustainable.
4. Enhanced resilience of people, livelihoods, communities and ecosystems is key to sustainable agriculture.
5. Sustainable food and agriculture require responsible and effective governance mechanisms.

Fruit and vegetable crops are different from staple crops: they are highly diverse, perishable and nutrient dense

This publication is an evolution of FAO's Save and Grow series. The first, *Save and Grow: A policymaker's guide to the sustainable intensification of smallholder crop production* (FAO, 2011a), followed by *Save and Grow: Cassava* (FAO, 2013a) and *Save and Grow in practice: maize, rice, wheat* (FAO, 2016). These publications set out an approach for meeting three interconnected challenges:

1. providing options for small-scale farmers and the most vulnerable people dependent on agriculture to increase their incomes, wellbeing and resilience;

2. safeguarding and revitalizing the natural resource base (water, land, soil and genetic resources), which is the foundation for global food and nutrition security, but which is being increasingly threatened and degraded by a number of factors, including disasters, climate change and unsustainable agricultural production systems that both harm the environment and threaten public health; and

3. supplying enough safe and nutritious food to meet the demands of expanding and increasingly urban populations whose dietary patterns are changing.

Many of the practices and principles for the sustainable production of staple crops to 1) generate income, 2) protect the environment, and 3) ensure social equity, are also appropriate to the production of fruit and vegetables. Similarly, many of the farmers and their households are coping with high levels of poverty and food and nutrition insecurity and are particularly vulnerable to the impacts of disasters and climate change, increasing water scarcity, pests and diseases, loss of soil fertility and shortage of productive land (due to unsustainable production methods).

However, fruit and vegetable crops are fundamentally different from staple crops. Fruit and vegetables are highly diverse, perishable and nutrient dense. They can generate significantly higher incomes from small units of land, little water and nutrients. Their sustainable production and post-harvest management are knowledge and labour intensive and require high-quality inputs such as seeds and technologies or practices to appropriately manage water, nutrients, soil, pests and diseases and to manage the perishability of the produce prior to reaching market. The high-value market potential and nutrient density of fruit and vegetables are directly linked to how they are produced and handled, and how fresh they are when delivered to markets. This generates unique opportunities for new on-farm and off-farm enterprises to provide high-quality inputs, post-harvest services and market linkages.

The vast diversity of fruit and vegetable crop species and their available varieties offer numerous opportunities for small-scale farmers to produce highly nutritious and high-value crops in their environment. At the same time, it is unrealistic to prepare a ''users guide'' that could be useful for all small-scale fruit and vegetable production systems.

The most appropriate pathway available to small-scale farmers will be determined by the type of crop, variety, cropping system, environmental conditions, local capacities, accessibility to, or proximity of, markets and other challenges, as well as the types of shocks and stresses that might be faced and will necessarily involve making trade-offs to find an inclusive approach to meet social, economic and environmental objectives.

For this reason, this document provides an overview of the general challenges and opportunities for small-scale farmers when starting up or expanding fruit and vegetable production or when integrating these crops into their existing production system. It provides guidance on options to ensure sustainable production, stable value chains and dynamic markets. Wherever possible recommendations are made on how policy makers can create an enabling environment to support a thriving fruit and vegetable sector in their country or region, and these are summarized in Table 4.

With these considerations in mind, this document has been divided into five chapters:

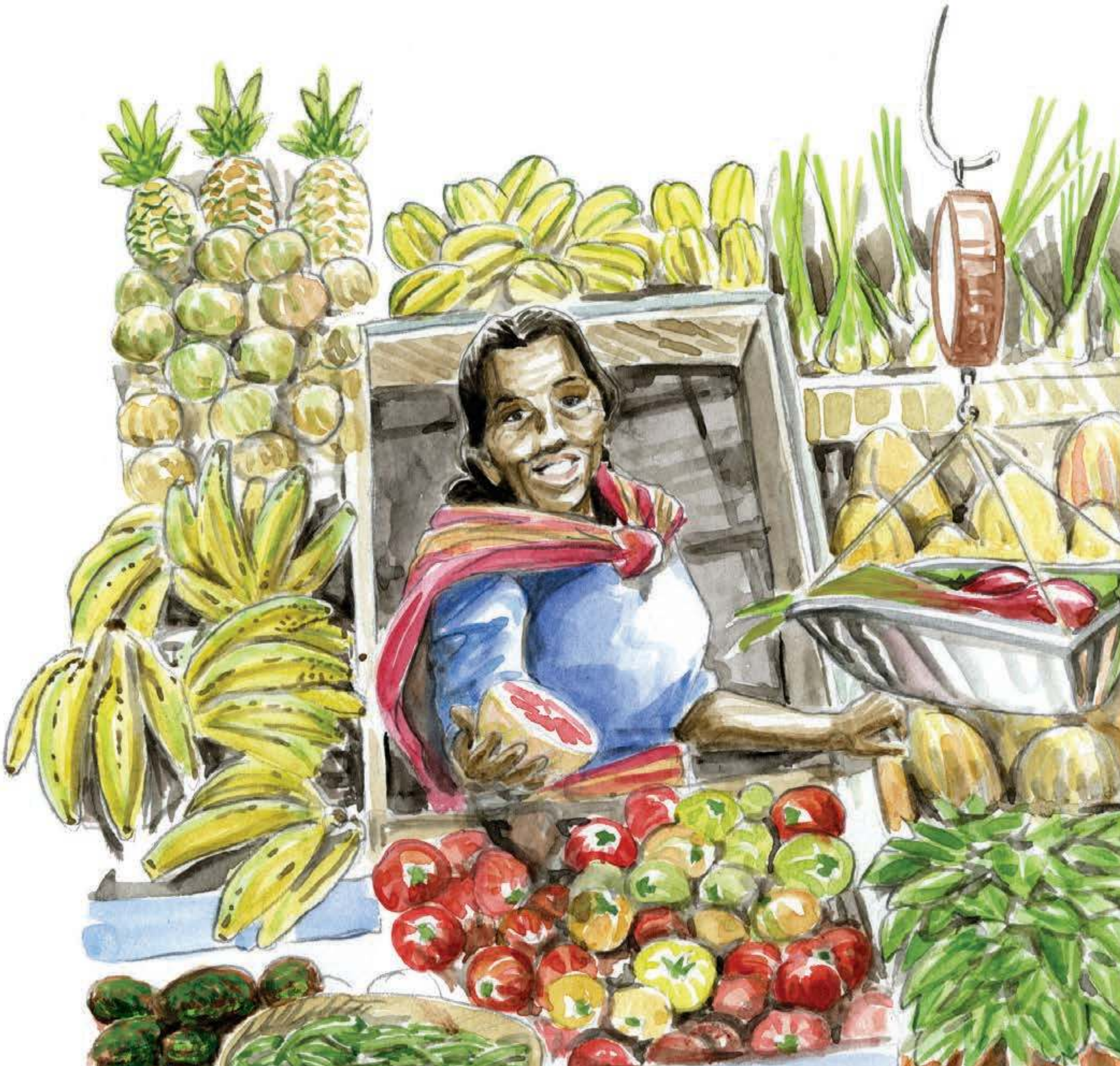
CHAPTER 1 **Introduction,** provides a working definition for fruit and vegetables and makes the case for supporting small-scale farmers to sustainably intensify and market their fruit and vegetable production.

CHAPTER 2 **Production systems, practices and technologies,** describes farm management options for small-scale fruit and vegetable farmers to ensure that production is sustainable, and it addresses crop genetic resources, seed systems and the management of water, soil, nutrients, pests and diseases in the context of disasters, climate change, nutrition insecurity and endangered biodiversity.

CHAPTER 3 **Value chains,** focuses on options to integrate small-scale commercial fruit and vegetable farmers into socially-inclusive value chains, including innovative post-harvest handling practices and services, market linkages, maintenance of or increases to nutritional densities, and to reduce food loss and waste.

CHAPTER 4 **Enabling environment,** describes actions by practitioners and policy makers in different governmental, institutional and social settings to promote the sustainable production and consumption of safe, nutritious and affordable fruit and vegetables.

CHAPTER 5 **The way forward,** presents key interventions and gaps that innovation could address to facilitate the sustainable production of fruit and vegetables in most low- and middle-income countries across the world.



CHAPTER 1

Introduction

• Defining and classifying fruit and vegetables

The International Year of Fruit and Vegetables defines fruit and vegetables as the "edible parts of plants (e.g. seed-bearing structures, flowers, buds, leaves, stems, shoots and roots), either cultivated or harvested wild, in their raw state or in a minimally processed form" (FAO, 2020f).

Excluded are:

- starchy roots and tubers such as cassava, potato, sweet potato and yams (although the leaves of these plants are consumed as vegetables);
- dry grain legumes (pulses);
- cereals including corn;
- nuts, seeds and oilseeds such as coconuts, walnuts, sunflower seeds;
- medicinal, herbal plants and spices, unless used as vegetables;
- stimulants such as tea, cacao, coffee; and
- processed and ultra-processed products made from fruit and vegetables such as alcoholic beverages (wine, spirits), plant-based meat meat substitutes, or fruit and vegetable products with added ingredients (packed fruit juices, ketchup).

The precise botanical definition of the word "fruit" is: the seed-bearing structure (or, more accurately, the ripened ovary as not all fruit have seeds) in flowering plants. The word "vegetable" is not a botanical term. For consumers, and for the purposes of this document, fruit and vegetables are distinguished by their culinary uses and their taste: a fruit is commonly the sweet or sour part of a plant, and a vegetable is the savoury part.

The different types of crops in the family Cucurbitaceae (cucurbits) can serve to illustrate how culinary tastes and uses distinguish fruit from vegetables. Cucurbits include squashes, zucchini and pumpkins (*Cucurbita* spp.), cucumbers and various melons (*Cucumis* spp.), watermelon (*Citrullus lanatus*) and gourds (*Momordica* spp., *Lagenaria siceraria, Luffa acutangula, Luffa cylindrica, Benincasa hispida, Trichosanthes* spp.). The edible part of all these crops is called the fruit (although zucchini flowers can also be eaten as a vegetable, as can the leaves of some pumpkins and chayote). It is the sweet tasting cucurbits (melons and watermelons) that are commonly considered as fruit, whereas other cucurbits are considered vegetables. Unripe papayas and mangoes can also be consumed as vegetables.

For some important vegetable crops, the edible part of the plant is the botanical fruit, for example tomatoes (*Solanum lycopersicum*), African

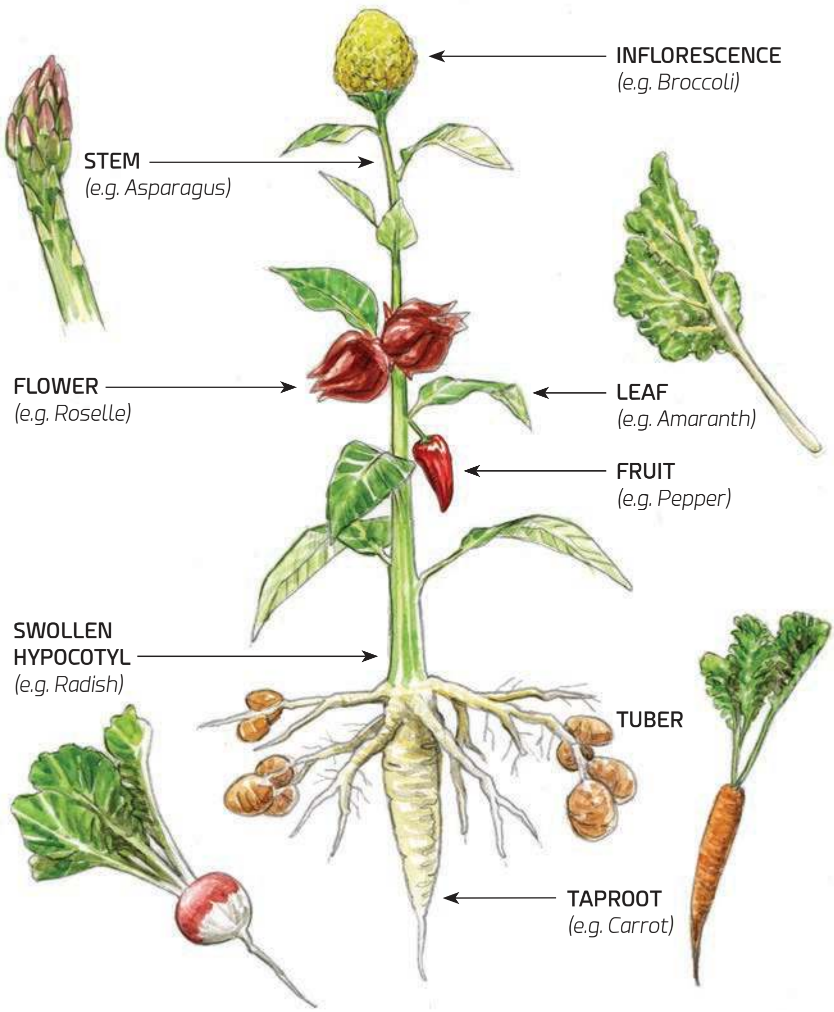


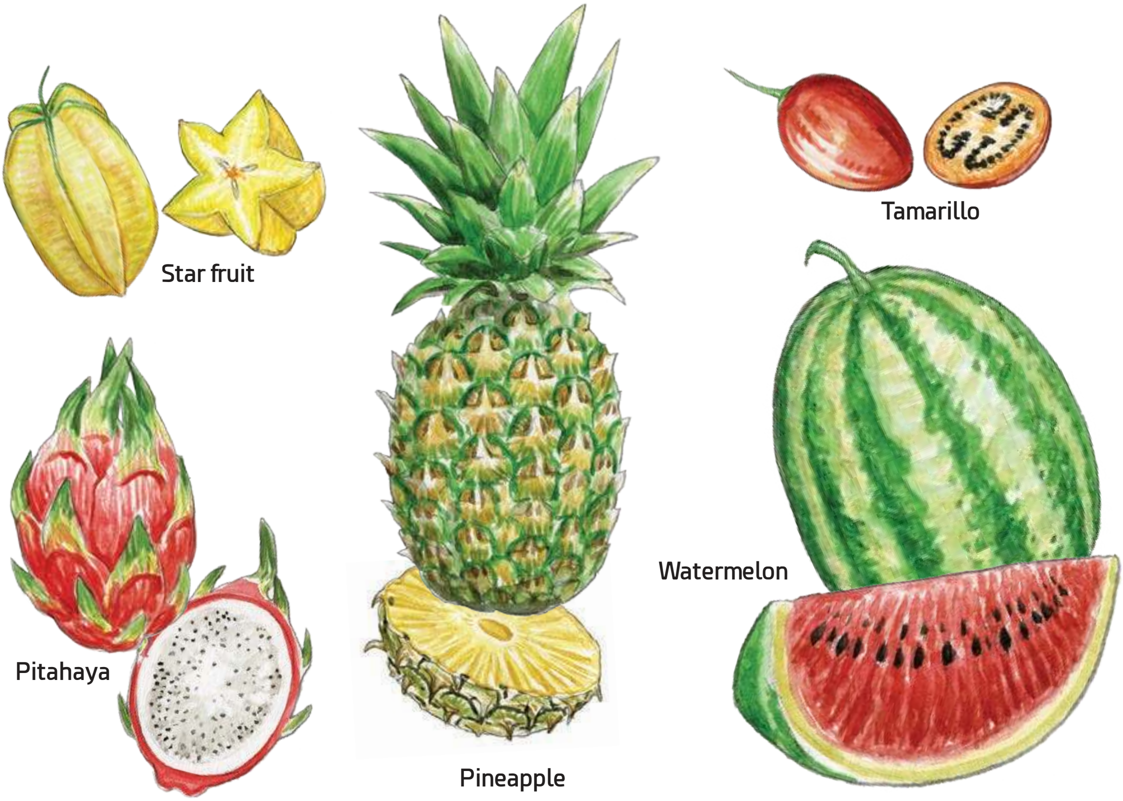
FIGURE 1
Types of vegetables
Adapted from Nichols and Hilmi (2011)

eggplants (*Solanum aethiopicum*) and different species of peppers (*Capsicum* spp.). But many parts of plants, including the leaves, roots, stems, shoots and bulbs are considered vegetables (**Figure 1**). Different vegetables can be produced even from the same plant. For example, beets (*Beta vulgaris* subsp. *vulgaris* 'Conditiva' Group) are grown both for their root (beetroot) and their leaves (beet greens).

Some familiar foods, such as carrots (*Daucus carota*), are grown for their roots and are considered vegetables. However, potatoes (*Solanum tuberosum*), whose starchy tubers are grown as a staple crop, are considered 'root crops', along with cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta*), yam (*Dioscorea* spp.) and corms of the Araceae family (*Xanthosoma* spp.). These crops are categorized separately from vegetables in the FAOSTAT primary production database and are beyond the scope of this document. However, the leaves of sweet potato, taro and cassava, which are a critically important part of many diets, are considered vegetables.

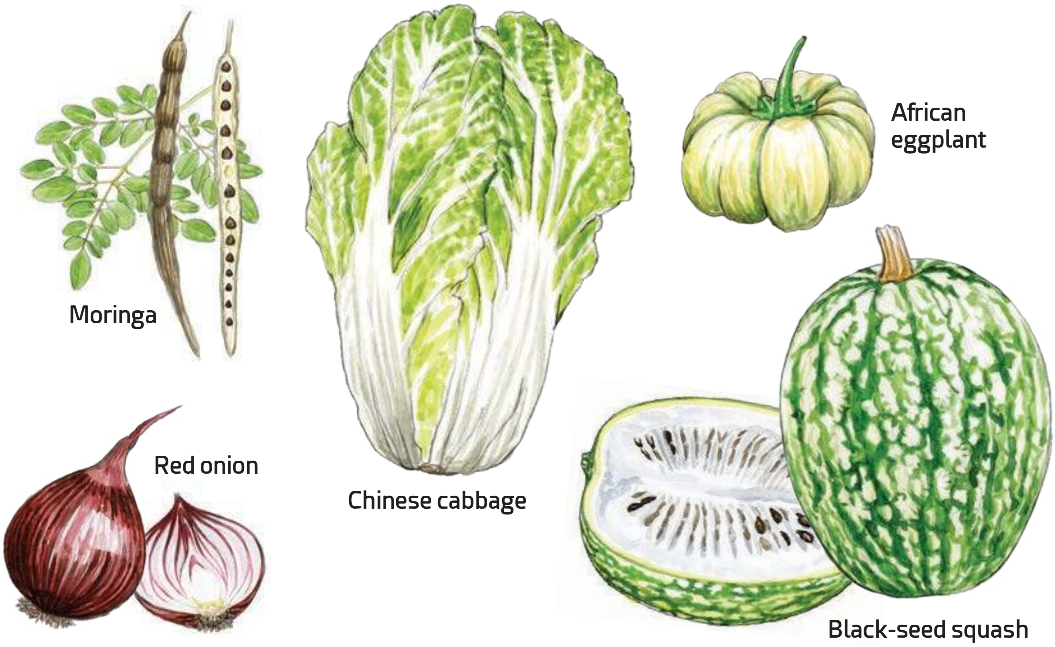
TABLE 1
Fruit crops included in FAOSTAT production and trade databases

FAMILY	SPECIES AND VARIETIES
Actinidiaceae	- kiwi fruit (*Actinidia* spp.)
Anacardiaceae Clusiaceae Myrtaceae	- mangoes, mangosteens, guavas (respectively *Mangifera indica*; *Garcinia* spp; *Psidium guajava*)
Arecaceae	- dates or date palm (*Phoenix dactylifera*)
Bromeliaceae	- pineapples (*Ananas comosus; A. sativa*)
Caricaceae	- papayas (*Carica papaya*)
Cucurbitaceae	- melons, cantaloupes (*Cucumis melo*) - watermelons (*Citrullus lanatus*)
Ebenaceae	- persimmons (*Diospyros kaki: D. virginiana*)
Ericaceae	- blueberries (*Vaccinium myrtillus; V. corymbosum*) - cranberries (*Vaccinium macrocarpon; V. oxycoccus*)
Grossulariaceae	- currants (*Ribes nigrum; R. rubrum*) - gooseberries (*Ribes grossularia*)
Lauraceae	- avocados (*Persea americana*)
Moraceae	- figs (*Ficus carica*)
Musaceae	- bananas (*Musa sapientum; M. cavendishii; M. nana*) - plantains (*Musa paradisiaca*)
Rosaceae	- apples (*Malus pumila; M. sylvestris; M. communis; Pyrus malus*) - pears (*Pyrus communis*) - peaches and nectarines (*Amygdalus persica; Persica laevis; Prunus persica*) - plums and sloes (*Prunus domestica; Prunus spinosa*) - apricots (*Prunus armeniaca*) - cherries (*Prunus avium; Cerasus avium;* var. *duracina;* var. *juliana*) - cherries, sour (*Prunus cerasus; Cerasus acida*) - quinces (*Cydonia oblonga; C. vulgaris; C. japonica*) - strawberries (*Fragaria* spp.) - raspberries (*Rubus* subg. *Idaeobatus*)
Rutaceae	- lemons and limes (*Citrus limon; C. aurantifolia; C. limetta*) - grapefruit and pomelos (*Citrus maxima; C. grandis; C. paradisi*) - oranges (*Citrus sinensis; C. aurantium*) - tangerines, mandarins (*Citrus reticulata*), clementines, satsumas (*C. unshiu*)
Vitaceae	- grapes (*Vitis vinifera*)



Also, leguminous crops, which are important rotational crops (e.g. in cereal-based cropping systems) provide another example because of their ability to establish symbiosis with bacteria and fix nitrogen in the soil. Leguminous crops are considered as vegetables when eaten fresh (green peas (*Pisum sativum*)), or as sprouts (mungbean (*Vigna radiata*) and soybean (*Glycine max*)), whereas other legumes, which are harvested for their dry seed (pulses), such as lentils (*Lens culinaris*) are not. Finally, field maize (*Zea mays*) is a cereal grain, but some varieties with higher sugar content (*Zea mays* convar. *saccharata* var. *rugosa*) are vegetables because they are grown to be eaten fresh, canned, or frozen. Baby corn or sweet corn, which is harvested very early from the field and eaten fresh, is also considered a vegetable.

The organization of fruit and vegetable crops and the botanical families they belong to, as applied in the FAOSTAT production and trade databases (FAO, 1994a), are shown in **Tables 1 and 2**, respectively. In the FAOSTAT databases, several vegetable and fruit crops are not named individually because they are of relatively minor international importance in terms of trade.



Fruit and vegetables statistics

In the FAOSTAT primary production databases, the aggregated list of vegetables, which is used to derive total production figures (area cultivated, yield, production quantity), includes mushrooms and truffles, which are not considered in this publication. In the FAOSTAT trade databases, which provide data on the quantity and value of imports and exports, fruit and vegetables are aggregated together, and the list includes many commodities that fall outside the scope of this publication (nuts, root crops, pulses) as well as derived products (flours, juices and homogenized preparations).

As with vegetables, FAOSTAT production and trade databases group fruit that have relatively minor international importance under a single category: ''fruit, fresh, not elsewhere specified (NES)''. The NES classification is also used in the subgroups: citrus fruit, tropical fruit, stone fruit, pome fruit and berries. They are grouped together under the single classification ''vegetables, fresh, NES''.

Information on the area planted and quantity produced must be interpreted with caution. There are a number of factors that make it particularly challenging to establish a methodology that can provide precise statistics on production. For example, vegetables are diverse; they have different growing cycles and cultivation methods, and they are grown on very different types of sizes of land and types of land holdings.

TABLE 2
Vegetable crops included in FAOSTAT production and trade databases

FAMILY	SPECIES AND VARIETIES
Alliaceae *(genus Allium)*	- onions, dry (*Allium cepa*): onions at a mature stage - onions, shallots (green) (*Allium cepa; A. fistulosum; A. ascalonicum*), young onions pulled before the bulb has enlarged; used especially in salads - leeks and other alliaceous vegetables (*Allium porrum; A. schoenoprasum;* other allium varieties)
Amaranthaceae	- spinach (*Spinacia oleracea*)
Apiaceae	- carrots and turnips (*Daucus carota*)
Asparagaceae	- asparagus (*Asparagus officinalis*)
Asteraceae	- lettuce and chicory (*Lactuca sativa; Cichorium intybus* var. *foliosum; C. endivia* var. *crispa; C. endivia* var. *latifolia*) - artichokes (*Cynara scolymus*)
Brassicaceae	- cabbages and other brassicas (*Brassica chinensis; B. oleracea*; all varieties except *B. oleracea botrytis*) - cauliflowers and broccoli (*Brassica oleracea* var. *botrytis,* subvar. *cauliflora* and *cymosa*)
Cucurbitaceae	- cucumbers and gherkins (*Cucumis sativus*) - pumpkins, squash, gourds (*Cucurbita* spp.)
Euphorbiaceae	- cassava leaves (*Manihot esculenta; M. utilissima*)
Leguminosae	- beans, green (*Phaseolus* and *Vigna* spp.): for shelling - broad beans, green (*Vicia faba*): for shelling - peas, green (*Pisum sativum*): mostly for shelling, but including edible-podded peas or sugar peas - string beans (*Phaseolus vulgaris; Vigna* spp.): not for shelling
Malvaceae	- okra (*Abelmoschus esculentus; Hibiscus esculentus*)
Poaceae	- green corn (maize) *Zea mays,* particularly *Z. mays* var. *saccharata*
Solanaceae	- tomatoes (*Solanum lycopersicum*) - chillies, peppers (green) (*Capsicum annuum; C. fructescens*) - eggplants (*Solanum melongena*)

Further complicating matters is the fact that their short growing cycle means that different vegetables can be intercropped, and they can be grown in rotation on the same piece of land during the same growing season (FAO, 2018a) or with staggered production cycles. It is also important to note that much of the fruit and vegetables grown are often not sold at all or are sold at informal markets, and in many countries, the production statistics reported will not capture the complete picture.

Nevertheless, it is worthwhile reviewing the available data in FAOSTAT to appreciate the most commonly reported fruit and vegetable crops and the total production of fruit and vegetables per region and per country, shown in **Table 3**.

FAOSTAT shows clear trends in increases in the global total production of fruit (**Figure 2**) and vegetables (**Figure 3**) between 1968 and 2018. While there are differences between different regions, the rapid increases in Asia are remarkable.

The types of fruit and vegetables categorized in FAOSTAT represent only a small fraction of the total fruit and vegetable diversity. Many fruit and vegetables have been categorized as neglected and underutilized species (NUS). This category encompasses thousands of domesticated, semi-domesticated or wild species that are not viewed as significant commodity crops and have received little attention from researchers and breeders in either the public or private sector (FAO, 2018b). The designation "NUS" can be somewhat fluid: a major crop in one country may be considered a neglected minor crop in another, and in some countries, agricultural statistics and research do not differentiate between NUS and other crops (Lin *et al.,* 2009; Padulosi *et al.,* 2013). Further, NUS have different uses in different countries. A few examples for Africa and Asia are shown in **Box 1**. Interested readers are also referred to **Table 3** of the publication from Ulian *et al.* (2020) that lists 100 NUS, many of which are fruit and vegetables. The publication cites the scientific studies or projects, networks or international agencies that recommend them and defines which parts are edible (leaves, inflorescences/flowers, fruit, seeds, roots/tubers and/or stems/shoots based on Diazgranados *et al.* (2020) and whether they are wild, cultivated or both.

Many fruit and vegetable crops are ignored by FAO and national statistics. Despite a lack of data on NUS, they are nutritionally important and many such as tropical fruit from the Amazonian basin (passiflora, roselle, jackfruit, dragon fruit) and from Asia (durian) are traded at local, informal markets. Similarly, numerous tropical vegetables are not included in national databases, especially leafy vegetables such as amaranths or spider plants (*Cleome* spp.), or seed vegetables such as egusi melons (cucurbits) in West Africa.

TABLE 3
Most commonly produced fruit and vegetable crops and production of total fruit and vegetables per region and per country (listed in descending order) in million tonnes (Mt)
Source: FAOSTAT (2020)

2018

VEGETABLES PER CROP	Mt
Vegetables, fresh (NES)	298
Tomatoes	182
Onions, dry	97
Cucumbers and gherkins	75
Cabbages and other brassicas	69
Eggplants (aubergines)	54
Carrots and turnips	40
Chillies and peppers, green	37
Garlic	28
Pumpkins, squash and gourds	28
Lettuce and chicory	27
Cauliflowers and broccoli	27
Spinach	26
Beans, green	25
Peas, green	21
Maize, green	12

2018

FRUIT PER CROP	Mt
Bananas	116
Watermelons	104
Apples	86
Grapes	79
Oranges	75
Mangoes, mangosteens, guavas	55
Plantains and others	39
Tangerines, mandarins, clementines, satsumas	34
Pineapples	28
Melons, other (incl. cantaloupes)	27
Peaches and nectarines	24
Pears	24
Lemons and limes	19
Fruit, citrus (NES)	14
Papayas	13
Plums and sloes	13

2017

VEGETABLES PER REGION	Mt
Asia	843
Europe	94
Africa	79
Latin America	46
North America	34
Oceania	3

2017

FRUIT PER REGION	Mt
Asia	490
Latin America	133
Africa	109
Europe	76
North America	27
Oceania	8

2018

VEGETABLES PER COUNTRY	Mt
China	552
India	128
United States of America	32
Turkey	24
Nigeria	16
Viet Nam	16
Mexico	16
Egypt	16
Iran (Islamic Republic of)	15
Russian Federation	14
Spain	13
Italy	12
Indonesia	12
Republic of Korea	10
Japan	10

2018

FRUIT PER COUNTRY	Mt
China	244
India	99
Brazil	40
United States of America	26
Turkey	24
Mexico	33
Indonesia	20
Spain	19
Iran (Islamic Republic of)	19
Italy	18
Philippines	17
Egypt	15
Nigeria	12
Colombia	12
Thailand	12

FIGURE 2
Production of fruit between 1968 and 2018, global total and per region in million tonnes (Mt)
Source: FAOSTAT (2020)

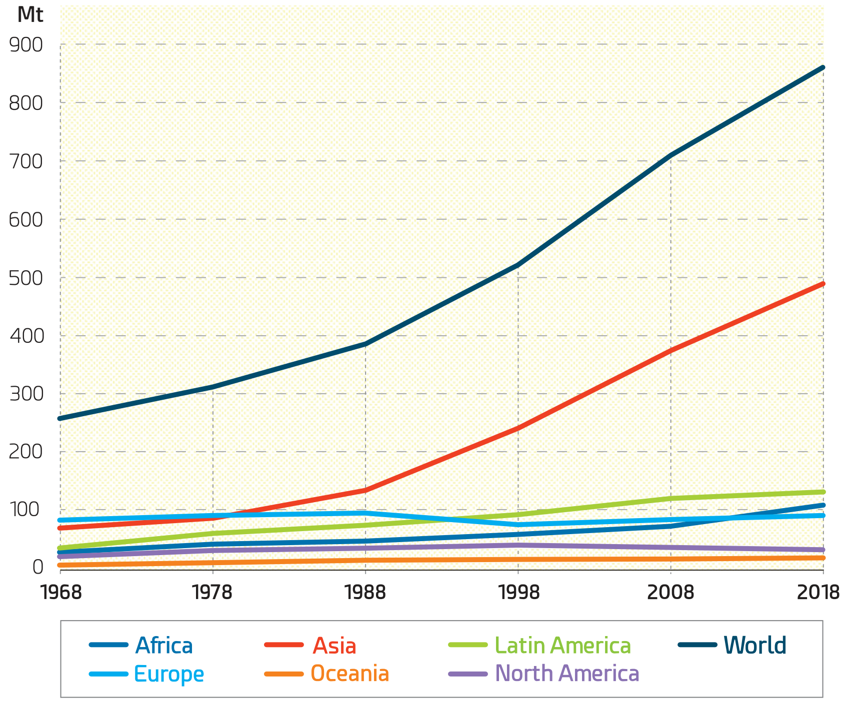
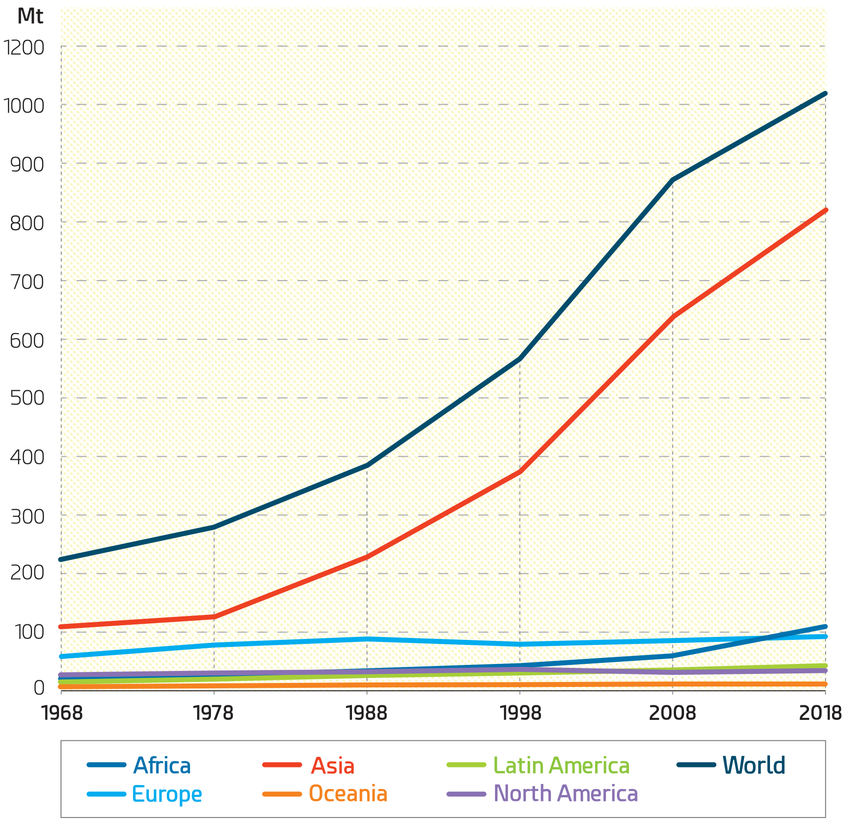


FIGURE 3
Production of vegetables between 1968 and 2018, global total and per region in million tonnes (Mt)
Source: FAOSTAT (2020)



Still, it is important that the often neglected "traditional" vegetables are also considered for building more nutritious food systems as they are often better adapted and more nutritious than their global cousins (Wopereis and Kuo, 2020). Van Zonneveld *et al.* (2020) show that the diversity of traditional vegetables is threatened, particularly in Africa, and action must be taken to conserve and use these vegetables.

Losses

Due to reasons such as labour demand and perishability, fruit and vegetable loss percentages are relatively high worldwide. Losses are highest in sub-Saharan Africa, commonly 15 to 50 percent. Losses are lower in East and South-eastern Asia (with a maximum of 13 percent) and lower still in Central and South Asia (with a maximum of 7 percent).

On-farm losses are, however, highly context-dependent, based on the crop, commodity group and geography. However, the following categories highlight the key factors: i) unsuitable harvest timing – farmers are often forced to harvest prematurely to meet an urgent need for food or cash, or due to insecurity and fear of theft; ii) unexpected harsh climatic conditions and environment – excessive rainfall or a lack of rain causes significant pre-harvest and post-harvest losses. Insect and pest infestations are another important cause of losses; iii) harvest and handling practices – part of a crop may be missed during harvest due to a lack of or inadequate machinery, and due to insufficient or excessive drying of crops; and iv) infrastructure and marketing challenges – farmers may prefer not to market, or even to harvest, their crops if, for instance, the cost of reaching markets due to poor transport is too high relative to the market price. Lack of storage facilities is another significant determinant of loss and compounds other causes of loss (FAO *et al.*, 2020).

The availability of fruit and vegetables worldwide has increased consistently from 1968 to 2017 (**see Figures 2 and 3**). Production in Asia grew by almost 750 percent in volume terms over the period, mainly driven by an increase of production in China; in Africa, production increased four-fold, from 45 to 180 million tonnes per year (although this volume remains low compared with other regions). The production of fruit and vegetables in Central and South America has increased 317 percent over the past 50 years. Meanwhile, production increased by 117 percent in Europe and by 174 percent in North America.

BOX 1. Examples of African and Asian NUS fruit and vegetables.
Source: Bioversity International (2007)

FRUIT

AFRICA
- Natal plum *(Carissa edulis)*
- Carob, locust bean *(Ceratonia siliqua)*

ASIA
- Jackfruit *(Artocarpus heterophyllus)*
- Lapsi *(Choerospondias axillaris)*
- Quince *(Cydonia oblonga)*
- Indian gooseberry *(Emblica officinalis)*
- Mangosteen *(Garcinia mangostana)*
- Ndjanssang *(Ricinodendron heudelotii)*
- Tamarind *(Tamarindus indica)*

AFRICA and ASIA
- Ber, jujube *(Ziziphus* spp.*)*

VEGETABLES

AFRICA
- Baobab *(Adansonia digitata)*
- Cat's whiskers *(Cleome gynandra)*
- Leucaena *(Leucaena leucocephala)*
- Black nightshade *(Solanum nigrum)*

ASIA
- Estragon *(Artemisia dracunculus)*
- Chicory *(Cichorium intybus)*
- Purslane *(Portulaca oleracea)*

AFRICA and ASIA
- Moringa *(Moringa oleifera)*

AFRICA, ASIA and LATIN AMERICA
- Amaranth *(Amaranthus* spp.*)*

AFRICA, ASIA and OCEANIA
- Ceylon spinach *(Basella rubra)*

AFRICA, ASIA and EUROPE
- Jute mallow *(Corchorus olitorius)*

Making the case for fruit and vegetables; based on the Sustainable Development Goals

IN BRIEF

1. Increasing the sustainable production of fruit and vegetables is necessary to fulfil global nutrition requirements (**SDGs 2 and 3**).

2. Fruit and vegetables are highly perishable crops, making them a "hot spot" in the fight to reduce food loss and waste (**SDGs 2 and 12**).

3. The diversity of fruit and vegetable crops provides small-scale farmers with greater options for adapting to climate shocks and stresses and mitigating climate change, and environmental and market shocks across different production settings (**SDGs 1, 13 and 15**).

4. Fruit and vegetables are high-value crops that can be grown on small areas of land, creating economic opportunities for small-scale farmers in rural, peri-urban and urban settings as well as in conflicts and fragile contexts (**SDGs 1, 3, 11 and 16**).

5. Since fruit and vegetables are often eaten fresh, food safety is a critical issue and promoting good practices in the production, harvesting and post-harvest handling of fresh produce lowers the risk of food contamination and helps maintain quality (**SDGs 2 and 12**).

6. Since fruit and vegetable value chains are labour and knowledge intensive, they can generate on-farm and off-farm employment opportunities, especially for youth and other vulnerable populations such as migrants (**SDGs 4 and 8**).

7. Initiatives to make fruit and vegetable production and supply chains more sustainable can be particularly strategic entry points for empowering women (**SDG 5**).

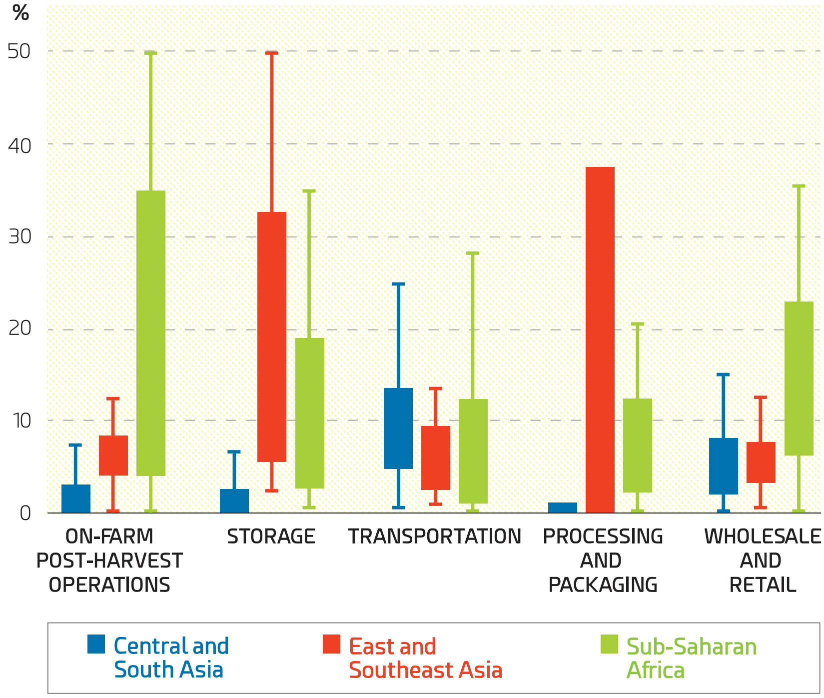
•••

1. Increasing the sustainable production of fruit and vegetables is necessary because the current supply does not meet global nutrition requirements (SDGs 2 and 3).

To meet target 2 of SDG 2 (Zero Hunger) it is necessary to end malnutrition in all its forms by 2030, and is therefore critical that fruit and vegetable production and also consumption is increased. The World Health Organization (WHO) recommends a daily minimum intake of fruit and vegetables of 400 g per person (adult) per day, and *The State of Food Security and Nutrition in the World* reports that world average per capita availability of fruit and vegetables is only 390 g per day (FAO *et al.,* 2020). Only upper-middle-income countries and parts of Asia are currently meeting the FAO/WHO recommendation for availability as well as daily consumption of fruit and vegetables. In Africa, the per capita availability of fruit and vegetables is only 191 g per day, and in low-income countries as a whole it is only 142 g per day. A simulation to estimate future availability, which explored the interactions between supply and demand in more than 150 countries from 1961 to 2050, concluded that it was not possible to satisfy the minimum WHO intake recommendations given the current amount of loss and waste combined with the threat to production from climate change and water scarcity (Mason-D'Croz *et al.,* 2019). Meeting the WHO recommendation will require improvements along the entire fruit and vegetable value chain, from production to processing to marketing to consumption.

Fruit and vegetables are rich sources of vitamins and minerals such as vitamin A, vitamin C, folate and iron as well as other micronutrients that are essential for a healthy life. They also provide organic acids, which stimulate appetite, help digestion and provide dietary fibres and natural compounds (antioxidants, anti-inflammatory agents) that can protect health. An inadequate intake of micronutrients, which enable the body to produce enzymes, hormones and other substances essential for proper growth and development, has serious health consequences.

FIGURE 4
Fruit and vegetable range (median and extremes) of reported food loss and waste percentages by supply chain stage, 2000–2017
Source: Adapted from FAO (2019a)



Young women of reproductive age, pregnant women, nursing mothers and infants and children during their first 1 000 days are particularly vulnerable to the adverse health impacts of micronutrient deficiencies.

Micronutrient deficiencies are a form of malnutrition. Undernutrition – the inadequate intake of dietary energy (calories), which is commonly used as an indicator of hunger – is another form. Overweight and obesity is a third form, which can result from an excessive intake of low-nutrient calories, is a risk factor for a number of non-communicable diseases such as type-2 diabetes, high blood pressure, heart attacks and some forms of cancer. Fruit and vegetables are among the few food groups with beneficial outcomes across all three forms of malnutrition (Beaudreault, 2019). Adopting a diet that includes enough fruit and vegetables can help support the maintenance of a healthy weight and prevent associated non-communicable diseases.

More than 690 million people are undernourished (FAO *et al.*, 2020). However, all forms of malnutrition affect a much greater proportion of the global population with one in three people in the world, or around

2.6 billion people, suffering some form of malnutrition (FAO and WHO, 2018). Malnutrition, in all its forms, has a large and detrimental effect on the global economy. In fact, malnutrition has been estimated to cost the global economy USD 3.5 trillion per year, or USD 500 per individual, due to lost labour and medical costs (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

The consumption of fruit and vegetables can be increased through a combination of supply-side interventions and behavioural changes with public communications that emphasize the importance and health benefits that result from regularly eating fruit and vegetables (Schreinemachers *et al.,* 2018). Investments in sustainable small-scale fruit and vegetable production can address all forms of malnutrition by increasing the incomes of farmers so they can purchase more diverse and nutritious foods for their households, and by making available a greater variety of fruit and vegetables to consumers who have been made aware of the health benefits of this essential food category.

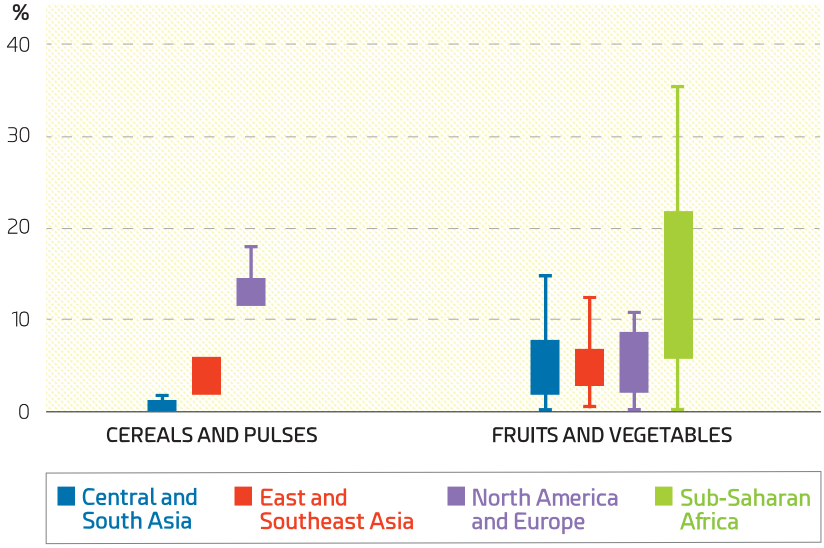
2. Fruit and vegetables are highly perishable crops, making them a "hot spot" in the fight to reduce food loss and waste (SDGs 2 and 12).

In 2016, around 22 percent of fruit and vegetables were lost globally every year from post-harvest to distribution, which is significantly higher than losses for pulses and cereals (FAO, 2019a). Fruit and vegetables were the food group with the second highest level of loss after roots, tubers and oil-bearing crops, more than 25 percent of which are lost per year. However, there were significant differences depending on the stage of the supply chain, the region under consideration (**Figure 4**) and considering the absence of statistics on informal markets.

Fruit and vegetables also have higher levels of waste at the retail stage than cereals and pulses. In all regions, up to 15 percent of fruit and vegetables are wasted at the retail level, except in sub-Saharan Africa where the percentage can be as high as 35 percent (**Figure 5**).

Addressing the high levels of food loss and waste in fruit and vegetable production and supply chains can make a significant contribution towards achieving target 3 of SDG 12 (Responsible Production and Consumption): ''By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses''. It is also essential that production practices change to make production more efficient. There is little point in producing more if one-third of it still goes to waste.

FIGURE 5
Range (median and extremes) of reported food loss and waste percentages at the wholesale and retail stage, 2001–2017
Adapted from FAO (2019a)



3. The diversity of fruit and vegetable crops provides small-scale farmers with greater options for adapting to climate shocks and stresses and mitigating climate change, and environmental and market shocks across different production settings (SDGs 1, 13 and 15).

There is great genetic diversity among fruit and vegetable species and varieties along with a multiplicity of traits. This allows for planting material to be selected to adapt to cultivation in specific environments where the plants will have to be resistant to prevailing pests and diseases, to tolerate drought and flooding, to withstand high or low temperatures, salinity, and fluctuating weather patterns. Further, such diversity enables farmers to grow crops with certain characteristics that meet the needs of local markets, whether they be the taste, shape or colour, or shelf life, packing and processing qualities.

In open fields, diversified production systems involving crops in associations, sequences and rotations, and using practices that minimize soil disturbance and enhance or maintain a protective organic cover on the soil surface, can increase the organic content of the soil and sequester and store carbon dioxide. Using more organic materials and less chemical fertilizer can also lower nitrous oxide emissions. Integrated Pest Management (IPM) strategies and improved soil health can reduce the need for chemical inputs, which in turn lowers the carbon dioxide emissions associated with their manufacture and transport. All of these climate-smart practices are fundamental to achieving sustainable crop production and will be discussed further in this publication.

Integrating perennial fruit trees and annual vegetable crops into an agroforestry system, as can be done in family home gardens, can support a number of ecosystem services such as improved water regulation and infiltration, and erosion and flood control that can buffer the impacts of disasters and climate change. The trees can also provide shade and windbreaks and create more favourable microclimates for integrated crop and livestock systems. Crop diversification is also a risk management strategy that provides a safety net in times of economic crisis, when climatic shocks affect one crop more than another and when there are market shifts.

Vegetables can also be produced under protected cultivation systems (greenhouses, netting or mulching) that make efficient use of water and nutrients, and that offer opportunities for alternative methods to control pests and diseases compared with field cultivation, and can enable production regardless of ambient climatic conditions. The World Meteorological Organization has stated that protected cultivation is a necessary approach to build resilient cities (cited in Dubbeling and de Zeeuw, 2011). In rural areas, when the environment and marketplace conditions allow, protected systems enable off-season production with better prices for farmers and more variety for consumers.

4. Fruit and vegetables are high-value crops that can be grown on small areas of land, creating economic opportunities for small-scale farmers in rural, peri-urban and urban settings as well as in conflict and fragile contexts (SDGs 1, 3, 11 and 16).

Flavourful, nutritious, fresh fruit and vegetables deliver higher economic returns to farmers than staple crops. Their high value means that fruit and vegetable crops do not need to be cultivated on the same scale as cereals for farmers to earn an equivalent income, which makes them particularly suitable for small-scale rural, peri-urban and urban farmers (Lumpkin *et al.,* 2005). Even resource-poor farming families, able to make only modest investments, can earn potentially higher incomes from fruit and vegetables if they have the appropriate inputs and knowledge. The global value of fruit and vegetable production exceeds that of all food grains combined (Schreinemachers *et al.,* 2018).

The production of fruit and vegetables has a comparative advantage in areas where farmers have limited access to land, where labour is abundant and where markets, particularly growing urban markets, are accessible (Joosten *et al.,* 2015). These conditions predominate in many areas where there is an insufficient supply of fruit and vegetables. For example, in sub-Saharan Africa, South Asia, East Asia and the Pacific, 85 to 95 percent of farms are smaller than 2 ha; in the Middle East and North Africa, Europe and Central Asia, the percentage is 60 to 70 percent; in Latin America and the Caribbean, it is 35 percent (Lowder *et al.,* 2019). In population dense cities like Cairo, Dhaka, Singapore or Tokyo, rooftop gardening or vertical farming is gaining in popularity. In other cities like Quito or São Paulo, vacant lots are made available to those who are interested in vegetable farming.

As many vegetable crops can be grown in quick rotation, small-scale farmers with insecure land tenure have an incentive to grow these higher-value crops. Fruit trees can often be grown on land less suitable for other crops and still generate an income for the farmer.

5. Since fruit and vegetables are often eaten fresh, food safety is a critical issue and promoting good practices in the production, harvesting and post-harvest handling of fresh produce lowers the risk of food contamination and helps maintain quality (SDGs 2 and 12).

Sustainable fruit and vegetable production includes IPM strategies or good agricultural practices (GAP) that eliminate or reduce the use of chemical pesticides. This reduces the risk of harm to consumers caused by pesticide residues. Farm management practices that maintain soil health and avoid using untreated municipal waste or grey water as fertilizer also reduce the risk of heavy metal contamination.

Good agricultural practices, encouraged by relevant regulations and policies, particularly in urban and peri-urban areas, can ensure that water is clean, and the manure used as fertilizer is properly composted so that the food does not become contaminated by food-borne pathogens. Actions to promote market-oriented sustainable fruit and vegetable production also encourage the use of good hygienic practices by farmers and others who handle the fresh produce in order to lower the transmission risk of food-borne diseases.

Good harvest and post-harvest practices are critical to preventing produce from being contaminated by mycotoxins, among other things. Mycotoxins are naturally occurring poisons produced by certain soil-borne fungi and have deleterious effects on human and animal health and, consequently, on trade. Moulds grow on different crops and foodstuffs, including chilis and dried fruit, often in hot and humid environments. Mycotoxins develop in the field, during post-harvest and storage and are stringently monitored by international trade standards. A comprehensive review of mycotoxins in fruit and vegetables is available for further reading (Barkai-Golan and Paster, 2008).

The commercial viability of small-scale fruit and vegetable production systems and supply chains depends on consumers having confidence that the food is safe.

6. Since fruit and vegetable value chains are labour and knowledge intensive, they can generate on-farm and off-farm employment opportunities, especially for youth and other vulnerable populations such as migrants (SDGs 4 and 8).

Fresh produce, especially vegetables, usually require considerably more labour than other crops for production, harvesting and post-harvest handling. Furthermore, sustainable production requires a broad range of skills and knowledge. In addition, small-scale farmers need to engage with a range of providers including advisory services and those providing production inputs such as seeds or planting materials, trellising, stakes, nettings, IPM inputs, fertilizers, an array of small tools and equipment (including for irrigation), renewable energy systems and for supply and maintenance of protective structures. Fruit and vegetable value chains are capital intensive and benefit from investment in protected cultivation technology, adequate storage facilities (particularly cold storage), processing facilities and smart ways to harmonize production and marketing to reduce losses.

Because perishable fruit and vegetables must be handled with care, it is rather difficult to mechanize many of the production, harvest and post-harvest operations. In rural or peri-urban areas where jobs are scarce, this creates opportunities for employment on farms as well as for post-harvest services to farmers aggregated in formal farmer's organizations to prepare their fruit and vegetable produce for markets (sorting, cleaning, washing, grading, packing, storing, cooling, transporting, distributing and marketing).

Employment opportunities will also be created in information and communication technologies (ICT) to increase the precision of on-farm management, decisions for pest and disease diagnostics, nutrient and water management and off-farm for coordinating the logistics

Women preparing traditional meals made of leafy vegetables in a city market

for the timely transportation of fresh fruit and vegetables along the different stages of the supply chain, managing inventories and making sure production is responsive to market requirements and to test that produce is safe. Youth employment through decent work opportunities and training can be facilitated through ICT services, which will help reduce rural migration to cities and provide employment to connect rural and urban areas. The rapid acceleration of ICT adoption during the COVID-19 pandemic has demonstrated significant opportunities for fruit and vegetable value chains (FAO, 2020d).

Fruit and vegetables also create opportunities for small- and medium-sized enterprises to preserve (fermentation, pickling) and to process produce for different markets while reducing food losses. Collaboration among farmers, suppliers, processors and retailers can create new markets for lesser-known fruit and vegetable crops that may be well adapted to local growing conditions and markets. Such collaboration can encompass promotional and social networking techniques that make use of the latest ICTs, which can be an attractive employment option for young women and men and people with disabilities.

Sustainable fruit and vegetable production opens up the possibility of establishing clusters of related businesses underpinned by the high economic value of these perishable foods. This will require small-scale farmers to work collectively in some type of organization so they can increase their economies of scale, more effectively communicate their needs, and improve their bargaining power. These clusters of farmer groups, small- and medium-sized agro-enterprises and related service providers, which crystalize around the sustainable production of fruit and vegetables, can form a foundation for sustainable industrial and agricultural development within a given territory.

7. Initiatives to make fruit and vegetable production and supply chains more sustainable can be particularly strategic points of entry for empowering women (SDG 5).

Women are often responsible for the production of fruit and vegetables in home gardens, although men will also contribute, and gender divisions of labour will vary depending on the context. Women also play a prominent role in the commercial production of fruit and vegetables. In African countries, staple crops (maize, sorghum) and cash crops (cotton, cocoa) are generally viewed as "male" crops, with men responsible for a significantly higher share of production management and allocation of the income. Whereas for vegetables the gender differences in production management and income allocation are less clear-cut, with women receiving more than half the income for some vegetable crops (Fischer *et al.,* 2018). In many countries, women play a prominent role in marketing fresh fruit and vegetables. They also make up a significant part of the labour force for post-harvest operations that prepare the fruit and vegetables for market and in processing industries. Fruit and vegetable production, particularly in urban agriculture, is important to women of low-income households in ways less directly related to monetary gain. Women use urban agriculture in processes of empowerment, to establish social networks, symbolize a sense of security and encourage community development (Slater, 2001). Finally, women are primarily responsible for preparing home meals, thus are directly involved in the nutritional status of the household's diet and the health of its members.

CHAPTER 2

Production systems, practices and technologies

Fruit and vegetable crops are grown under a wide range of production systems that can be classified according to the nature and quantity of labour involved, the level of investment or knowledge, but also according to the agronomical and technological characteristics of the respective production system. The level of agrobiodiversity in the system is a first important variable. The level of use of technology and external inputs (pesticides, biological control agents, fertilizers) is a second indicator of the type of system, based on the intensification level. Both indicators determine a typology of production systems (**Figure 6**) in which fruit and vegetables make the best use of the natural resources, available and affordable inputs, in a constrained environment where the most limiting factors are water, soil fertility, and pest and disease management.

• Water management

The primary limiting factor for growing fruit and vegetables is water, both in terms of quantity and quality. Water scarcity can be due to the climate, especially in arid areas, or to unpredictable rainfall patterns due to climate change and to competition with other human activities such as domestic or industrial uses in urbanized areas. Non-adapted agricultural practices can also affect the quantity and quality of the available water. The short life cycle of most vegetable species is an advantage for production, and the perennial status of most tropical fruit species is a beneficial trait for withstanding dry periods. Humans have developed fruit and vegetable farming in deserts (such as in Death Valley in California and the Jordan and Nile valleys) using irrigation. Too much water is also a constraint in the tropics and sub-tropics, and protected cropping systems can save a harvest from flood as well as from drought.

When considering watering crops that will be consumed fresh or raw, the sanitary status of the water used is of critical importance, either at a local scale (water polluted by urban waste, heavy metals or chemicals, or sewage containing disease causing microorganisms) or at a watershed level (increasing salinity of deep soil water).

• Rainfed cultivation

While many small-scale farmers rely on rainfed vegetable production, supplementary irrigation is commonly applied using watering cans. However, in dry areas of India, many drought tolerant vegetable crops, including varieties of tomato, eggplant, chilli, pumpkin and watermelon, are grown successfully under rainfed conditions. In the Sudan-Sahel

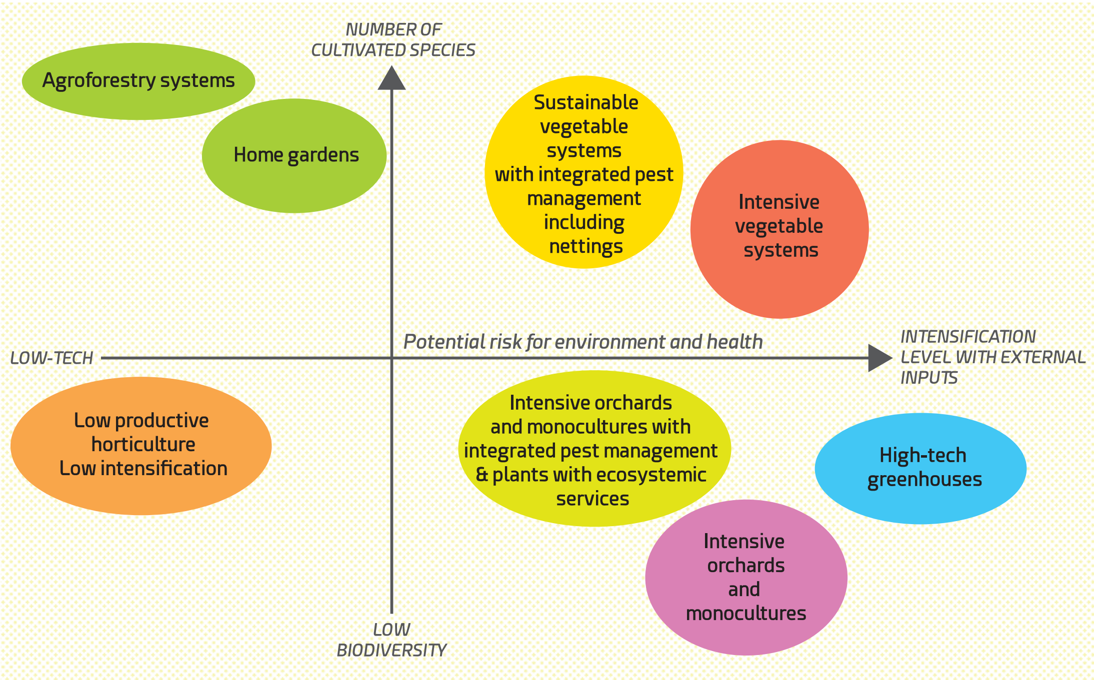


FIGURE 6
Different types of fruit and vegetable production systems depending on levels of intensification with external inputs (X-axis) and on agrobiodiversity (Y-axis)

Source: Adapted from Malézieux et al. *(2009)*

region, exotic vegetables are mainly produced during the dry cool season as irrigated crops to avoid flooding, poor drainage, limited fruit set in many flowering plants and excessive disease pressure during the rainy season. In the inland valleys of Benin, for instance, tomatoes and peppers are grown during the dry season (to avoid high pest and disease incidence during the rainy season), yet increases in production will require supplemental irrigation (Sintondji *et al.*, 2016).

Conversely, many species of fruit trees grow well under rainfed conditions. In Iran, for example, figs have been grown by small-scale farmers on sloping land under rainfed conditions for many generations (Ministry of Jihad-e-Agriculture, 2011). The Central Research Institute for Dryland Agriculture (CRIDA), under the Indian Council of Agricultural Research (ICAR), has identified nine fruit trees that can be commercially cultivated under rainfed conditions: mango, guava, pomegranate, custard apple, jamun (*Syzygium cumini*), ber or Indian jujube (*Ziziphus mauritiana*), sapota (*Achras zapota*), tamarind (*Tamarindus indica*) and acid lime (*Citrus aurantifolia*) (Reddy *et al.*, 2019). It should be noted that fruit tree seedlings in general need to be watered when being developed in nurseries and after being transplanted in fields.

In the semi-arid regions of central Mexico, cactus pear (*Opuntia ficus-indica*) has become the most dependable and even profitable option for using rainfed semi-arid lands. Cactus pear can be cultivated for food – both its fruit and its pads (cladodes) are edible, as well as for fodder and industrial uses. It can grow where no other crops can, and it contributes to the restoration of degraded lands. The cultivation of cactus pear has spread from Mexico to other countries, including Brazil, Ethiopia, India, Italy, Morocco, South Africa and Tunisia (FAO, 2017a).

In dryland forest ecosystems in south-central Africa (Miombo woodlands), many traditional fruit, such as sugar plum or mahobohobo (*Uapaca kirkiana*), tutu or idofun (*Parinari curatellifolia*) and monkey orange (*Strychnos cocculoides*), are harvested from wild or semi-domesticated tree species. These types of fruit are important for household nutrition and may have some commercial value in local markets. A survey from Malawi, Mozambique and Zambia found that 26 to 50 percent of rural households depended on indigenous fruit during the seasonal hunger period. Since the fruit trees ripen at different times, they can cover the nutritional needs of rural households throughout the year (Akinnifesi *et al.,* 2004, 2006).

Irrigated cultivation

Many small-scale farmers rely on access to water in private or community wells. In densely populated areas, balancing the needs of different water users can be challenging. The options small-scale farmers choose for irrigating their crops will be determined by a number of social and economic factors, particularly the costs associated with inputs and labour. Furthermore, irrigation planning, system design and management entail a complex method comprised of four key components: water balance between water resources and crop water requirements, institutional systems, conveyance and delivered water services (Maher *et al.,* 2019). These factors will be context-dependent making each irrigation scheme and small-scale farmers requirements unique. It is important to keep in mind that using water efficiently is not just about irrigation system management, and that other farm management practices play a role. For example, understanding the soil type and structure, keeping the soil covered with living or organic mulch so that it retains moisture, selecting drought-tolerant crop species and varieties, which also reduces the demand for water, understanding the need of water depending on the seasons and the development cycle of the crops.

Water collection

The most essential point for irrigated fruit and vegetables is to grow them close to a reliable water source: a river, a dam, or any water storage, a well, or a tap in certain urban areas. The volume of the available water source and the trend of water transportation from the source to the crops, will determine the size of the cultivated plot. Therefore, water collection necessitates infrastructures and possibly joined investments, to catch it (borehole, pump such as solar or treadmill pumps), to store it (tank, dam) and to distribute it (cans, pipes). Therefore, growing fruit and vegetables around a water source is often regulated by an agreement among small-scale farmers, often in agreement with non-agricultural use of water (domestic), or with herders.

Sustainable fruit and vegetable production depends on clean and non-polluted water supplies. For many small-scale growers in low- and lower-middle-income countries, especially those in peri-urban and urban settings, untreated wastewater will be the primary source of water for irrigation. In some countries (e.g. Ghana), the area under informal irrigation using wastewater in urban and peri-urban settings is greater than the area under formal irrigation in the whole country (Drechsel *et al.,* 2006, Obuobie *et al.,* 2003). The use of untreated wastewater for irrigation in vegetable production presents clear public health risks. The long-term goal is to create conditions where all farmers have access to treated wastewater and knowledge of how to ensure that their produce is safe. For example, studies carried out in Accra, Ghana (Keraita *et al.,* 2012) recommended four wastewater irrigation practices that reduced the risk of biological contamination of vegetables:

- sedimentation ponds (or drums) and disturbing the water as little as possible when collecting it;
- filtration techniques (sand filtration or fabric sieves);
- irrigation methods that reduce water contact with the leaves (drip irrigation or hand watering with the spout held low to the ground); and
- stopping irrigation several days before harvest, as most food-borne pathogens are killed by exposure to sunlight.

These wastewater management practices, along with other topics are described in *On-farm Practices for the Safe Use of Wastewater in Urban and Peri-urban Horticulture - A training handbook for farmer field schools* (FAO, 2012a).

Low-cost irrigation

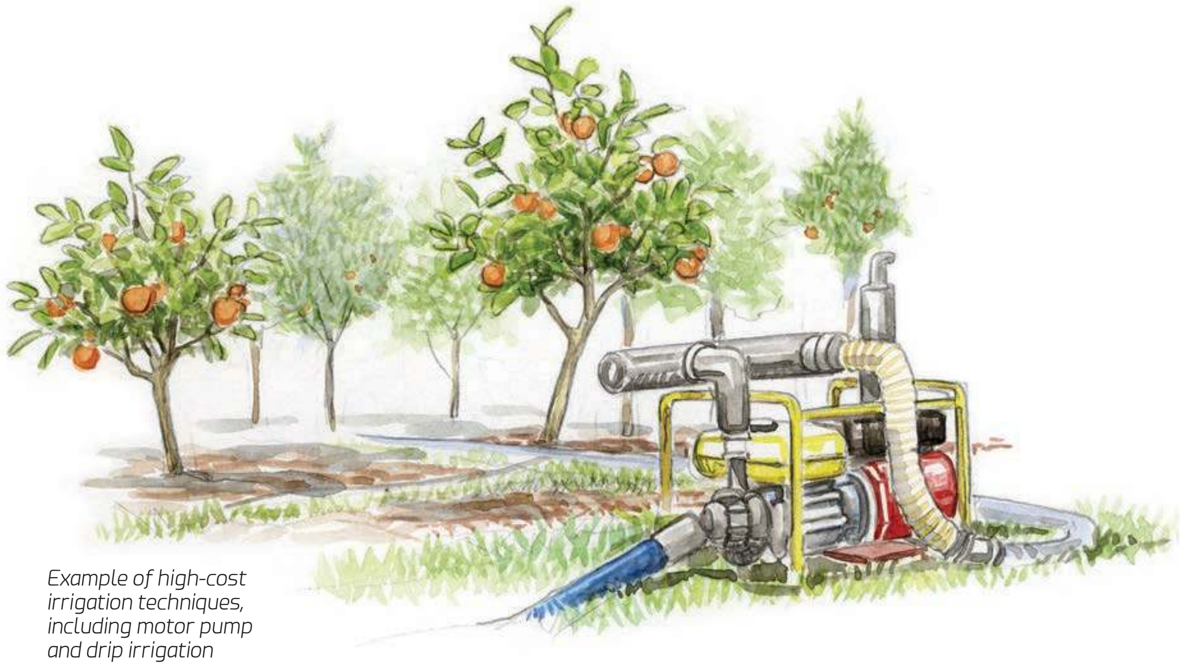
Transporting water from its source and watering crops by hand is widely practiced by small-scale farmers for vegetable production. The watering can is a simple, low-cost and accessible tool, and for many growers it is the only irrigation option they can afford. Watering vegetable crops by hand is labour intensive and only suitable for relatively small plots. Frequently the burden of collecting water and applying it to crops falls on women. This is the main method of irrigation in the urban and peri-urban vegetable systems of sub-Saharan Africa. Treadmill treadle pumps are a valuable alternative for the more expensive motorized versions and have become popular in some countries in sub-Saharan Africa.

Example of low-cost irrigation techniques, including bore well and hand watering

Furrow irrigation, a method of surface irrigation in which water is channelled along slightly sloping furrows between rows of plants, is suitable for fruit and vegetable crops and is the conventional approach for many growers, as it does not require expensive equipment. Furrow irrigation requires accurate land levelling, regular maintenance and a high level of farmer organization to operate the system. It does not apply water to crops in an efficient manner and can contribute to the spread of soil-borne diseases as well as weeds.

High-cost irrigation systems

Sprinkler systems where water is under pressure, such as those mediated by solar, electric or generator-powered pumps or through gravitational flow from elevated tanks through pipes and sprayed into the air through rotating sprinkler heads, require more financial investment and adequate water availability but require less labour and can be used on sloping and uneven land. Such systems are suitable for some fruit orchards and some vegetables crops, although more fragile crops, such as lettuce, may be damaged by the falling drops. Sprinklers can be used to irrigate a relatively small area, but distribution is affected by winds and evaporation losses are high. Sprinklers also represent high energy and operation costs.



Example of high-cost irrigation techniques, including motor pump and drip irrigation

In drip irrigation, water under pressure is supplied to narrow pipes that act to maintain flow rates. It is then released via tiny pores or through emitters, slowly and in small quantities, close to the base of plants. Drip irrigation offers the best results in terms of water use efficiency even compared with hand watering, and it reduces labour needs. However, drip irrigation systems require regular maintenance to prevent blockages in pipes, filters, pores and emitters by soil particles and dust.

Drip irrigation systems can also be used for the precise application of liquid fertilizer (fertigation). In this type of micro-irrigation, the leaves and stems of plants remain dry, which helps control diseases that tend to develop in high humidity. Drip irrigation also reduces soil erosion and pressure from weeds.

The high cost of drip irrigation can be prohibitive for small-scale farmers in low- and middle-income countries. Low-cost solutions have been developed (FAO, 2007) to allow small-scale farmers to have access to this efficient irrigation system.

Deficit irrigation

In deficit irrigation, water is applied only during drought-sensitive stages of the plant's growth. It has proven to be successful for various crops, particularly fruit trees and vines and in locations where a certain amount of seasonal moisture is guaranteed. In south-eastern Australia, regulated deficit irrigation of fruit trees increased water use efficiency by 60 percent with no loss in yield (Goodwin and Boland, 2000). However, for most field and vegetable crops, deficit irrigation has limited prospects (Steduto *et al.,* 2012). Deficit irrigation reduces water use but requires knowledge on the development and drought tolerances for different crops, and the needs of different species and varieties (Geerts and Raes, 2009). For guidelines on the crop yield response to water for fruit trees and vines, see Steduto *et al.* (2012); for a review of responses to deficit irrigation strategies to emerging fruit crops in semi-arid Mediterranean agricultural systems, see Galindo *et al. (*2018).

● Soil health

Sustainable crop production in open field systems is dependent on soils with good structure to prevent erosion, retain water, nutrients, air and a rich biodiversity for soil formation, nutrient cycling and biological control of pests and diseases (Beed *et al.,* 2011, 2017). Soil organic matter – the product of on-site biological decomposition – affects the chemical and physical properties of the soil and its overall health. Its composition and breakdown rate affect the soil structure and porosity, the water infiltration rate and moisture holding capacity of soils, the diversity and biological activity of soil organisms, and plant nutrient availability (FAO, 2005b).

Correct salt and pH levels ensure that nutrients in the soil are made available to crop plants. Worldwide, the area of land that is slightly and moderately saline is increasing every year, which limits the possibilities for growing vegetables and fruit. In this regard, it is necessary to develop and introduce technologies that promote desalinization of lands.

The management of nutrients in fruit and vegetable production requires careful attention. Fruit and vegetable crops have specific nutrient requirements, which may change depending on the species, variety and on the stage of development. It is important for farmers to understand these requirements and to know the amount and type of fertilizer to use and how and when to apply it to provide adequate nutrition for the crops. This keeps production costs to a minimum and prevents runoff and pollution of soils, waterways and the air.

Conservation agriculture

Conservation agriculture is commonly applied in sustainable cereal-based cropping systems (Shaxson and Barber, 2003) and is also applicable to commercial fruit and vegetable crops. It is based on three objectifs:

- minimizing soil disturbance, e.g. no-tillage;
- maintaining a protective organic cover over the soil; and
- cultivating a diverse range of plant species in associations, sequences, or rotations.

Minimizing soil disturbance

Avoiding tillage is important because the more often the land is ploughed, the more the soil may lose organic matter, structure and biodiversity as well as resistance to erosion and compaction.

Cultivating fruit trees and vines, because they are perennial crops, requires less tillage. Their deep root systems act to conserve soil, preventing erosion and loss of soil carbon. Cultivating fruit trees can also contribute to long-term efforts to rehabilitate degraded lands. For example, just as some fruit tree species can be cultivated under semi-arid rainfed conditions, some species can tolerate soils that have been degraded through unsustainable agricultural practices. Findings from a study in India (Dagar *et al.,* 2001) showed that seven years after planting (with gypsum as a soil amendment), *Ziziphus mauritiana, Syzygium cumini, Psidium guajava, Emblica officinalis* and *Carissa caranandus* were able to establish themselves and grow in high alkaline soils that had become unsuitable for most agricultural crops. Fruit trees can be grown on slopes to reduce erosion in arid countries (e.g. fig production in Iran) and in tropical highlands (Schreinemachers *et al.,* 2013), additionally contributing to reduce risks of landslides. In mountainous areas in central Asian countries, farmers have conserved and used local fruit tree varieties to increase incomes while restoring agriculture lands (Lapeña *et al.,* 2014).

Maintaining a protective organic cover over the soil

Many vegetable farmers are aware of the benefits of keeping the soil covered with vegetation. An alternative, to avoid increased evaporation due to the evapotranspiration of these cover crops and to avoid competition with the cover crops for nutrients is to use a protective layer of material (mulch). Cover crops and mulch help to retain moisture in the soil and reduce the need for irrigation. Cover crops and mulch also contribute to controlling weeds and reduce the need for herbicides and rouging, which is particularly important for empowering women who are commonly responsible for the arduous task of weeding. However, the labour requirement for collecting and spreading organic mulch can also be high and attention must be paid to ensure that mulch does not provide a moist and suitable habitat for crop pests and diseases.

A common problem faced by many farmers is the difficulty of obtaining enough organic material of sufficiently high quality for mulching. The competition for organic material on farms can be strong, particularly on farms where crop residues are used for livestock feed or fuel wood. As a result, the use of plastic mulch has become common in vegetable cultivation especially in conjunction with subsurface and drip irrigation and has played a major role in the increases in production of tomato, pepper, eggplant, melon, watermelon, cucumber and squash. Plastic mulch keeps fruit (e.g. strawberries) off the soil, which reduces contact with soil-borne pathogens that can cause fruit rot and other diseases. It has also been reported that transparent plastic mulch increased the temperature of the soil around the roots of the plants by conserving heat from the sun. This adversely affected the activities of the root knot nematodes in the soil thereby creating a conducive environment for the plants to make maximum use of soil nutrients by the roots (Ogwulumba and Ugwuoke, 2011).

Plastic mulch can cause problems if not managed well. When temperatures are high and watering excessive, heat and steam are released, which damage the plants and can lead to fungal diseases during the first days after transplanting. Problems are aggravated when plastic is improperly installed and becomes loose in the field.

The widespread use of plastic mulch, which is made of polyethylene and is not biodegradable, has led to serious environmental pollution (Teuten *et al.,* 2009; Liu *et al.,* 2014; Steinmetz *et al.,* 2016). The mulch sheets are often contaminated with dirt, pesticides and other materials after the growing season and require cleaning before recycling. Furthermore, collection and recycling options are rarely available. Very thin mulches are quite difficult to collect and are sometimes simply abandoned in the landscape or burned. Thicker plastic sheets are easier to recover and are most often disposed of through landfill and incineration. Some countries have established standards on the thickness of the mulch sheeting and regulations on its recovery and disposal. Other countries have completely banned the use of plastic mulch, which has left farmers struggling to find other materials to cover the soil.

BOX 2. Various stages of the SAFTA transitional agroforestry cropping system, Brazilian Amazon. *Source: Bolfe (2010); Junior and da Silva (2014)*

The successional cocoa-based agroforestry system: *Sistema Agroflorestal de Tomé-Açu* (SAFTA) of the Brazilian Amazon, developed by immigrant Japanese family farmers and their descendants over a century, has realized diversification and enrichment in both farm income and the agroecosystem. The farmers receive continuous income from short (annual) and medium (perennial) term intercrops while growing multistoried orchards with high aggregated productivity. While the farmers wait for the establishment of cocoa (their main crop), annual vegetable crops are intercropped to generate income. Other perennial crops such as bananas and papaya are grown as shade trees and to diversify income. Finally, intercropped timber trees also provide shade and income. The establishment of a farmer cooperative was key to ensure value addition and market access.

Finding alternatives to plastic mulch is important for vegetable production. Biodegradable plastic and polysaccharide mulch have been developed as an alternative to polyethylene, but their performance and cost has not led to high levels of uptake (Limpus, 2012). In addition, uncertainty remains as to the environmental footprint of biodegradable plastic mulch (Lambert and Wagner, 2017).

Crop rotations and associations

Fruit trees can be grown with other crops in associations, sequences, intercropping and rotations to maintain healthy soils. Diversified production systems offer different market opportunities and provide insurance against the failure of any one given crop. Which agroforestry system to select depends on local climatic and market conditions. Understory cover crops, such as leguminous "green manure" crops, add nitrogen to the soil. Fodder crops can also be included to create agroforestry-pastoral systems. Integrated fruit tree and vegetable cultivation is also practiced and is common in many home gardens as well as in commercial systems. Since vegetables are short-cycle crops with shallow roots and relatively low plant height, they are well suited as companion crops for fruit trees with deeper roots as they mine nutrients and water from different depths. Furthermore, fruit trees make use of otherwise unavailable water from deeper depths than the shallow rooting of vegetables, reduce runoff and stabilize the soil by improving water infiltration, which contributes to reducing erosion and risk of landslides in sloping areas. As fruit trees develop and their canopy closes, more shade tolerant vegetable crops are increasingly grown in association such as in the Brazilian cocoa-based agroforestry system (**Box 2**).

For many farmers, establishing agroforestry systems that integrate fruit trees and vegetable crops require significant investment and a long-term management plan. To facilitate the adoption of these practices, for which farmers may lack resources, access to land, secure tenure and markets, incentives and agronomic skills need to be provided.

For short-cycle vegetables it is common practice to rotate different families of crops on the same unit of land to avoid the depletion of the same nutrient profile and water from the same depth, and to avoid pest and disease build up. A good example is the management of the soil-borne bacterium *Ralstonia solanacearum* that causes wilt disease in crops belonging to the Solanaceae family, which includes sweet and hot peppers, eggplant, tomato, nightshade, tree tomato, as well as potatoes and tobacco (**Box 3**).

Managing fertilizers

Even healthy soils require some form of fertilization to replenish nutrients taken up by crops. The nutritional requirements of different fruit and vegetable crops vary and can depend on their stage of development. For example, if leaves are the part that is consumed (e.g. lettuce), little variation in the type of fertilizer is required. However, for fruit such as apples, tomatoes and pumpkins, the timing and balance of nutrients is important to stimulate fruiting. Farmers need to be aware of these requirements. Ideally, farmers would undertake soil analysis to determine the available plant nutrients. The results enable farmers to select crop species and varieties whose nutrient requirements are best suited to their fields and to apply appropriate fertilizer regimes. For many small-scale farmers in low-income countries soil analysis services are not always available or are prohibitively costly. However, new technologies, such as test strips for assessing key nutrients in soil and water and electronic scanners, can be used by small-scale farmers (Testen *et al.,* 2018; Agriterra, 2018).

Nutrients can be applied as organic inputs such as compost, animal manure or crop residues, which help to maintain or increase soil biodiversity, structure and organic matter. Nutrients can also be applied using inorganic fertilizers (fertilizer produced industrially by chemical processes, mineral extraction or by mechanical grinding). The International Code of Conduct for the Sustainable Use and Management of Fertilizers notes there are many sources of plant nutrients available and they should be considered as complementary rather than exclusive to one another (FAO, 2019b). Organic fertilizers generally have lower nutrient content than inorganic fertilizers and they also make their nutrients available to the plants at a much slower rate. However, they are recognized as helping to maintain healthier soils and to produce food richer in minerals and antioxidants.

For many farmers, it can be difficult to obtain sufficient quantities of organic fertilizers and amendments, especially in arid countries, urban and peri-urban settings and farming areas where there may be high competition for biomass. Raw organic materials such as crop residues, animal manure, food waste and some municipal and industrial waste can be used for compost. Composting is the natural process in which micro-organisms decompose organic matter and kill food-borne pathogens. Vermicomposting has gained popularity over recent years. In this technique, worms of different species are used to accelerate the decomposition process. However, chemical contaminants such as pesticides, antibiotics and heavy metals can remain. In some areas, sewage sludge, such as solid materials removed from the wastewater stream originating from a public sewage system and composted (FAO, 2019a), is used as an organic fertilizer. It is critical that sludge be regularly analysed and treated to ensure that dangerous chemicals and food-borne pathogens do not persist.

Inorganic fertilizers make nutrients immediately available to the plants and can be selected based on their composition to contain key micronutrients such as boron, manganese, calcium, molybdenum and zinc, enabling crop specific supplements. However, because inorganic fertilizers are water soluble, any nutrients not taken up by crops are at risk of leaching into waterways. Although, the solubility of inorganic fertilizers can vary, with some types releasing nutrients more slowly, nutrient pollution is a serious environmental problem. Moreover, the manufacture of inorganic fertilizers is a source of carbon dioxide emissions and excessive application of nitrogen fertilizers is a significant source of nitrous oxide emissions. Overuse and misuse of fertilizers can also lead to increased soil salinity. Furthermore, the application of inorganic nutrients suppresses the activity and survival of microbes, insects and nematodes that cycle nutrients in soils (Beed *et al.,* 2017).

As already mentioned, fertigation allows for frequent applications of very small amounts of fertilizer, adjusted to the specific requirements of a given crop at a given time. Subsurface and drip irrigation increases nutrient delivery by directing water to the area where crops are growing, thus reducing nutrient runoff and pollution.

Plant health

Nutrient-rich fruit and vegetables are not just highly attractive to people but also to a vast array of pests and diseases which may render the growth of fruit and vegetables impossible without pesticides, which, as a consequence, entails a higher risk of pesticide overuse and the presence of pesticide residues in case of poor management.

Managing pests and diseases in fruit and vegetable crops is a significant issue for small-scale growers that can be best addressed through IPM strategies. This includes avoiding pests and disease by adopting preventive instead of curative measures (seedling nurseries under protected cultivation, physical barriers, clean water, soil and tools), the use of resistant varieties, the use of trap crops and pheromone traps, biological control agents and the judicious use of chemical pesticides. Traps are usually simple interception devices that capture insects moving through an area. Traps are also used to detect new invasions of insect pests in time and/or space, to reduce infestations and to monitor the populations of established pests (Epsky *et al.,* 2008).

The success of IPM strategies by individual growers increases when their neighbours deploy the same techniques. For example, farmers worked collectively to carry out mass trappings using pheromone traps to reduce the numbers of the tomato leafminer (*Tuta absoluta*) in the Near East (FAO, 2012b) and eggplant fruit and shoot borer (*Leucinodes orbonalis*) in South Asia (Alam *et al.,* 2006). Recognizing the importance of collective action, FAO worked with farmers to create community IPM strategies through the Farmer Field School (FFS) approach at the community level and with local institutions (Pontius *et al.,* 2000).

Surveillance and detection

Growers must be familiar with the enemies and friends of their crops and when attacks are most likely in terms of environmental conditions, season or due to certain agronomic practices. Regular observation or scouting of crops to monitor for pests and diseases is fundamental, especially on vegetable crops due to their rapid production cycles. Regular scouting enables growers to detect problems early, to rapidly deploy appropriate control interventions, before pest and disease damage reaches economic threshold levels, and to evaluate the efficacy of control interventions. When scouting exercises are coordinated across a region, involving several national research and plant protection organizations, and are provided with technical support from laboratory services, efficiencies and knowledge sharing is increased, as was realized, for example, for known and new diseases of banana in the Great Lakes region of Africa (Beed *et al.,* 2013).

In general, for any given crop and location, there are common pests and diseases. As with human medicine, diagnosis of the pest and causal agent of disease in plants is the first and most important critical step towards the deployment of the most appropriate control intervention (Miller *et al.,* 2009). When there is a new pest or disease, invasion growers must be supported by advisory services or research institutions to diagnose the problem and provided with early warnings and advice on control measures. The first step in recognizing symptoms linked to pests and diseases is for growers to know what a healthy crop looks like, to identify differences between crop varieties and to differentiate pest and disease symptoms from those caused by physical stresses such as nutrient deficiencies, drought, flooding, heat, sun, cold or salinity. Symptoms of ill health are evident as deviations from normal crop function and are manifested as changes in appearance. There are a variety of organisms that cause disease symptoms, including insects, bacteria, fungi, viruses, nematodes and phytoplasmas. There are different types of symptoms associated with each such as wilt, spots, cankers, curling, blights, mosaics, galls, profuse flowering, rots, dieback, malformation and discolouration. The most appropriate method of control is dependent on the type of organism causing the disease and their epidemiology (how they are transmitted and what conditions facilitate their infection). For some growers, public and private extension services assist with diagnoses. For growers with access to the Internet, an online search that combines a symptom description with the crop type will reveal the potential disease causal agent and appropriate control measures.

Another general principle of IPM is ensuring proper field sanitation. The removal of diseased and pest damaged plants or plant parts and crop residues after harvest will help to reduce pest and disease pressures. Regularly cleaning farm machinery, tools and clothing can also help prevent the spread of diseases. Similarly, ensuring water supplies are free from pests and diseases is important.

Resistant varieties and healthy seeds

Deployment of resistant varieties forms the foundation of any IPM programme. Whenever they are available, fruit and vegetable varieties with known resistance against common pests or diseases in a given locale should be selected and used. Using healthy seeds will reduce the incidence of seed-borne diseases. Seed treatment using biological control agents such as *Trichoderma* spp. or *Pseudomonas* spp. has been shown to reduce the incidence of some seed- and soil-borne pathogens in vegetables (Mancini and Romanazzi, 2013). Managing the plant diversity (within and among varieties and species) is also a strategy to sustain the efficiency of resistance genes. The Hortivar database (**http://www.fao.org/hortivar/**) is based on a network of scientists who are engaged in collating and disseminating information on the field performance of fruit and vegetable cultivars including their resistance to pests and diseases, to help farmers identify the best-adapted varieties. The important role of resistance traits has been recognized by the private sector and seed companies as a priority (Schreinemachers *et al.,* 2016b). Similarly, research into improving resistance in vegetable varieties has shown returns on investment that are as high as those previously reported for some staple crops (Schreinemachers *et al.,* 2017b).

Chemical control

Even though chemical pesticides should only be applied as a last resort, based on considerations including cost, food safety and human and environmental health, chemical control remains a common method for small-scale fruit and vegetable growers who can afford it. Many feel obliged to use pesticides – and also herbicides – as a precautionary measure to protect their crops since pest and disease outbreaks can lead to total crop failure and substantial economic losses. The impetus to apply pesticides is also exacerbated because the appearance of fruit and vegetables is important for their marketability and even slight blemishes caused by pests and diseases can mean a loss of income.

However, fruit and vegetable growers are often inclined to apply excessive amounts of chemical pesticides and herbicides to their crops and even to use the wrong chemical, combinations of incompatible chemicals, doses, timing, types of application, storage and disposal (Schreinemachers *et al.,* 2017a), which can all expose farm workers to pesticide poisoning. Further, misuse of pesticides harms the environment and kills organisms that benefit sustainable crop production (Beed *et al.,* 2017) and contributes to pests becoming pesticide-resistant, creating a vicious circle in which more and more pesticides are applied only to achieve less and less protection. Pesticide residues above accepted levels, maximum residues levels (MRL), prohibit trade and therefore directly lead to food loss or, if consumed, to consumers being exposed to increased levels of pesticide residues. Incidents of chemical contamination of foods from pesticides undermine efforts to increase consumption and consequently the demand and supply of fresh and nutritious foods. International export markets are strictly regulated for pesticide MRLs, and, if exceeded, they can significantly harm the reputation of the exporting country and limit future trading opportunities. Conversely, for many local markets, there is no systematic monitoring of pesticide residues.

In many countries, the technical considerations for safely and correctly applying pesticides and herbicides are often neglected, unknown or unregulated. Farmers and small pesticide dealers become ill because they ignore, or are unaware of, the technical principles of their safe application, storage and disposal and don't have access to individual protection equipment. Very often pesticides are sold in small quantities, distributed from larger bottles into smaller ones to allow small-scale farmers to buy the amount they need at affordable prices. Some small pesticide dealers do not comply with regulations, and may even sell prohibited or obsolete, out of date products. Supporting growers to adopt a range of IPM methods and not only rely on pesticides requires knowledge and appropriate policy support (Schreinemachers *et al.,* 2015). It is critical that fruit and vegetable growers are better educated and informed to choose what pesticides suit their needs, how to apply them and to respect interval periods between application and harvest.

In general, the following considerations should be observed with regard to pesticide application as a part of an IPM programme:

- Pesticides are the last resort in an IPM programme, thus other pest management interventions already noted above should be tried before considering the use of pesticides. The decision to use pesticides should be guided by the economics of the action while the selection of the pesticide should be guided by human health (both producers and consumers) as well as environmental concerns. Biopesticides can help reduce the use of chemical pesticides, but should not always be considered as totally harmless for humans or the environment.

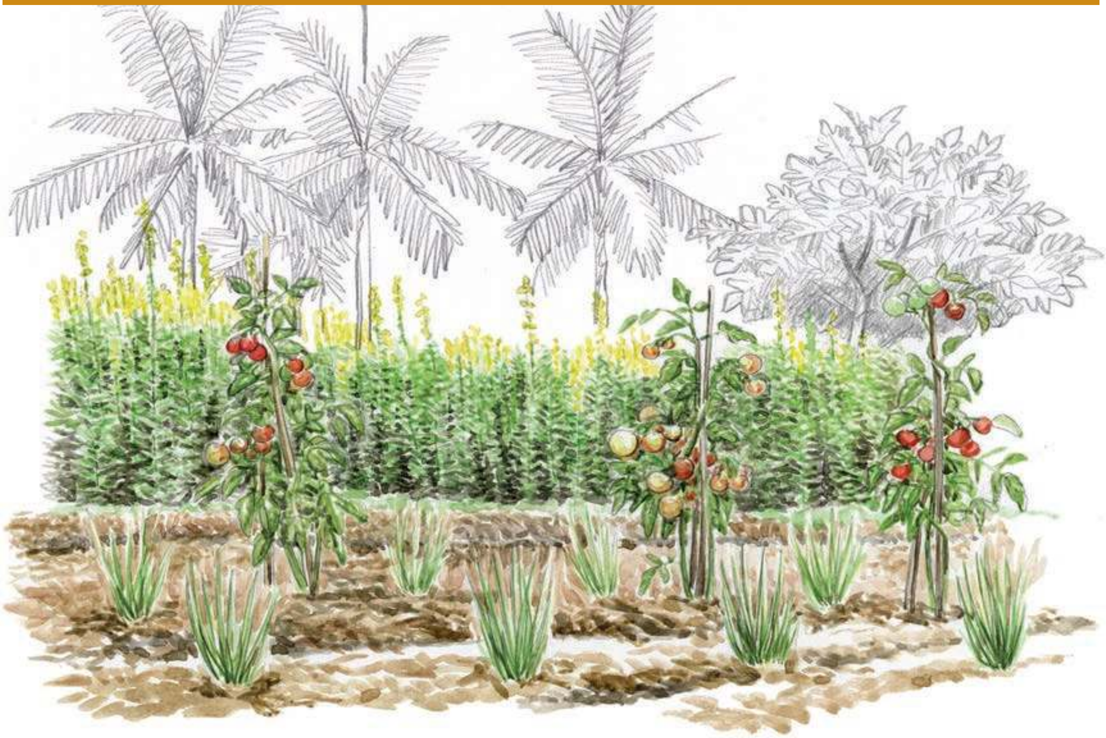
- Economic threshold is the most common guide for making the decision for pesticide use, even though it is not yet generally known by vegetable farmers given the diversity of crops, varieties, growing seasons and conditions. The economic threshold represents numerous pest populations or plants showing a certain level of severity/incidence that can trigger a pesticide application decision. Frequent scouting for pests and injured plants is important to gather this information. Determination of economic threshold is highly reliant on the costs of action and the farmgate price of the crops. Additionally, the threshold should also take into account the resistance/tolerance level of a particular variety. Thus, the estimation of thresholds is best done in a specific agroecosystem/socio-economic context. Pesticide application that is not guided by an economic threshold risks wasting resources on pest or disease damages that do not affect yield significantly enough to warrant an action.
- If a decision is made to apply a pesticide based on an economic threshold, it is important to select pesticides with low risks to human health and the environment. Numerous insecticidal active ingredients have been shown to disrupt beneficial insect populations such as natural enemies and pollinators. To avoid this scenario, pesticides must be selected to affect the target pest only and not other organisms.
- Ensure proper use of the selected products for approved applications to reduce risks to producers and consumers, this includes using relevant personal protective equipment, properly storing and disposing of used containers, respecting re-entry and pre-harvest intervals and complying with international standards (FAO, 2010d; FAO and WHO, 2014).
- Rotate the active ingredients among the selected pesticides with different modes of action to avoid developing resistance among pests and pathogens.

Cultural practices

Integrated production and protection

Integrated production and protection (IPP) has been advocated as a means to help small-scale farmers adopt non-chemical pest and disease control in support of sustainable intensification. The concept of IPP is to consider not only the pest and disease complex affecting a crop, and identify the best available means of control for each component within that complex, but also to consider commonly used cultural practices that could control pests and diseases (Hanafi, 1999).

BOX 3. Crop rotation to combat bacterial wilt of tomato in the French West Indies. *Source: Deberdt* et al., *2018*



Bacterial wilt caused by the bacterium *Ralstonia solanacearum* is highly aggressive towards tomato crops all over the tropical world. Emerging strains of *R. solanacearum* have overcome disease resistance traits in most commercial varieties. Faced with the lack of approved protection products against bacterial wilt, a biocontrol strategy based on the use of sanitizing plants in intercropping or in crop rotation was developed and tested in Martinique (French West Indies).

Multisite agronomic trials were carried out on eight species and varieties of potential sanitizing plants belonging to three families (Brassicaceae, Asteraceae and Fabaceae). These plants, selected because of their hardiness, competitiveness with weeds and high biomass production, were then evaluated for their host status with respect to *R. solanacearum* and for their sanitizing potential. The trials were conducted in a fully-controlled climatic chamber, then under semi-controlled conditions in a greenhouse. The plants selected from earlier stages were finally tested under real conditions on a farm in Martinique.

The lowest bacterial densities in the soil were observed when fodder radish (*Raphanus sativus* cv. Melody), marigold (*Tagetes patula*) and showy rattlepod (*Crotalaria spectabilis*) were grown. In greenhouses, the cultivation of sunn hemp (*Crotalaria juncea*), rattle box, and fodder radish before planting tomatoes was able to significantly reduce the incidence of bacterial wilt. On-farm field trials showed that, compared with the tomato control, cultivating velvet bean (*Mucuna deeringiana*) before planting tomatoes reduced the incidence of tomato bacterial wilt by 53 percent, showy rattlepod reduced it by 58 percent, and sunn hemp by 71 percent.

This innovative plant protection technique is currently being transferred to small-scale vegetable producers in the French West Indies. The sanitizing properties of showy rattlepod, sunn hemp and fodder radish as rotational cover crops can also help control nematodes, which are also major pests of vegetable crops. Both velvet bean and fodder radish can also be used as fodder for animals.

BOX 4. The control of fruit flies on the French island of Réunion in the Indian Ocean. *Source: Deguine* et al. *(2017)*

In Réunion, fruit fly (Diptera: Tephritidae) species that affect cucurbit crops (*Bactrocera cucurbitae, Dacus ciliatus* and *Dacus demmerezi*) are the most damaging pests. Spraying chemical insecticides is ineffective because the flies live in the surrounding vegetation. Regular multiple sprays also lead to a build-up of pesticide-resistant pest populations and it eliminates the natural enemies of fruit flies. In the late 2000s, studies were undertaken to move towards a preventive plant protection programme based on a technical package consisting of five major components:

- monitoring with pheromone traps;
- sanitation measures (removal of infested or infected parts of the host plant), along with the increased presence of natural predators (augmentorium technique);
- assisted push–pull with trap plants (maize) spot-sprayed with a fruit fly bait containing an organic insecticide, spinosad;
- mass trapping with pheromone traps; and
- biological control, mainly through habitat management to support natural enemies.

The results from 28 conventional farms and four organic farms growing mainly zucchini (*Cucurbita pepo*) and chayote (*Sechium edule*) showed no negative effect from eliminating chemical insecticides, and showed that crop protection costs were reduced.

Although the push–pull component was essential to the protection schemes for zucchini and pumpkins, it was relatively less successful for chayote. This was primarily because the chayote value chain is well organized and chayote growers can benefit from technical support and market demand.

Producers of other cucurbits also tend to be involved in other economic activities and they cultivate cucumber or zucchini on smaller fields to reap any benefits from fluctuating market prices. This appears not to be compatible to investing in such a crop protection strategy.

Managing the agrobiodiversity

Natural ecological systems, undisturbed by the activities of man, tend to sustain the greatest diversity of living organisms. Agricultural practices, by their very definition, promote certain species over others and efforts are required to ensure that agrobiodiversity is not threatened (FAO, 2019c; FAO, 2020e). The performance of crop species relies on ''associated biodiversity'' such as pollinators, biological control agents and soil-dwelling organisms. Sustainable crop production, particularly the need for environmental protection and continued income generation, is dependent on associated biodiversity. This can be promoted through mixed farming systems and by diversifying the number and type of crops cultivated and by using companion crops. Crop rotation, for instance, is an effective technique for reducing weeds, pest populations and diseases, especially for those that attack only one botanical family or crop variety. For example, the diamondback moth (*Plutella xylostela*) only damages crops in the brassica family (cabbage, cauliflower, broccoli) during its larval stage. In this case, the rotation planting of brassica crops, both in space and time, with crops from other botanical families will break the diamondback moth's life cycle and reduce its numbers. Another example is water mould (*Pseudoperonospora cubensis*), which is a pathogen of the cucurbit family (cantaloupe, cucumber, pumpkin, squash, watermelon). Rotating cucurbit crops with other crops reduces the prevalence of this pathogen. Bacterial wilt caused by *Ralstonia solanacearum* is a serious problem for vegetable growers in tropical and sub-tropical regions, particularly for crops in the families Solanaceae (pepper, tomato, eggplant, potato) and also Cucurbitaceae. This soil-borne disease is difficult to control because it can survive for long periods under a wide range of environmental conditions and has a wide range of hosts (more than 200 species). For this reason, crops of the Solanaceae and Cucurbitaceae families should not be cultivated in succession (**Box 3**). In addition, to control this bacterium, it is critical to keep farm tools and irrigation systems clean after use.

Intercropping, plant association and planting trap crops and barrier (border) crops can also prevent or reduce the incidence of insect pests on fruit and vegetable crops. Sujayanand *et al.* (2015) found that when eggplant was grown with intercrops such as coriander, mint and marigold, with maize as the border crop, the diversity of the natural enemies of eggplant pests was significantly higher compared with eggplant grown as the only crop. Another study (Srinivasan *et al.,* 2013) showed that tropical soda apple (*Solanum viarum*), a perennial shrub, was an effective ''dead-end'' trap crop to manage tomato fruit worm (*Helicoverpa armigera*). Dead-end trap crops do not require any pesticide treatment to prevent the pest population from moving onto the main crop. They should be planted in field borders where they can intercept adults of the pest and thereby reduce damage to the main crop (Shelton and Badenes-Pérez, 2006). Sequential trap cropping with Indian mustard (*Brassica juncea*) is an effective way of using crop planning to reduce diamondback moth damage in brassicas.

The push-pull strategy is another method of plant protection based on intercropping. It uses a combination of stimuli to modify the behaviour of insect pests and beneficial insects, which influences their numbers and distribution (Cook *et al.,* 2007). In this strategy, the pests are pushed away from the main crop by using plants that either mask the presence of the potential crop host, or repel the pest. At the same time, the insect pests are pulled to other areas by traps or trap crops using highly obvious and attractive stimuli. Once they are concentrated in a given area, the insect pests can be more easily managed. The source (push) depends on the crop management tactics and can take the form of visual and/or chemical cues. The stimulus is generally a plant-produced compound, but it can also be a synthetic blend (Cook *et al.,* 2007). The push–pull strategy for control of stem borers in maize was described in *Save and Grow in Practice: Maize rice wheat* (FAO, 2016). The push–pull strategy can also be used in vegetable crops, using a maize-tomato system that was developed on the French island of Réunion in the Indian Ocean (**Box 4**).

Grafting

Grafting, which increases the yield and quality of fruit and vegetable crops, is done by joining the severed part (the bud or scion) of one plant to the stem or branch of another (rootstock) to form a new plant. The commercially important section is the upper part called the scion while the lower stem and roots section is the rootstock. The crop variety selected for the scion is based on desirable market traits and the crop variety selected for the rootstock is based on its resistance to soil-borne diseases or capacity to grow in specific soils. Grafting of fruit trees is an ancient practice and is common because fruit trees grown from seed will not produce fruit with the same genetic traits as the parent tree.

Since the rootstock of some varieties provide resistance to soil-borne diseases (fungi, bacteria, nematodes) affecting root systems, grafting has been used to protect fruit and vegetable crops without the need for pesticides. The most famous example of this occurred in the 1870s when European grape vines were attacked by the insect pest *phylloxera* (or *Daktulosphaira vitifoliae*), which feeds on the roots and leaves

BOX 5. Grafting tomato to combat bacterial wilt caused by *Ralstonia solanacearum* in Viet Nam. *Source: Genova* et al. *(2013)*

The World Vegetable Center started working on tomato grafting in 1992 as a means of controlling bacterial wilt caused by the bacterium *Ralstonia solanacearum* and demonstrated the technique to Vietnamese scientists in September 1998. From 2002 to 2006, the technique was introduced to Lam Dong province in southern Viet Nam in collaboration with the Potato, Vegetable and Flower Research Center. In the Red River Delta in northern Viet Nam, the technique was introduced in collaboration with the Fruit and Vegetable Research Institute (FAVRI) in Hanoi. In Lam Dong province, where the problem of bacterial wilt is experienced all year round due to high humidity, the rootstock of a tomato variety that was resistant to bacterial wilt was used for the grafted plants. In the Red River Delta, where tomatoes are grown in the wet season and flooding is a problem, the rootstock of an eggplant variety that is both resistant to bacterial wilt and tolerates waterlogging was used.

Farmers in Lam Dong province began planting the grafted varieties in 2002, and the results of a 2013 questionnaire survey of over 200 farmers there indicated that there was a 100 percent adoption rate for the grafted tomato plant. In the Red River Delta, where farmer participation in field trials started in 2007, the findings of the survey revealed a 50 percent adoption rate. In a comparison of grafted and non-grafted tomato plants in the Red River Delta, the average yield was over 30 percent higher for the grafted tomato plant, and their farm gate price for tomatoes was nearly 40 percent higher. The costs, particularly the labour costs, of cultivating grafted tomato plants were notably greater, but the difference in revenue was large enough to make them much more profitable.

Based on the average difference in profits between grafted and non-grafted tomato plants, the estimated profit in Lam Dong province for tomato farmers was USD 41.7 million higher than if the same area had been planted with non-grafted tomato plants. The study clearly shows that in areas where bacterial wilt and other soil-borne diseases affecting tomato plants are a problem, tomato grafting can deliver monetary benefits to farmers.

BOX 6. Low-cost anti-insect netting for small-scale vegetable growers in Africa.
Source: Martin et al. *(2019)*

Since 2006, the African manufacturer A to Z Textile Mills Ltd in the United Republic of Tanzania, national and international research organizations, and farmers from Benin and Kenya, have been investigating the potential of nets to control pests in small-scale fruit and vegetable cultivation in tropical Africa. The technique applies the same principles of using mosquito nets to protect human health to fruit and vegetable crops. The main purpose is to reduce the use of pesticides, which are often applied weekly to tomato crops in open field cultivation, by placing a physical barrier between the crop and the pest. Participatory approaches were followed to address the agronomic and economic impacts of the netting, as well as their environmental impacts and social acceptability.

On-station experiments were carried out to design the best net mesh, colour and thickness depending on the crop (tomatoes, cabbage, beans) and the targeted insects (moths, aphids, white flies). On-farm trials then collected information on the most economic and appropriate ways of handling, storing and recycling the netting. Most of the results were encouraging, and small-scale farmers in Benin, Kenya and Senegal adopted the nets whenever they were available.

A cost benefit analysis in Benin revealed that using nets on cabbage crops is three times more profitable than the current practice. However, farmers in Benin, also stated that investment costs and the limited availability of nets, as well as the labour costs involved in the time and effort it took to manage small nets in a large field were constraints that made them reluctant to invest in them.

of grapevines. The insect had been introduced from North America and the solution was to graft North American grapevine rootstock, which had developed a resistance to *phylloxera*, with scions from the European plants. To this day, there is no other cure for *phylloxera.*

Vegetable grafting is also an old practice, but it only became widespread in the twentieth century. It began in the 1920s when resistant rootstocks were used in Japan and Korea to control Fusarium wilt, a soil-borne disease in fruit and vegetables caused by the fungus, *Fusarium oxysporum.* The practice is now rapidly spreading and has expanded to include vegetables such as cucumber, melons, eggplant, tomato, pepper and several other solanaceous crops. Vegetable grafting can make these crops more tolerant to a number of other widespread soil-borne diseases, such as bacterial wilt, that used to be fought with chemical products that are now banned (e.g. methyl bromide), and different species of nematodes that are very difficult and expensive to control with chemical pesticides (**Box 5**).

Netting

Insect-proof nets (technically a form of protected agriculture) are physical barriers that cover fields to protect crops from flies, butterflies and moths, and depending on the mesh size, whiteflies, aphids and thrips. Many of these pests not only cause damage by eating the plants, but also act as vectors for disease-causing organisms, such as viruses and bacteria. Using nets reduces the need for insecticides and protects crops from pesticide resistant populations of insect pests (Martin *et al.,* 2015).

Under the appropriate climate conditions, and with careful management of possible higher temperatures under the netting, there are numerous benefits of insect-proof nets in tropical fruit and vegetable production (**Box 6**), such as:

- They are safe for human health and the environment compared to pesticides.
- For the greenhouses, 50 mesh anti-insect nets are usually recommended in combination with other sustainable protective measures (sticky tapes, disinfection at the entrance, etc.), which can reduce the use of insecticides by 70 to 90 percent.

- Anti-insect nets are also compatible with biological control options, such as using natural enemies of crop pests (predatory mites, small parasitoids) and insect attractants or repellents.

- They improve yields and the marketability of the vegetables.

- Investments in netting are recouped in one year and the nets last for three to five years after which they can be recycled.

- They are recommended for vegetable and fruit nurseries to produce disease free seedlings for transplanting to fields.

- The effectiveness of some biopesticides may be improved under the nets as a result of UV protection and microclimate enhancement.

- They also protect fruit orchards from hailstorms.

In fruit crops, physical protection against pests can be done by placing bags over the developing fruit. This practice, which originated in Asia, has been spreading to other regions. Fruit bagging is a plant protection option that requires significant inputs and is labour-intensive but has proven effective at reducing pesticide use and can contribute to improving the overall appearance of the fruit.

Soil solarization and heat treatments

Soil solarization is a physical method used in warm climates for destroying soil-borne pathogens. It is a mulching process used primarily for vegetable crops that involves covering moist soil for a minimum of one to two months during the summer in transparent plastic film and leaving it exposed to sunlight. Soil-borne organisms are killed by the high temperatures that occur during the solar heating. Thermotherapy is also a physical method for eliminating plant pathogens, particularly fungi, viruses and bacteria. Simple in principle, it consists of heat treating plant parts at temperature/time regimes to kill the conserved pathogen and that only slightly injures the host. Heat is applied mainly by water, air or vapour. A large variety of plant parts can be heat treated: whole trees, scions, *in vitro* plantlets, seedlings, stalks, cuttings, sprouts, cut flowers, seeds, bulbs, tubers, corms, or fruit and vegetables in storage (Galindo *et al.*, 1994).

Biological control

The use of biological control agents is a proven technology for fruit and vegetable crops. These control agents are organisms that feed on pests, pathogens (fungi, bacteria, nematodes) or weeds (Beed and Dubois, 2009).

Biological control can be mediated in three ways (Beed *et al.,* 2011):

- conserving natural enemies of pests and diseases;
- augmenting the numbers of these natural enemies; and
- introducing new enemies.

Conserving natural enemies that act as biological control agents can involve providing alternative hosts or prey, food or nesting sites, or modifying cropping practices to favour natural enemies. The conservation of biological control agents can also be enhanced by maintaining semi-natural areas near the fields. These uncultivated spaces provide beneficial organisms (pirate bugs, ground beetles, lacewings, ladybirds, hoverflies and parasitoid micro-wasps) with habitats from which they can manage insect pests of crops. Nine out of ten natural enemies of pests (as opposed to only five out of ten pest species) need to retreat to semi-natural habitats at some time of the year in order to complete one or more phases of their life cycle.

Augmenting biological control involves increasing the numbers of natural predators and parasitoids or pathogens of crop pests and diseases. This can be done through commercial biological pest control products, such as insecticides that contain the naturally occurring pathogens of fruit and vegetable pests (*Bacillus thuringiensis,* a bacterium; or *Beauveria bassiana,* a fungus). Biological control can also be augmented by releasing, at strategic times, large numbers of mass-reared natural enemies of crop pests, such as lacewings (Neuroptera: Chrysopidae), predatory mites (Acari: Phytoseiidae) and flower bugs (Hemiptera: Anthocoridae). This service is often carried out by commercial or government institutions, although there are some small-scale businesses also raising beneficial insects.

Introducing exotic natural enemies of fruit and vegetable pests and diseases as biocontrol agents is a complex and environmentally sensitive process, and is usually undertaken, or regulated, by public organizations, and done on a large scale in collaboration with farmer groups and agricultural research and development institutions (Upanisakorn *et al.,* 2011). For example, from 1989 to 1992, the Asian Vegetable Network (AVNET), united national agricultural research systems in Indonesia, Malaysia, the Philippines and Thailand to implement an IPM programme to control the diamondback moth. The programme included introducing exotic parasitoid wasps (*Diadegma semiclausum, Diadromus collaris*), releasing indigenous wasps (*Cotesia plutellae* and *Trichogrammatoidea bactrae*) that kill diamondback moth larvae, and applying biopesticides containing *Bacillus thuringiensis* (AVRDC, 1993). The introduced species are quite vulnerable to pesticides, so farmers had to work together to adopt IPM strategies to reduce their pesticide use in order to allow the new predator insect species to establish themselves. Farmer Field Schools (FFS) were used as a means of informing the farmers about biological control methods and fostering collective action. For farmers involved in the field schools, the programme resulted in increased production and significant reductions in pesticide use and associated costs.

A similar programme using FFS was then carried out in Viet Nam in 1996 by the country's Plant Protection Department with the support of the FAO Regional Vegetable IPM Programme and the international development organization Centre for Agriculture and Bioscience International (CABI) (Guan Soon, 1997; Nga and Kumar, 2008). From 2000 to 2008, with funding from the International Fund for Agricultural Development (IFAD), the International Centre of Insect Physiology and Ecology (ICIPE) worked with national agricultural research and extension systems in Ethiopia, Kenya, Uganda, and the United Republic of Tanzania to implement IPM for brassica farmers that included rearing, releasing and monitoring *Diadegma semiclausum* as a biological control agent, which was imported from the World Vegetable Center in 2001 (Momanyi *et al.,* 2006). From 2012 to 2016, a scaling-up project was carried out in Malawi, Mozambique, Rwanda and Zambia. A comprehensive overview of past and more recent experiences was made by Bonsignore and Vacante (2017).

The sterile insect technique and area-wide integrated pest management

This is an environmentally friendly technique that has been used for over 60 years to control insect pests of livestock and fruit and vegetable crops as well as insects that act as vectors of diseases. It involves mass breeding of specific flying insect pests and sterilizing the male flies with low doses of radiation. Released into infested areas, the sterile males mate with wild females. If the sterile males vastly outnumber the fertile wild males, the wild fly population quickly dies out.

For this technique to be cost-effective, the density of the pest population in the wild must already have been reduced to low levels through area-wide IPM strategies that include insecticide baits, orchard sanitation practices and biocontrol agents. Such programmes are complex and long-term and require research, feasibility studies, regulatory measures and field pilot studies before they can become operational. To be successful, these programmes demand a collective effort by farmers and farmer organizations, national plant protection organizations, government agencies, and the private as well as the public sector. FAO and the International Atomic Energy Agency (IAEA) have played a fundamental role in supporting countries all over the world to implement these programmes.

Used in combination with area-wide IPM strategies, the sterile insect technique has been successful in controlling species in the fruit fly family (Tephritidae); for example, the technique was used in programmes to eradicate the Mediterranean fruit fly (*Ceratitis capitata*) from Mexico and parts of Guatemala (1984), northern Chile (1995), southern Argentina (2004) and the Dominican Republic (2017). As a result of these programmes, pesticide use has been reduced and the countries have overcome phytosanitary barriers and are now able to export fruit to profitable markets in North America and Asia. Chile and Mexico, in particular, have become two of the leading fruit-exporting countries in the world.

The technique has also been used to eradicate the Mediterranean fruit fly in other regions, for example in Western Australia. In the Hex River Valley in South Africa, it has been used to create an internationally recognized area of low pest prevalence for the fruit fly, and has substantially reduced control costs for grape producers and has lowered the number of produce rejections by phytosanitary inspectors.

Other species of fruit fly that have been controlled using the sterile insect technique include the Mexican fruit fly (*Anastrepha ludens*), which has been eradicated from California and Texas, in the United States of America, as well as from northern Mexico where the West Indian fruit fly (*Anastrepha obliqua*) has also been eradicated. In Asia and the Pacific, the technique has been used as part of an area-wide IPM programme to eradicate the melon fruit fly (*Bactrocera cucurbitae*) from Okinawa in Japan and the Queensland fruit fly (*Bactrocera tryoni*) from Western Australia. In Thailand, the technique has been used successfully to suppress the Oriental fruit fly (*Bactrocera dorsalis*) and reduce losses for fruit producers.

The technique can also be used on fruit against moth pests. In Mexico in 2009, an outbreak of the Cactus moth (*Cactoblastis cactorum* (Berg)) was controlled and the pest eliminated from islands off the Yucatán Peninsula. In New Zealand, the technique was used to eradicate the Australian painted apple moth (*Teia anartoides*). In the Okanagan valley of British Colombia, the technique has been used since 1994 to suppress the codling moth (*Cydia pomonella*) in apple and pear orchards and in South Africa since 2007 to suppress the false codling moth (*Thaumatotibia leucotreta*) in citrus groves.

The technique has also been used to suppress the onion fly (*Delia antiqua* (Meigen)) in the Netherlands. Since onion flies do not disperse widely, individual growers can purchase sterile insect technique services from private companies (FAO, 2019d; Marec and Vreysen, 2019).

Crops and varieties and access to genetic resources

The tremendous genetic diversity of fruit and vegetable species and varieties provides options for small-scale famers to grow crops that are adapted to their specific environment and markets. To realize this potential, the seeds and planting materials used must be of high quality (homogeneous, disease free and with high germination rates and vigour).

Access to seeds and planting materials

Whatever crops they grow, farmers obtain their seeds and planting materials through either informal or formal seed systems. In informal systems, farmers save seeds and planting materials from their own crops, collect seeds from neighbourhood seed stands or from high-performing trees, trade for seeds and planting materials with other farmers, or purchase seed and planting materials from non-regulated local seed producers and traders, non-governmental organizations (NGO) or community-based schemes. FAO has produced and regularly updates the Voluntary Guidelines for National Seed Policy Formulation (**http://www.fao.org/seeds/en/**) and a six-module seed toolkit to impart the knowledge and skills needed to deliver high-quality seeds and planting materials of well-adapted crop varieties to farmers.

In a formal system, farmers obtain the seeds and planting materials of clearly indicated varieties whose traits and quality have been assured or certified through a rigorous regulatory process. In many cases, farmers access these seeds and planting materials through agrodealers which themselves have access to national or transnational seed companies.

In some countries, government or parastatal seed suppliers, agricultural universities, or national and international agricultural research institutions may also be sources of certified seeds. In some West and Central African countries, it has been noted that cooperatives have become registered as certified seed producers and can be viewed as being part of a formal seed system. Their portfolios generally feature crops not covered by seed companies, with different cooperatives producing seeds for indigenous and traditional vegetables. However, the long-term viability of seed-producing cooperatives is not always certain (Access to Seeds Foundation, 2018).

Many small-scale farmers do not rely on a single system – they use the two systems in different ways depending on their specific needs and resources (Sperling and Cooper, 2004). It is, therefore, important not to prioritize one system over the other. To ensure that small-scale farmers can access and afford the vegetable and fruit crop diversity they need, both formal and informal seed systems need to be strengthened and treated as complementary services (Croft *et al.,* 2018).

In general, vegetables are annual crops grown from seed whereas the main fruit crops are perennial grown from vegetatively propagated materials. For this reason, fruit and vegetables are considered separately.

Vegetable crops

The percentage of vegetable seeds received through formal systems is far greater than for other food crops; for example in West and Central Africa in 2013 only 12 percent of arable farms used certified seed, and in a nine-country study, formal systems supplied less than 5 percent of seed used by small-scale farmers for most cereal and legume crops, but for vegetable crops this was over 20 percent (Djamen, 2016; McGuire and Sperling, 2016). A seed survey in the Sudan found that 90 percent of seed used by farmers came from the informal sector, but for vegetable seed, the percentage was only 53 percent. The remaining seeds were imported varieties (29 percent) and locally certified varieties (18 percent). The seed obtained from the informal sector included leafy vegetables, such as arugula, parsley, fennel, jute mallow (*Corchorus olitorius*) along with beet, squash and chili pepper. Imported certified seeds were used for watermelon, sweet melon, carrots and tomatoes, and locally-certified seed were used for okra and eggplant (Key2Market, 2018).

A common assumption is that traditional crops and varieties are associated with informal systems and that improved varieties are associated with formal systems (Sperling and Cooper, 2004). In the United Republic of Tanzania, 70 to 75 percent of traditional vegetable seed originated in the informal sector (Ellis-Jones *et al.,* cited in FAO and ICRISAT, 2015). However, for exotic species, most farmers cultivated certified varieties, even in sub-Saharan Africa, in part because of relatively modest seed costs (Ellis-Jones *et al.,* cited by Lynam *et al.,* 2010). A survey from 2000 in Nigeria, found that for tomato, okra, amaranth and hot pepper most farmers bought seeds of improved varieties from agrodealers that were produced by either private companies or national agricultural research institutions, and there was minimal seed exchange between farmers (Daniel and Adetumbi, 2004). This suggests the disappearance of indigenous varieties, species and landraces, and the dependency of farmers on a restricted choice of exotic ones, with impacts on food sovereignty.

While some NUS of vegetables are associated with informal seed systems it is important to stress that NUS often predominate in local markets, despite not being major global commodities. A market survey in the town of Foumbot in Cameroon found that African nightshade (*Solanum nigrum*), an indigenous vegetable, was sold by the largest share of vegetable vendors (26 percent) followed by tomato (25 percent), and that more vendors sold garden egg (*Solanum gilo*), an indigenous variety of eggplant, than green peppers, carrots and lettuce (Schippers, 2000). For African leafy vegetables in western Kenya, 72 percent of growers sourced seeds from local markets and then saved their own seeds when possible (Abukutsa-Onyango, 2005).

Neglected and underutilized species, being adapted to local environments and with long-standing consumer acceptance, have been described as ''development opportunity crops'' (Kahane *et al.,* 2013). Further adoption would be facilitated by greater access to high-quality seeds, particularly in Africa (Schippers, 2000; Adebooye *et al.,* 2005).

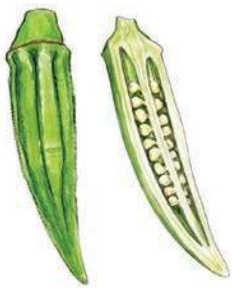
□ *Vegetable seed production*

For cereals, there is no botanical distinction between seed and grain (the edible part of the plant is the same as that used to grow crops), but for vegetables the edible part of the plant is different to the seed used to grow the crop (although the seed may also be eaten). Therefore, the multiplication of vegetable seeds is a specialized process that is distinct from food production. This specialization creates numerous distinct challenges for small-scale farmers and informal seed suppliers, and partly explains why the cost share of vegetable seeds is higher relative to cereals. However, this demand for specialized seed services provides opportunities to develop local enterprises to supply farmers with high-quality seeds through an intermediate or semi-formal seed system.

To produce vegetable seeds that are true to type (that will generate a plant with the same desirable traits as its parents), the mode of pollination must be understood. Many major vegetable crops (tomatoes, green peppers and chili peppers, eggplants, green beans, lima beans, sweet peas) are self-pollinated and thus do not need pollinators (birds, insects or bats), or other agents (wind, water) to reproduce. But if they are grown in greenhouses, the flowers must be gently shaken by hand or by an insect (often bumblebees) to ensure pollination. Seeds that are saved from these crops are likely to have relatively little genetic variation from one generation to the next, except when first generation (F1) hybrid seeds were used.

Cross-pollinating crops (brassicas, cucurbits) require pollinators and are at risk that the plant with the desired traits will receive pollen from plants of different varieties. For some crops (such as carrots), cross-pollination can be from weedy varieties and the seeds produced will be genetically different from the parents and will not be true to type. Cross-pollinating crops and also self-pollinating crops that cross-pollinate easily (such as amaranth, onion), need to be grown isolated from other varieties (sometimes up to one kilometre) or under a protective net to ensure that the seeds produced are genetically identical to their parents.

For seed processing, the methods will also vary depending on the type of vegetable. The seeds of leafy vegetable crops (amaranth, lettuce) and some other vegetables (okra) can be dry processed using mature seeds collected from plants (threshing, winnowing, cleaning). The seeds from vegetables that are botanical fruit (tomatoes, cucurbits, eggplants) must be wet processed (separated from the fruit structure, cleaned and dried). After processing, the seeds must be stored properly in dry and cool conditions to minimize respiration and to protect them from pests and diseases. This is critical to ensure their viability and health status. In tropical countries with hot and humid climates, it can be challenging or costly to maintain adequate seed storage conditions, particularly when electricity for cooling and drying is unavailable or unreliable. Furthermore, prior to planting some seeds (such as tomato), the seed will also need to be soaked in water or fermented, a prerequisite for seed germination.



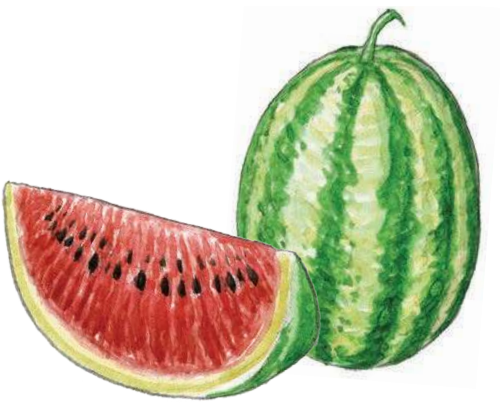
Okra *(Abelmoschus esculentus L.)*

Seed produced locally by farmers and communities can often become infected by seed-borne or seed-transmitted viruses, fungi, bacteria and insects, and they may include an undesirable degree of genetic variation, which will reduce the crop yield and perhaps even lead to complete crop failure. To satisfy the demand for high-quality vegetable seed, it is critical that informal systems are provided with the necessary technical capacity (FAO and AfricaSeeds, 2018). Along with these challenges, local suppliers operating at a semi-formal level must also contend with difficulties related to economies of scale to provide high-quality seed that is also affordable.

◻ *Formal seed systems*

It is the formal seed system, especially private and global companies, that plays a significant role in supplying vegetable seeds to small-scale farmers, though with a lesser reach in Africa. Government and parastatal seed companies, generally focusing more on staple crops, continue to operate in some countries, but their prominence has diminished in the wake of the deregulation and privatization of the seed sector in the late 1990s. In Asia, where there is a strong consumer demand for fresh vegetables, there has been particularly strong growth of the private sector into the vegetable seed market (Lynam *et al.*, 2010; Spielman and Kennedy, 2016; FAO, 2020b).

In 2019, the Access to Seeds Foundation published the second edition of the *Access to Seeds Index,* covering 62 global and regional seed companies of which 28 sell vegetable seed, from South and Southeast Asia, Eastern and Southern Africa and Western and Central Africa (Access to Seeds Foundation, 2019). Some seed companies are state-owned enterprises (Ethiopian Agricultural Business Corporation, Kenya Seed Company, National Seeds Corporation from India, Punjab Seed Corporation from Pakistan and Vinaseed from Viet Nam) and one was a large NGO (BRAC Seed and Agro Enterprise in Bangladesh). The 2019 *Access to Seeds Index Synthesis Report* notes that small-scale farmers constitute a relatively new clientele. However, two global companies were exceptions: Advanta (the global seed enterprise of United Phosphorus Ltd, an Indian multinational focusing on agricultural inputs and East-West Seed (Thailand). East-West Seed, whose seed portfolio focuses heavily on vegetables, has a business model based almost exclusively on supplying seeds and relevant technical support such as agronomic guidance to small-scale farmers. It is, therefore, not surprising that East-West Seed had the Index's highest ranking in South and Southeast Asia. In Eastern and Southern Africa, the regional seed company, East African Seed (Kenya), ranked highest and in Western and Central Africa, it was Value Seeds (Nigeria). Seed companies sometimes include local vegetable



Watermelon
(Citrullus lanatus)

crops, which the Index also refers to as NUS crops, with East-West Seed selling the most with 16 species, Technisem (France), which is the largest portfolio of local crops available in Western and Central Africa, sells nine, and Limagrain (France), whose clientele is 81 percent small-scale farmers, sells seven.

African eggplant
(Solanum macrocarpon L.)

For cross-pollinated and fruiting vegetable crops, global seed companies concentrate on selling hybrid varieties, which are obtained through the controlled cross-pollination of two parent lines, each with desirable traits. Seeds from hybrid varieties will not breed true, so there is no benefit to farmers saving these seeds. Hybrids offer seed companies repeat revenues from annual purchases and offer small-scale farmers higher yields and other desirable traits, such as greater resistance to abiotic stress, pests and diseases, and early and uniform ripening.

The open-pollinated vegetable crops (non-hybrid) will breed true for several seasons and thus are suitable for farmers to save. A few smaller regional seed companies, especially in Africa, offer portfolios with a mix of hybrid and open-pollinated varieties. Several global companies, Advanta, East-West Seed, Limagrain, Sakata (Japan) and Technisem focus on both open-pollinated varieties and hybrids. Many of the local vegetable crops sold are open-pollinated varieties (onions in West Africa, for example). It is common for farmers to use saved seeds from open-pollinated varieties before purchasing new seed (Access to Seeds Foundation, 2019).

Small-scale farmers will not benefit from improved seed purchased through formal systems, and seed companies will not gain repeat customers unless the seed companies offer their clients guidance and support in adopting farm management techniques that will deliver the promised increases in productivity. Most of the seed companies covered by the *Access to Seeds Index* provide extension services to their clients. However, these capacity building activities are mostly limited to companies' primary markets and, as a result, small-scale farmers in many countries, particularly in Western and Central Africa and Latin America, do not receive support.

Half of the seed companies covered by the Index incorporate small-scale farmers in their seed production activities. Corteva Agriscience, which has no vegetable seeds in its portfolio, involves small-scale farmers in all of its seed production locations in the countries included in the Index. East-West Seed and Advanta involve small-scale farmers in their seed production in most of the countries where they produce seeds.

The 2030 Agenda for Sustainable Development recognizes the need for public-private partnerships to achieve the SDGs. The fact that Mr Simon

Groot, the founder of East-West Seed, was awarded the 2019 World Food Prize because of the company's clear commitment to improving the livelihoods of small-scale farmers is a recognition of the important role private sector companies play in supporting sustainable agricultural development.

Fruit crops

Farmers cultivating perennial fruit crops do not need to obtain seed every year but do require high-quality planting material to establish their orchards or plantations or natural stands. As with vegetables, fruit are diverse, and the constraints related to small-scale farmer access to planting materials are connected to how different species reproduce. In this respect, it is convenient to divide fruit crops into two main types: woody fruit crops, which include fruit trees (mango, oranges, avocado) plus fruit vines (grapes, kiwis and berries), and herbaceous fruit crops (banana, pineapple and strawberries).

□ *Woody fruit crops*

Fruit grown on trees or vines can be cultivated from seed (if they are not a seedless hybrid variety). However, because fruit trees are cross-pollinating, trees grown from seed will not produce fruit with the same uniform characteristics as the parent. To obtain trees and vines that will produce the fruit of the desired quality, market-oriented fruit growers need access to seedlings that are genetic clones of the parent plant by having been produced through vegetative propagation or grafting. Vegetatively propagated or grafted fruit trees provide high-quality, true to type fruit and maturity is reached more rapidly than if trees are grown from seed.

Vegetative propagation of fruit trees and vines can be undertaken using different methods:

- Planting stem cuttings to take root in soil, which is applicable to only a few tropical fruit such as pitaya or dragon fruit (*Hylocereus* spp.), cactus pear (*Opuntia* spp.) and spondias (*Spondia* spp.);

- Air layering involves developing roots on a stem that is still attached to the parent plant before cutting and planting, which is applicable to tropical fruit such as guavas, lychees and longans; and

- Grafting involves splicing scions to robust rootstock, which is applicable to major temperate, tropical and semi-tropical fruit tree species (Wasielewski and Balerd, 2019).

The vegetative propagation of fruit trees is a delicate, specialized process that is both labour and knowledge intensive. Market-oriented small-scale farmers seeking either to embark on a decades-long venture to integrate fruit trees into their production system, or to upgrade or diversify their existing fruit production must be assured that they have disease-free certified planting materials. This material can generally only be obtained through commercial nurseries, or in some countries through government-run nurseries. In many countries of sub-Saharan Africa, the number of nurseries capable of producing high-quality fruit tree seedlings is limited. Relative to other crops, informal systems will play a considerably less prominent role in supplying tree fruit crop planting material to small-scale farmers.

□ *Herbaceous fruit crops*

Traditionally, the major tropical herbaceous fruit crops, banana and pineapple, are multiplied by uprooting the suckers, the lateral shoot that develops from the mother plant. For pineapple, the crown can also be used as planting material. Large-scale banana producers that focus on a single type of banana (such as the most widely exported variety, Cavendish) and research institutes can produce millions of pest-free and high-quality tissue culture plantlets through *in vitro* cultivation. While Cavendish bananas account for nearly half of global banana production, there are over 1 000 varieties grown around the world. In Africa, which is the third largest regional producer, between 70 to 80 percent of the production are local varieties (OECD and FAO, 2020).

Small-scale banana farmers rely heavily on informal systems for obtaining suckers and grow a range of cultivars. In a study from the Mukono district in central Uganda, banana farmers grew 10 different banana cultivars and were aware of 40 others (Kilwinger *et al.,* 2019). This diversity ensured that harvesting could be done all year and reflects the many different uses of the banana cultivars: for cooking, dessert, roasting and brewing. Other parts of the plant are used for fodder, packaging, mulch, fibres and the male flower is consumed as a vegetable. Farmers obtained most of their suckers (almost 60 percent) from their own farms, as well as from friends, relatives and neighbours with only 5 percent supplied through the national agricultural advisory services and the government extension programme. The farmers preferred to source suckers from existing mats on their own farm because they were familiar with their properties and performance. Sourcing planting material through informal seed systems presents the risk of spreading pests and diseases and new techniques need to be developed.

● Breeding

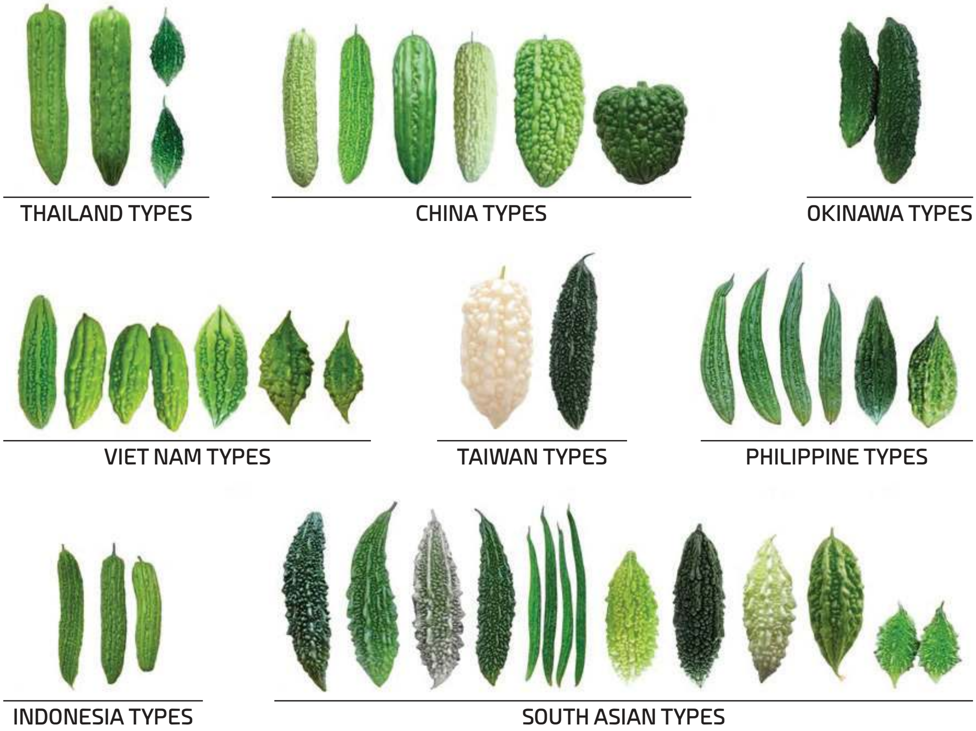
Developing and selecting new varieties with improved traits (nutritional density, taste, shape, colour, cooking times, the removal of anti-nutritional compounds, high yields, hardiness to pests, diseases, temperature and water fluctuations, salinity and suitability for transport, storage or processing) is of critical importance to provide small-scale farmers with options suited to their environments and markets.

Historically, farmers, through the careful selection of plants that meet their particular environmental and cultural needs, have helped make available the great diversity of fruit and vegetables that exist today. In the last century, formal plant breeding has become increasingly sophisticated and demands significantly high fixed costs in terms of fields, equipment and scientific expertise. It can take between 5 to 20 years of research to develop an improved variety and the process to register a variety in a country or region can also take a few years and significant investments. In general, only large private companies or subsidized public entities can afford such ventures (Minot *et al.*, 2007). However, in Asia smaller companies have started developing their own vegetable varieties (Schreinemachers *et al.*, 2017a). Countries that do not have mature breeding programmes or a viable seed industry must rely on imported seeds that will not always include varieties adapted to local conditions and markets (cabbage seeds are imported by South Asian countries, carrot seeds are exported by New Zealand).

Vegetables

The 2019 *Access to Seeds Index* found that in South and Southeast Asia, the portfolios of all the regional companies involved included vegetables, and all of the companies, except two that were state-owned, have breeding programmes. However, for both Eastern and Southern Africa and Western and Central Africa, breeding activities were largely limited to maize with very little attention paid to vegetables.

BOX 7. The cucurbit breeding programme of the World Vegetable Center and private sector partnerships. *Source: Dhillon* et al. *(2016; 2020a,b)*



The global cucurbit breeding programme of the World Vegetable Center focuses on four species: bitter gourd (*Momordica charantia*), tropical pumpkin (*Cucurbita moschata*), ridge gourd (*Luffa acutangula*), and sponge gourd (*Luffa cylindrica* syn. L. *aegyptiaca*). This programme is based in Thailand and recognizes that cucurbit crops make an important contribution to global food and nutrition security and are economically important to small-scale farmers, who account for 83 percent of global cucurbit production in Asia.

Considering bitter gourd; there are a range of shapes, spine types, colours, tastes and cooking characteristics favoured by different markets.

While improved varieties have been developed by the private seed industry, repeated recycling of lines derived from elite hybrids has narrowed the genetic base and reduced genetic gains for yield and other key traits. What is required is a concerted effort to introduce new genetic variability into elite hybrids.

The World Vegetable Center developed a breeding consortium with various seed companies to facilitate access to the Center's new breeding lines derived from hitherto unexploited landraces to develop genetically diverse, improved cucurbit cultivars with higher yields and enhanced resistance to major diseases. Private seed industry staff engaged in breeding, product development, sales and marketing select lines and F1 hybrids based on their performance and characteristics demonstrated through annual field visits.

The benefit to the World Vegetable Center is continued financial support, while each seed company obtains lines with improved traits that can be incorporated into their breeding programmes for eventual varietal registration and mass seed production and distribution (protected by rigorous quality assurances). The benefit to small-scale farmers is access to affordable seeds of improved varieties.

BOX 8. Fruit and vegetables in the International Treaty on Plant Genetic Resources for Food and Agriculture. *Source: International Treaty for Plant Genetic Resources for Food and Agriculture (http://www.fao.org/plant-treaty/en/)*

The International Treaty on Plant Genetic Resources for Food and Agriculture was adopted by the Thirty-First Session of the FAO Conference in 2001. The objectives of the International Treaty on Plant Genetic Resources for Food and Agriculture are the conservation and sustainable use of all plant genetic resources for food and agriculture and the fair and equitable sharing of the benefits arising out of their use, in harmony with the Convention on Biological Diversity, for sustainable agriculture and food security. The Treaty established the Multilateral System (http://www.fao.org/plant-treaty/areas-of-work/the-multilateral-system/the-smta/en/) for access and benefit sharing that places 64 of the world's most important crops into an easily accessible global pool of genetic resources that is freely available to potential users in the nations that have ratified the Treaty for research, breeding and training for food and agriculture under a Standard Materials Transfer Agreement.

The fruit and vegetables included in Annex 1 of the Treaty are:

- Vegetables: asparagus, beet, brassica, carrot, eggplant;
- Fruit: apple, banana, breadfruit, citrus, strawberry.

Due to the impacts of disasters and climate change, breeding for tolerance to abiotic stress and resistance to pests and diseases is recognized as a priority. Although some breeding has been done to improve the provitamin A content of some staple crops (orange fleshed sweet potato, yellow cassava and yellow corn), breeding for higher nutritional value remains the lowest priority in breeding programmes (Access to Seeds Foundation, 2019).

The seed portfolios of the world's largest seed companies have been significantly shaped by the work carried out by national and international research institutes, and for vegetable varieties the World Vegetable Center has made critical contributions. Based on available information on companies' sourcing of varieties, three-quarters of market varieties were developed by national and international agricultural research institutes. For regional companies, the share was 80 percent; for global companies, 50 percent. State-owned companies almost exclusively sell varieties developed by their national agricultural research system, though on a limited scale.

These figures illustrate how partnerships between public organizations and private companies have been critical for both the development of new vegetable varieties and their delivery to farmers.

In 2017, the World Vegetable Center and the Asia and Pacific Seed Association (APSA) jointly established the APSA-WorldVeg Vegetable Breeding Consortium in order to further strengthen these partnerships. In 2018, the World Vegetable Center and the African Seed Trade Association (AFSTA) jointly formed the Africa Vegetable Breeding Consortium (AVBC). The cucurbit breeding programme of the World Vegetable Center has been particularly innovative in seeking support from private seed companies to benefit small-scale farmers (**Box 7**). Several global vegetable seed companies have also come together to establish the International Licensing Platform, which ensures companies have access to vegetable germplasm on reasonable terms for breeding purposes.

Plant breeders, both public and private, recognize the need to develop appropriate traits in their varieties through cooperation with small-scale farmers. This can be achieved through participatory varietal selection, as was done, for example, for African vegetables in Mali (Diouf, Gueye and Samb, 2017). This process is considered to be particularly relevant for areas that do not have prime agricultural land to grow more local crops (Weltzien *et al.*, 1999). A review of publications on participatory plant breeding found few were focused on vegetables (Ceccarelli and Grando, 2020). For an example of participatory plant breeding for tomato in Spain, see Casals *et al.* (2019).

Once new breeding lines are developed their availability may be limited to the public or private companies that have invested in creating them, or limited to the country where they originate, by global regulations from the Convention on Biological Diversity or national regulations depending on whether governments have ratified and complied with the Nagoya Protocol. While an International Treaty was established to facilitate the accessibility of several crops recognized as being of critical importance to agriculture in the developing world, the number of fruit and vegetable species is limited, and efforts to increase this number would support the global development of the sector (**Box 8**).

Fruit

Given the time it takes for fruit trees to reach maturity, the process of breeding more adapted varieties of these species is much slower than for vegetable crops. Only the major tropical fruit crops (avocado, banana, citrus, mango, papaya, pineapple) as well as (water)melons, are subject to significant breeding activities, and these are driven by the demands of large-scale producers and international trade markets.

Conservation

The conservation of plant genetic resources for food and agriculture serves to maintain genetic diversity among and within plant species. Conservation strategies include safeguarding resources such as crop wild relatives (CWR) *in situ* (in their natural habitats); managing a diversity of crops and their varieties on-farm (including farmers' varieties, landraces and NUS); and conserving samples (accessions) *ex situ* in genebanks (FAO, 2017b). Much of this plant diversity is important for cultivating and breeding well-adapted crop varieties that are suited to various environmental conditions and/or that fulfil consumer preferences.

The breeding of high-quality and well-adapted fruit and vegetable varieties, and their adoption by small-scale farmers, is a prerequisite for production systems that are sustainable and inclusive. The genetic material from local varieties and their wild relatives is of crucial importance in developing improved varieties, such as for tomatoes. Virtually all significant disease resistant genes have been sourced from wild relatives (Ebert and Schafleitner, 2015). Therefore, breeding of fruit and vegetable varieties must be supported by conservation and characterization of their genetic diversity combined with that of their wild relatives.

In situ conservation

Conservation of genetic resources *in situ* involves locating, describing the conservation status, and actively managing and monitoring targeted wild plant populations in their natural habitats. Many populations of CWR are at considerable risk from drivers such as habitat loss, habitat fragmentation, changes in land use and disasters and climate change. Unfortunately, many countries lag behind in protecting CWR, especially in their natural environments, despite the increased public, political and scientific interest in conserving plant genetic resources (FAO, 2017c).

On-farm management

A significant amount of crop diversity is maintained only in farmer's fields, orchards or home gardens (FAO, 2019c). Many farmers continue to cultivate farmers' varieties and landraces due to agronomic, culinary, or quality preferences as well as locally important cultural values.

This continued on-farm management of diversity results in exposure to different production regimes, environments, farmers' selection and seed exchange systems, contributing to their continued evolution and adaptation (Jarvis *et al.*, 2000). Unfortunately, crop diversity managed on-farm is also threatened by urban encroachment on farmland, unsustainable use of natural resources, introduction of alien invasive species and climate change, as well as the absence of, or inappropriate, legislation and policy, and the promotion of genetically uniform varieties in replacement of local varieties and changing patterns of human consumption (Dhillon *et al.*, 2016, 2020a,b; FAO, 2019c). Efforts in this area require, and create opportunities for, collaboration between farmers, breeders and organizations working to conserve genetic resources. For an example of community-based conservation and sustainable use of cultivated and wild tropical fruit tree diversity, see Sthapit *et al.* (2012).

Ex situ conservation

The conservation of plant genetic resources *ex situ* in genebanks safeguards a large and important number of resources that are vital to present and future global food security. Conservation in genebanks and other facilities includes storage of seed in seed genebanks and safeguarding species that produce nonorthodox seeds or propagate clonally as live plants in field genebanks or as plantlets through *in vitro* culture or cryopreservation (FAO, 2014a). *Ex situ* conservation involves the acquisition, storage, regeneration, characterization, evaluation, safety duplication and documentation of accessions.

It is crucial to secure adequate storage or maintenance conditions for the genetic materials already collected. This is possible through the application of standards and procedures that ensure their continued survival and availability (FAO, 2014a). Genebanks globally hold *ex situ* collections of a broad range of crop diversity, including CWR, with the overall aim of long-term conservation and the accessibility of plant germplasm to plant breeders, researchers and other users. Germplasm of crop species and their wild relatives is conserved in more than 700 genebanks worldwide, with approximately 5.4 million accessions maintained under medium- and long-term conditions (FAO, 2020a). Many ex situ collections, however, are still vulnerable, exposed to natural hazard-induced disasters and man-made calamities such as civil unrest, as well as lack of funding and/or poor management.

BOX 9. Germplasm collection of bananas in the world.

The world's largest collection of banana germplasm is maintained by the Bioversity International Musa Germplasm Transit Centre (ITC), hosted at the KU Leuven University, Belgium. The conserved germplasm, which includes more than 1 500 accessions of edible and wild species of banana, is placed in the Multilateral System of Access and Benefit Sharing of the International Treaty on Plant Genetic Resources for Food and Agriculture. The accessions are kept *in vitro* under slow growth conditions at 16 °C and the samples are also frozen to -196 °C through cryopreservation. The cryopreserved collection is duplicated at the *Institut de recherche et de développement* (IRD) in Montpellier, France. For more information about the long-term conservation and use of *Musa* genetic resources visit the site http://www.musanet.org/

Vegetable genetic resource conservation

Globally, about 1 million accessions of crops used at least partially as vegetables are conserved *ex situ*. For crops that are exclusively used as vegetables, there are about 500 000 accessions representing 7 percent of the 7.4 million accessions of plant genetic resources that are maintained *ex situ* (Ebert, 2013). Among vegetable commodities, tomato, capsicum, melon and cantaloupe, brassicas, cucurbits, alliums, okra and eggplant are well represented in *ex situ* collections at the global level, with between 22 000 and 84 000 accessions per vegetable group.

The WorldVeg Genebank (**https://avrdc.org/our-work/managing-germplasm/**) maintains the world's largest public vegetable germplasm collection with more than 65 000 accessions from over 150 countries of more than 450 species. The collection includes the WorldVeg Genebank in Arusha, United Republic of Tanzania, which maintains about 2 400 accessions of 35 traditional African vegetables. The World Vegetable Center collaborates in the collection and conservation of vegetable germplasm with national partners which maintain duplicate collections. Since 2013, 183 000 seed samples of promising accessions and open-pollinated breeding lines of traditional African vegetables have also been distributed to farmers in East Africa (Stoilova *et al.,* 2019).

Ex situ conservation of vegetable genetic resources in genebanks or botanical gardens removes the species from their natural ecological and evolutionary context, which leads to ''a 'static' conservation in which evolutionary and adaptive potential are frozen'' (Galluzzi *et al.,* 2010). *In situ* conservation of vegetable genetic resources (the management of genetic diversity and landraces on farms and in home gardens) is also critical and the best strategy is to have both (Galluzzi *et al.,* 2010; FAO, 2019c).

Fruit genetic resource conservation

The conservation of tree fruit genetic resources (and that of some perennial vegetables) is particularly challenging, as these species have recalcitrant seeds that cannot be dried and stored in cold conditions and, therefore, won't survive in genebanks. This makes it crucial to find solutions for their on-farm and *in situ* conservation. Efforts in this area will require, and create, opportunities for collaboration among farmers, breeders and organizations working to conserve genetic resources. For an example of community-based conservation and sustainable use of cultivated and wild tropical fruit tree diversity, see Sthapit *et al.* (2012).

• Protected cultivation systems

Protected cultivation includes different types of structures, providing a fully, partially or modified microclimate around the plants to protect them against adverse climatic conditions, and extending the cultivation season or providing out of season production.

Protected cropping system, low-tech (plastic tunnels)

Growing vegetables in greenhouses and nethouses is a common approach for many larger commercial growers (refer to the section on plant health for more details on netting as a crop protection technique). In some temperate countries, grapes are grown in protective structures, and growing bananas and sometimes papayas in greenhouses is becoming increasingly popular in places without the ideal conditions for the crop. However, in general, fruit trees are seldom grown under protected cultivation, as is more common for vegetables.

In some instances, the gradations between open field cultivation and protected cultivation can be difficult to discern. For example, the use of mulch is technically considered a protected cultivation technique. Protected agriculture also includes material or structures such as low tunnels that are set up over the bed rows, high shelters that are placed over the entire crop to protect the plants from harsh sunlight (shade nets), insects (insect nets), hail (hail nets) or heavy rains (rain shelters) and grafting chambers, which provide dark environments with high humidity to encourage adhesion between the rootstock and scion.

There are advantages to protected cultivation systems. In tropical countries, where high temperatures and high humidity create favourable conditions for many plant pests and diseases, the shift to protected cultivation is practiced to reduce problems with pests and diseases. Protected cultivation in the tropics also protects the crop against wind, drought, flooding and physical damage by heavy rains (FAO, 1999). In cooler climates, protected cultivation allows farmers to extend the growing season, and increase the number of harvests per year, and, perhaps, to achieve year-round production. This gives farmers the opportunity to meet consumer demand for out-of-season fresh produce and obtain higher prices on the market. Other advantages of protected cultivation include higher yields, quality and greater food safety but agronomic principals such as crop rotation or diversification are still required to avoid an accumulation of pests and diseases.

Protected cropping system high-tech (automatic glasshouse)

In all parts of the world, climate change is leading to greater seasonal variations in temperature and precipitation and extreme weather events are increasing in frequency and intensity. This makes it harder for farmers to plan their cultivation schedule and increases the risks of losses in production and quality. Protected cultivation can help farmers adapt to these impacts while also making more efficient use of land, water and nutrients.

Recently, vertical farming has been gaining more interest in places, such as in city centres, where there is limited access to land. Vertical farming is a broad term that includes open structures that use commonly known vertical spaces, such as walls or rooftops, as well as high-tech indoor farming structures with complete climate control. Vertical farming maximizes the use of limited space by increasing production upwards. In the cities of some upper- and upper-middle-income countries, plant factories and vertical farms are now supplying vegetables to urban consumers.

Whatever the level of technology, cultivating fruit and vegetables in greenhouses involves very different practices and technologies for managing water resources, protecting plants from pests and diseases, soil health and crop species and varieties. It should be noted that growers can combine open field cultivation with protected cultivation, such as when seedlings and other planting materials are raised in protected nurseries before being transplanted to open fields.

FAO has enabled technical networks to capitalize on experience and to exchange knowledge on protected cultivation in the Mediterranean climate areas and in south eastern European countries. This regional cooperation has resulted in the compilation and publication of two technical papers on good agriculture practices for greenhouse vegetable production in these regions (FAO, 2013c; FAO, 2017d).

Climate management

When growing crops under protected cultivation, farmers seek to create and maintain a stable microclimate within the structure that can provide the plants with the ideal conditions for growth. But there is no single type or design of greenhouse that can provide optimal results for plant growth in all settings. The selection of the greenhouse site and the type and design of the greenhouse will depend on the local climate conditions, as well as on the financial means of the farmer. Furthermore, higher crop production and improved quality will not happen automatically but is dependent on the knowledge and skill of the farmer.

Net houses are often used in warmer climates and/or areas with low rainfall. They can serve several purposes, although they are primarily used to protect crops from insect pests. A simple structure with a high net roof (or polyethylene sheeting) can be used to protect the plant from damage from heavy rains. Net houses can also be used to moderate the temperatures around the crop. In summer months, the netting can help reduce heat stress by providing shade, while in winter it can raise temperatures to promote growth. As the seasons change, side netting can be added or removed or opened up as necessary to regulate the temperature and circulation of the air. This can be done when the structure uses a combination of plastic sheeting and net. As the seasons change, the plastic sheeting on the sides is opened or removed to increase ventilation. In general, removing or opening nets is not recommended, as insect pests and disease vectors would not be excluded.

The net covering also protects the crops against excessive UV radiation and, depending on what type and colour of plastic or net is used, can create more diffuse light, which is conducive to plant growth. In hot climates, net houses are particularly suited for commercial or on-farm nurseries, where they protect delicate fruit and vegetable seedlings from excessive heat and heavy rains.

Greenhouses tend to be used in colder climates (such as in temperate regions and at higher altitudes) to increase temperatures and to extend the growing seasons for some crops. In all protective cultivation structures, but especially in greenhouses, proper ventilation is essential to keep the temperature and humidity from becoming excessive so that it does not promote infection from fungal diseases such as *Botrytis* or powdery mildew.

In temperate high-income countries (such as the Netherlands), greenhouses are equipped with the latest technology to precisely monitor and regulate temperature, humidity, radiation and carbon dioxide, as well as a range of other inputs such as water and nutrients; and to practice biocontrol to avoid using chemical pesticides. This ensures intensive year-round production. For small-scale farmers in low- and middle-income countries, this level of technology is out of reach. However, in cooler climates, there are some low-tech options that small-scale farmers have for heating greenhouses. For example, greenhouses can be constructed alongside the residence of the farmer, to share the heating that is used for the house. Another example is the Chinese passive solar greenhouse. Typically it is composed of three walls of brick or clay with the fourth side on the south. This side consists of transparent material (usually plastic foil) to allow the sunlight into the greenhouse. The heat that is accumulated in the walls during the day is released at night, allowing crop cultivation in cold climates. In tropical climates, keeping temperatures and humidity at optimal levels in greenhouses and net houses without expensive mechanical (forced) ventilation or cooling can be a challenge. In higher altitudes in the tropics, it is possible to add vents to the roof of the greenhouse and situate the structure in a place where the prevailing breezes pass, to create natural (non-forced) ventilation.

Water management

Net houses allow rainfall to reach the plants, but greenhouses do not. Greenhouses and nethouses can be equipped with gutters to collect rainwater and store it in tanks, which will reduce the need for freshwater withdrawals for irrigation. The benefit of greenhouses is that the water transpired by plants condenses onto the inner greenhouse surfaces and is made available again to the crop, as opposed to open fields where the water transpired by crops is lost. By protecting crops from the heat generated by sunlight, net houses can reduce water demands.

The water requirements of the crops must be understood and compared with water availability to allow the determination of the most appropriate areas, crops to cultivate and irrigation techniques for protected cultivation systems. In general, because of the water demands of vegetable crops and the cost to invest in protective structures, drip irrigation systems, including fertigation, are preferred over furrow and hand watering, which are seldom practiced in greenhouses. Farmers growing vegetables in greenhouses have the added impetus to irrigate judiciously, as excessive watering can increase humidity and the risk of fungal and bacterial diseases.

Greenhouse technologies offer the possibility of growing vegetables in ways that significantly optimize water consumption using soilless culture. Different techniques of soilless cultivation exist. In hydroponic systems, for example, plants are grown in containers with hydroponic solutions supplied by pipe. They are held in place artificially without substrate, with their roots suspended below. The hydroponic solution contains nutrient profiles tailored to the type of crop and its development stage. Hydroponics is up to 90 percent more water-efficient than open field cultivation (Sharma *et al.,* 2019).

Plants can be grown in vertical structures that may or may not be protected (on shelves or in tubes, etc.) to maximize the use of scarce land, especially in cities, drought prone areas or where soil has been depleted or is infested with soil-borne pathogens. Since they can be established almost anywhere, hydroponic greenhouses can produce food nearer to markets and consumers, which can reduce transportation costs and food losses. It is critical that clean water be used, or a disinfection/sterilization system be installed, as water-borne pathogens such as fungi and bacteria can spread rapidly and destroy the whole crop.

Soil health

Crops can be grown in soil under protected cultivation, and options for maintaining soil health and providing nutrients to the plants are similar to those described previously for open field cultivation. Soilless cultivation involves containers, such as bags, pots or trays, filled with a substrate, which can be organic (peat, rice husk, coconut fibre, sawdust, bark) or inorganic (perlite, rock wool, vermiculite), or a combination of both. Substrates are also used in the form of prepared cubes (rockwool cubes), mats (polyurethane foam) and troughs (rockwool). Using substrates allows farmers with limited amounts of land, or with poor quality soils, to cultivate high-value crops. While they also increase costs, substrates can help farmers avoid economic losses due to nematodes and other soil-borne diseases.

Depending on the type of material used, the substrate can either be replaced completely at regular intervals or sterilized (with soil solarization) to ensure that it contains no crop pathogens. In the highly advanced and large-scale protected cultivation systems in high-income countries, growing vegetables in substrates is common, and locally sourced relatively low-cost options are available to small-scale farmers in low- and middle-income countries as well. Irrespective of whether soil or substrate is used, fertigation systems can deliver optimal nutrient profiles for any given crop and development stage.

Plant health

Insect-proof net houses are used to exclude insect pests from crops and seedlings in nurseries. However, in low altitude tropical areas where temperatures are high, the need to provide adequate ventilation and reduce heat stress can make it difficult for farmers to keep their crops protected with insect-proof nets at all times during the growing season. Polyethylene plastic sheets that are used in tropical areas to protect crops from excessive rain can allow fungal and bacterial diseases to proliferate. In some cases, when crops are protected from direct rainfall in semi-open structures, the infestation by some pests can be higher than under non-protected conditions (red spider mite (*Tetranychus urticae*) on tomatoes).

As with open field cultivation, scouting remains a critical element of plant protection. It is also important to keep the greenhouses or net houses well maintained and to repair holes or gaps where insects and other pests can enter. To reduce the risk of pest and disease outbreaks, it is critical to keep the interior of the structure sanitized and well weeded.

In commercial greenhouses, insect pheromone traps and biological control methods have become widespread and are particularly successful because of the confined space, and lack of wind and other predators. In greenhouse vegetable cultivation, for example, the release of the predaceous mite (*Phytoseiulus persimilis*) to control the red spider mite is a common IPM strategy. More than 30 species of natural enemies are routinely used against more than 22 pest species. Between 1970 and 2013, the greenhouse area to which biological pest control was used increased from 400 ha to over 50 000 ha (Abdelhaq, 2013).

Crops and varieties

Just as for open field cultivation, farmers need to select the crops and crop varieties that are best adapted to their growing conditions as well as market and economic conditions, crop characteristics and requirements, compatibility between crop and microclimate and soil characteristics and soil-borne diseases. Not all vegetable crops are suitable for cultivation in greenhouses and net houses, and often the preferred crops are those that can be continually harvested (such as tomatoes, cucumbers or peppers) or those with short crop cycles (e.g. lettuce). Certain varieties of these crops have been bred and selected for traits specific to high performance under protected conditions.

Pollination

For some vegetable species special care is needed to ensure natural pollination occurs. This can be facilitated by introducing bees, for example in brassicas, cucurbits and carrots. Other species that have closed bisexual flowers and can self-pollinate require assistance to shake off the pollen at the appropriate time to reach the female pistil. Bumblebees are particularly effective for this, and mechanical devices can also be used (for example, on tomato).

Adoption constraints

For small-scale farmers, a major obstacle to the uptake of protected cultivation technologies is the cost, both in terms of initial investment and maintenance. This is especially true for the more advanced systems such as hydroponics and fertigation. Conversely, many farmers who can afford the investment and would use protected cultivation technologies or materials cannot access them in the local market.

However, for many farmers the lack of financial capital is perhaps not the main obstacle. In fact, banks often have a greater willingness to invest in protected cultivation systems because the production is high value, it can yield high off season returns, and the risk of crop loss is less than in open field cultivation systems. Some countries also provide subsidies to support farmers to make a shift to protected cultivation systems. However, to obtain these loans and subsidies, farmers need to be able to demonstrate that they have the skills and knowledge to avoid the risk of financial loss and make the venture a success. Overcoming a lack of capacity is often the primary obstacle that prevents farmers from engaging in the protected cultivation of high-value vegetables.

Labour can also be a constraint. It is often mistakenly believed that protected cultivation requires less labour than open field cultivation, whereas the opposite can be true. Protected cultivation is labour-intensive and relies on skilled labour for managing the crop and for system maintenance.

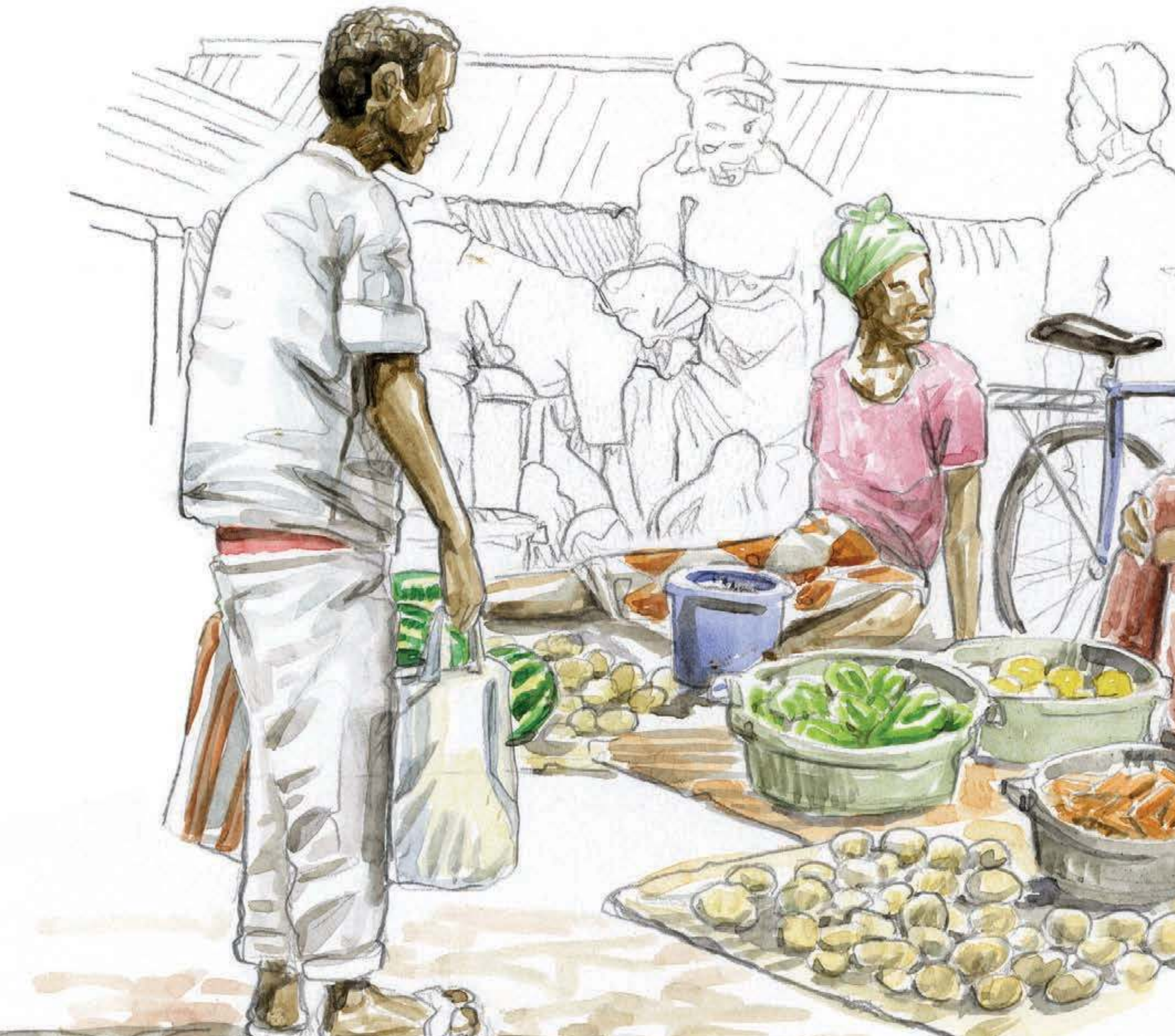
Nordey *et al.* (2017), in their review of protected cultivation for vegetable crops in sub-Saharan Africa, concluded:

- Low-tech protected cultivation techniques are not suitable in all climatic conditions in sub-Saharan Africa and need to be combined with other methods to ensure adequate pest control.

- The profitability of protected cultivation techniques relies on the capacity to offset increased production costs by higher yields and higher selling prices to be obtained with off-season and/or higher quality products;

- Breaking with existing cropping systems, a lack of technical support and skills, and limited access to investment funding are major obstacles to adopting protected cultivation techniques by small-scale farmers.

- Life cycle assessments conducted in northern countries suggested that more efficient use of agricultural inputs would offset the negative impacts of protected cultivation techniques if they were properly managed, but further studies are required to be sure these results can be extrapolated to the context of sub-Saharan Africa.



CHAPTER 3

Value chains

To be sustainable, the production of fruit and vegetables must be linked intrinsically to markets and consumers through stable value chains. While the term value chain typically includes production, this chapter focuses on post-harvest activities while recognizing that many of the decisions made by farmers influence the suitability of produce for post-harvest activities and markets. The value chain approach explains how a sector is organized by examining the structure and dynamics of the interaction between the different actors involved (Fernandez-Stark *et al.* 2012; FAO, 2014c). It is also worth highlighting that low-income consumers worldwide face challenges related to access to, and the affordability of, fresh fruit and vegetables, and that processed foods can provide a solution (FAO, 2020d). At the same time, rapid urbanization and the emergence of a middle class with growing disposable incomes in low- and middle-income countries boosts the demand for fresh fruit and vegetables. By virtue of the high value of fruit and vegetables, stable and inclusive value chains offer significant opportunities for social equity and decent work (FAO, IFAD and ILO, 2010).

Some challenges affecting social and economic sustainability include high labour demand with unregulated protection, post-harvest activities carried out by small traders (transport, grading, storage, distribution) before going to wholesale, processing or retail markets, and unbalanced income distribution due to seasonality and perishability of the products and the poor governance of local value chains. However, tangible opportunities exist for fruit and vegetable value chains to deliver decent employment and incomes for all, including women and youth, equitable distribution of wealth, and provision of societal services to supply safe and nutritious foods.

Given these diverse livelihood strategies of small-scale farmers, the High-Level Panel of Experts on Food Security and Nutrition (HLPE, 2013) stressed that there is no "one size fits all" definition of small-scale agriculture, which also applies to increasing sustainable small-scale production of fruit and vegetables. Small-scale farmers need a flexible approach that recognizes the range of different livelihood strategies if they are to adopt sustainable management practices to increase their fruit and vegetable production and to ensure that they are connected to stable value chains that give them access to markets. This flexibility will ensure that all small-scale farmers, whatever their resources, will be able to upgrade their production in ways that are within their means and meet their needs.

Fruit harvesting

• Pre-harvest planning, harvesting, post-harvest handling and processing

An important factor that contributes to the sustainability of fruit and vegetable production and stable value chains systems is prevention of loss after harvest: ''the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers and consumers'' (FAO, 2019a). Actions need to be undertaken when planning cropping systems, farm management, and harvest and post-harvest operations. Post-harvest services are commonly offered to producers who aggregate their production and enable individual small-scale fruit and vegetable farmers to overcome constraints associated with economies of scale and connection to markets.

The locations where fresh fruit and vegetables are aggregated to be prepared and delivered to markets can also serve as important checkpoints for ensuring food safety and for building consumer confidence in locally produced fresh produce. Since post-harvest facilities provide a range of services and goods to both farmers, wholesale marketers, retailers, processers and consumers, they can become catalysts for expanding and diversifying local economies and creating employment.

Pre-harvest planning

Selecting which crops are preferred by markets, and thus will have reduced losses, requires up-to-date information. Farmers need access to seeds and planting materials of crop species and varieties whose genetic qualities are well-suited both to local growing conditions and to the requirements of their intended buyers (local consumers, more distant retailers, processors for juicing, sauces, canning, etc.).

Since produce from many small-scale farmers will be aggregated into larger volumes as it moves through a supply chain, it is best if planning is done collectively. Close coordination among members of farmer groups, cooperatives and associations can help ensure that a diverse range of fruit and vegetables are being cultivated and improve the capacity of farmers to negotiate better prices. This diversity can help meet different consumer demands and avoid an oversupply of a particular crop on the market, which can result in food loss. This collective planning can also reduce farmers' production costs through activities like procuring inputs in bulk, in addition to aggregating post-harvest services.

The timing of harvest

Harvesting fruit and vegetable crops before they reach the required maturity or when they are over-mature contributes to food loss and reduced farm income. For fruit and vegetable crops, determining the optimal time to harvest can pose challenges. The decision will depend on numerous factors including the type of crop, how it will be consumed (fresh or processed), the distance to markets and processing centres, and whether transportation and storage will require cooling.

Fruit and vegetables may not necessarily be harvested after they have reached physiological maturity. For example, many vegetables, such as cucumber, zucchini, green beans, peas and baby vegetables, reach their commercial potential before their physiological maturity. Some fruit (climacteric fruit) produce a hormone (ethylene) that enables them to continue ripening after harvest. Major climacteric fruit include apple, avocado, banana, mango, melon, pear and watermelon. The flavour and appearance of these types of fruit may improve after harvest (for example, pears taste better when ripened off the tree and Cavendish bananas have a better colour and taste following artificial ripening). For climacteric crops, harvesting occurs early so full maturity is achieved at the market or at the consumer's end. Non-climacteric fruit include pineapple, citrus fruit, litchi and longan. For non-climacteric fruit and vegetables, the flavour and quality will not improve if they are harvested before they are fully ripe because their sugar and acid content does not increase further.

Assessing when to harvest requires knowledge and experience. Different measures can help. It also depends on which part of the crop is harvested. For some fast-growing vegetable crops, such as radish, maturity can be measured chronologically by counting the days from planting or from flowering. For many fruit and vegetables, farmers consider their colour, size and firmness. Other methods involve more advanced technologies, such as a chemical analysis or determination of sugars in fruit (Brix), which is a direct measure of taste, quality and readiness for harvesting and marketing. Several non-destructive and destructive methods are readily available to determine Brix levels.

Examples of low-cost tools that can be used by small-scale farmers include farm record books to keep track of the calendar of crop development, calibrated callipers and tapes for measuring size, and customized colour charts. See Okiror *et al.* (2017) for a study on the use of these tools by small-scale farmers in Uganda.

To ensure that crops are not chemically contaminated by pesticide residues, farmers should be familiar with, and practice, GAPs. For instance, pesticides that are not approved for food production should never be used on food crops. But also, labels on authorized pesticides indicate conditions for their application, such as the minimum number of days (the pre-harvest interval) between application and harvest.

During harvest

Many fruit and vegetable crops will have an extended harvest period. Often, individual plants in a field or orchard develop at slightly different rates and thus require staggered harvesting. Many hybrid vegetable varieties ripen at a uniform rate, which makes harvesting and overall farm management easier and more conducive to mechanical operations, reducing labour costs. In general, because of their fragility and the importance of their appearance, fruit and vegetables tend to be harvested by hand, unless intended for processing where appearance is not important and mechanized operations are more suitable. Small-scale farmers commonly harvest their fruit and vegetables by hand themselves or engage hired labour for assistance.

In some cases where the farmer has sold the produce before harvest – usually through a contract with a buyer – the buyer may bring in trained personnel for harvesting and transportation from the farm. The farmer needs to closely monitor the harvesting activities to ensure that the harvesting team, which is focused on one crop, does not inadvertently damage other crops in the field where there is a mixed cropping system.

Fruit and vegetables need to be harvested carefully as cuts and bruises can make the produce unmarketable and create entry points for insects, fungi and bacteria that cause decay. Harvested produce should not come into contact with the soil or unclean surfaces as these can also serve as inoculum of pests and diseases. Produce should be transferred carefully with a minimum drop height into clean sturdy containers that have no rough surfaces or jagged edges. Often small-scale farmers use containers made of natural fibre such as sacks, baskets, crates. Although they are affordable, they cannot be easily cleaned, and, because they were not designed for stacking, they can lead to bruising and food loss (López Camelo, 2004). If available and affordable, reusable, stackable, vented plastic crates that are easy to clean help reduce losses, if they are handled with care and are not overloaded.

Harvesting should be done early in the morning when it is cool, and the harvested produce must be kept in the shade. Temperature is the most important environmental factor that influences the deterioration of fresh fruit and vegetables. Keeping fresh produce cool is one of the fundamental challenges on the farm and at all stages in the supply chain. Small storage containers that keep the produce cool using solar power are becoming available.

Dry and hot conditions during harvest accelerate water loss, and when produce loses 5 to 10 percent of its fresh weight, it begins to wilt and soon becomes unusable (FAO, 1989). This also translates into loss of weight to sale and, therefore, to lower incomes. The rate at which water is lost varies with the type of produce; for example, leafy green vegetables are particularly vulnerable.

Post-harvest handling

Post-harvest handling is critical to ensure quality, food safety and marketability. A number of factors such as the resources of the farmer, the type of crop harvested, the volume of production and the location of the farm will determine who is involved in post-harvest handling activities and where they will be carried out. Small-scale producers who have limited resources, produce relatively small volumes, and are not part of any farmer organization, may be entirely responsible for all aspects of preparing and delivering their produce to local informal markets. For farmers who have more resources, some post-harvest operations will be done in the field by members of the household (perhaps with additional hired labour), and the produce will then be transported to an off-farm post-harvest facility (sometimes referred to as a packhouse) for additional preparation and distribution to markets. The Codex code of practice for packaging and transporting fresh fruit and vegetables (FAO/WHO, 1995: CAC/RCP 44-1995) provides further guidance on how to maintain produce quality during transportation and marketing.

Post-harvest operations that keep the handling of produce to a minimum will reduce losses and maintain quality, as well as lower costs. Therefore, it is preferable that as much of the post-harvest handling as possible is carried out in the field. However, this is generally only an option with especially perishable products (such as leafy vegetables) or small volumes destined for nearby markets. For farms harvesting large volumes of highly perishable produce, setting up mobile structures near the harvesting site for some post-harvest operations may be an option.

In some cases, farmers may need to store produce before transporting it to a post-harvest facility. Before storing the produce, farmers need to remove damaged or diseased produce. They may be able to temporarily store vegetable crops that are less fragile (onions, pumpkins) in the field by placing them in heaps and covering them with a tarpaulin, straw or with other materials. More fragile produce will need to be stored inside or under a clean, protective and well-ventilated structure that can keep the produce dry, shaded and cool.

For farmers with adequate storage facilities on their farm, temporary storage may be a strategy for achieving higher returns by avoiding gluts (e.g. for onions). Advances in renewable energy, especially solar power, are increasing options for cold storage. For example, in drier climates, the use of simple evaporative cool storage structures can provide up to 10 °C reduction in temperature, which will double post-harvest shelf life and reduce losses due to water loss and decay. For a review of various evaporative cooling methods, see Basediya *et al.* (2013).

Brèdes (green edible leaves) of chayote *(Sechium edulis)*

Low-cost cooling system (charcoal cabinet)

Climacteric fruit continue to ripen after harvest, giving off ethylene, which accelerates the deterioration of non-climacteric fruit, so it is important they are kept separate.

Transportation from the farm to a post-harvest facility requires careful loading into vehicles, ideally in sturdy containers with no rough surfaces, with shade, good ventilation and free from exhaust fumes. In low-income countries, access to cold chain is hardly available or affordable to small-scale farmers but is a critical element for reducing food loss and increasing the incomes of fruit and vegetable farmers.

Post-harvest facilities

A post-harvest facility (or packhouse) is a designated space that is protected from weather and where produce is aggregated and handled through a centralized operation (Winrock, 2009). Facilities vary in scale and technological capacity, but all prepare farm produce for further distribution and market access, and achieve greater efficiency than possible on-farm facilities due to the economy of scale and availability of appropriate technologies. Post-harvest operations reduce food loss and expand market opportunities for small-scale farmers. A compilation of recommended and cost-effective post-harvest tools and best practices is available as a free book download (Teutsch, 2019).

It is often critical to establish a cold chain to slow down the process of respiration in the harvested fruit and vegetables with cool temperatures. After harvesting, the cells of fruit and vegetables are still alive and continue to respire, generating carbon dioxide, water and heat, reducing reserves of sugar, starch and water. Different crops have different respiration rates. For example, onions and cucumbers have very low rates, whereas for cauliflower, melons and okra they are very high. Most perishable temperate zone fruit and vegetables have an optimal shelf life at temperatures of 0 to 2 °C, while subtropical and tropical crops are best suited to handling and storage temperatures of 12 to 15 °C (Kitinoja, 2013).

These facilities can be managed by local farmer groups or associations, or by more formal farmer organizations, such as cooperatives, government agencies or private ventures. Larger facilities can be mechanized and include storage rooms and offices for arranging transactions with buyers. What is common across all types of facilities are the types of operations undertaken:

- Sorting: damaged, decaying and in some cases defective produce is discarded. This helps reduce food loss and preserve the quality of the produce by preventing spread of pathogens. Ideally, to avoid food loss and to diversify income options for farmers, produce that is merely defective (does not meet formal market standards for shape or appearance) but is otherwise fine should be directed to other markets (food processors or informal retailers). Also, organic waste should be composted or, if possible, used as biofuel or animal feed.

- Cleaning: soil and dust is removed manually from produce without water, and in larger facilities this is done using special machines with brushes.

- Washing and sterilizing: clean water, sometimes with a regulated amount of detergent or disinfectant, is used to remove soil, insects, sap, surface bacteria and fungi.

- Grading and sizing: farm produce is characterized and separated according to market requirements (size, shape, weight, colour, maturity). This can be done manually or by using tools and equipment (mechanical sizing, electronic colour grading). Sensors can be used to check some quality criterion (such as hexanol, an indicator of food deterioration) and equipment can be used to measure fruit maturity (refractometer for Brix measurement of fruit juice).

- Waxing and treating: food grade wax is applied to replace natural wax removed during washing to maintain the quality of the produce. Waxing reduces water loss and increases the cosmetic value of the produce. Certain produce may also be treated with chemicals (essential oils, fungicides and antibiotics) to increase shelf life. Edible coatings can also be applied to reduce respiration and water loss.

- Packing: produce is placed into appropriate containers either for storage, transport, or direct supply to markets. When being prepared for direct supply to markets, the type of packaging used can increase the attractiveness of produce to consumers and its marketability may be increased through specific labelling or branding. Innovations are being made in biodegradable and recyclable packaging materials. Modified atmosphere packaging, in which the oxygen is replaced with other gases, is used to reduce respiration.

- Cooling: fruit and vegetables are normally taken to a specially designed cold storage room with temperature and humidity set at levels according to the type of produce. Electricity is required, and this can be provided by mains supply or from a generator or solar panels. Alternatively, simple evaporative structures can be used. Some facilities may also have the capacity to control the levels of ethylene to stimulate ripening for crops such as tomato and banana. Ideally, cooling extends to transport and to market. Cold chain capacities significantly reduce food losses. For a review of pre-cooling systems for small-scale producers, see Kitinoja and Thompson (2010).

There are significant financial and technical challenges to establishing such facilities and to assuring access to small-scale producers, especially women and youth. In most of sub-Saharan Africa, packhouses are usually owned by big exporting companies and established local traders. The concept of aggregation centres equipped with basic post-harvest handling facilities has been promoted among small-scale farmers because individual farmers may not be able to afford the facilities on their own and it does not make economic sense to invest in such facilities. Such centres, which are owned by farmer groups, are also being used to train farmers/producers on better pre-harvest practices to ensure high produce quality, proper post-harvest handling practices and food safety, among other issues.

By creating a focal point where fresh produce is aggregated, post-harvest facilities can also provide an important location for monitoring the safety of fruit and vegetables before they reach different markets. This can be done either by having food safety inspectors travel to the facility or by establishing permanent safety checkpoints to evaluate pesticide residues and other chemical and biological contaminants. Undertaking food safety inspections at the post-harvest facility increases consumer confidence and market opportunities and makes it possible to identify sources of contamination and to take corrective action.

It is also important to recognize that the post-harvest facility itself can be a potential source of food contamination. It is critical that all

Low-cost solar drier

surfaces and tools are sterile and that regular sanitation practices are implemented using approved cleaning compounds. Workers should wear appropriate food safety garments, such as gloves, hairnets and smocks, and appreciate the importance of cleanliness and hygiene standards. The water used to wash the produce must be clean and safe to drink.

The high economic value of the fruit and vegetables handled at these facilities can drive the development of a diverse range of off-farm businesses, including: companies that can provide, install and maintain cooling systems and other equipment; transportation services that can offer the timely and safe delivery of produce from the farm to the facility and from the facility to markets and processors; information and communication equipment and service providers that can support logistical planning and networking and the management of inventories; and companies that can supply goods needed for the operation of the facility, such as pallets, containers, cleaning and office supplies. In addition to these businesses, food processing industries can take advantage of the different grades of fresh produce handled at the facility that do not meet the requirements of fresh retail markets. Subsequently, the provision of those services maintain the high value of fruit and vegetables as demonstrated in South Asia (FAO, 2017e; 2018e).

Processing

Food processing businesses can be operated at a very small scale or at an industrial level and generate employment opportunities in the areas where the fruit and vegetables are grown. They play a critical role in reducing food loss by taking the produce that is not up to the standard for fresh retail markets and converting it into nutritious and profitable products. Processed products have the advantage of not being limited by shelf life and can be introduced to markets throughout the year. They are not sensitive to price fluctuations due to seasonal prices for fresh produce and gluts in production and can provide some out of season nutrients and affordable products.

Since fruit and vegetables are so diverse, many different types of foods can be produced including dried and canned products, chutneys, pickles, jams, sauces, pastes, snacks, oils and juices. When conditions are unsuitable for storage or for the immediate marketing of fresh produce, many horticultural crops can be processed using simple technologies including drying, fermenting, canning, freezing, preserving and juicing. Fruit, vegetables and flowers can be dried and stored for use or future sale. Technologies are evolving for drying fruit on a small-scale (e.g. for banana, Kiggundu *et al.,* 2017), and on-farm processing and technologies suited to small-scale producers are shown on the Technologies and Practices for Small Agricultural Producers website (**http://www.fao.org/teca/en/**). Fermentation is popular throughout the world as a food preservation method, and over 3 500 individual fermented foods have been described by Campbell-Platt (1987). Fruit and vegetables can be canned or frozen, but processed products must be packaged and stored properly in order to achieve their potential shelf life of up to one year. Dried products must be packaged in air-tight containers (glass or plastic bottles or sealed plastic bags). Canned and bottled products must be adequately heat processed using high quality containers that provide good seals. Dried and canned or bottled products are best stored under cool and dark conditions. Post-harvest handling, transport and marketing of processed products can be much simpler and less costly than for fresh products since refrigeration is unnecessary. Dried products take up much less space than their fresh equivalents, further reducing transport and storage costs (Kitinoja and Kader, 2004).

Wherever possible, processed fruit and vegetables should contain a minimum of food additives and ingredients such as salt and sugar, in order to preserve their nutritional benefits and to make a positive contribution to fighting all forms of malnutrition.

Labour at farm level

Sustainable fruit and vegetable production is labour-intensive and on small-scale fruit and vegetable farms much of this labour will be carried out by families. FAO has proposed the following definition for family farming:

- Family Farming is a means of organizing agricultural, forestry, fisheries, pastoral and aquaculture production which is managed and operated by a family and predominantly reliant on labour, both women's and men's (Garner and de la O Campos, 2014; Bosc *et al.,* 2015, 2018).

Livelihood strategies on family farms

Fruit and vegetable crops, because of their diversity and the fact that they can be grown on small areas of land, offer a tremendous range of options to families involved in small-scale farming for improving their livelihoods. On some family farms, fruit and vegetable crops may be cultivated intensively on a year-round basis in open field or protected cultivation systems. On others, fruit and vegetable crops are one component in a diversified portfolio of commercial agricultural activities that include other crops or perhaps even livestock production, tree growing, or aquaculture. In some cases, they are grown partly for household consumption and partly for sale. Elsewhere, fruit and vegetables are grown almost exclusively for household production in home or kitchen gardens and make only a modest contribution to household income.

This diversity of production options matches well with the diverse livelihood strategies that are characteristic of family farms. The quantity of labour and other resources in which farm families can invest to increase their fruit and vegetable production will depend not only on household farm labour but also on incomes earned from other employment. Off-farm employment is often a critical element in the livelihood strategies of farming families. This is not a recent phenomenon, and it is the norm in both high-income and low-income countries. Even in high-income countries, farm revenues are seldom the only source of income on family farms (HLPE, 2013).

In some families, members of the household may hold full-time salaried positions off the farm. Household members engage in their own small or medium size enterprises, either on or off the farm. These diverse sources of income make it more affordable for the family to hire temporary workers to meet the labour requirements for fruit

Example of a home garden

and vegetable cultivation and to invest in sustainable practices and technologies to increase production and yields. Hiring labour is not uncommon for small-scale farmers. A study carried out in four African countries found that more than half of all households hire labour (Baudron *et al.,* 2019). Some lower-income farming families cannot afford to hire farm labour, with themselves depending on earnings from wage labour on other farms, in off-farm agro-industries or in other sectors. Remittances from family members who have migrated out of their communities may also be a crucial part of their livelihood.

The nearer farming families live to urban centres, the more options they have for diversifying their livelihoods and earning income that can be invested into their farms. In remote rural areas, the scarcity of off-farm employment opportunities and, in some contexts, the lack of farm labour, along with the distances to urban markets, can severely constrain the options and the incentives farm families have for increasing their production of fruit and vegetables. However, the remoteness may make household production of fruit and vegetables more important for family nutrition.

Gender division of labour in fruit and vegetable production on family farms

In family farms, both women and men provide labour to grow fruit and vegetable crops. Depending on the cultural context, gender norms may significantly influence the division of labour in both household and commercial production of fruit and vegetables. In some households, especially female-headed households, the labour requirement for fruit and vegetable cultivation can be a significant constraint.

Gender biases affect women's access to land, training, infrastructure, finance, education, information (through networks, for example) and markets. The constraints faced by women differ according to their position in the supply chain: self employment and unpaid family labour in small-scale horticultural production and wage labour in post-harvest operations, where contract conditions often discriminate against women. Case studies show that this negatively affects women's ability to capture a faire share of benefits along the horticulture value chain (Bamber and Fernandez-Stark, 2013).

Home gardens

In many rural areas, farming families cultivate fruit and vegetables in home gardens (household gardens or kitchen gardens). Urban and peri-urban households may also grow vegetables in backyard plots, or set up micro-gardens on rooftops, balconies, or patios. In these gardens, the focus is on household consumption, but in some cases, if well managed, they can produce a surplus that can be sold at local markets or given as gifts to others to build the social status of the grower.

Since women commonly manage gardens and are also responsible for feeding household members, home gardens are seen as a particularly useful approach for combatting micronutrient deficiencies in young mothers, infants and children. However, men also contribute to home gardens, carrying some of the heavier tasks, such as soil bed preparation, and will also have a say in which foods are grown (Beaudreault, 2019; Otieno *et al.,* 2016).

Home gardens can deliver significant nutritional benefits (Hawkes, 2013). In a study in India, Keatinge *et al.* (2011) calculated that a small home garden (six square metres) in which different vegetables are grown can provide much of the vitamin A and C requirement for a family of four during the entire year. An assessment of home gardening initiatives in Bangladesh indicated that the nutritional benefits gained from home gardens could translate into a significant reduction in the number of disability-adjusted life years (Schreinemachers *et al.,* 2016a).

Despite their small size, home gardens require a certain level of knowledge, along with labour and other inputs. Close attention needs to be paid to soil management, irrigation, plant protection and the selection of seeds and planting materials. Home gardens, therefore, can provide a space where farming and business skills can be acquired and passed onto others.

However, the heavy workload borne by women on family farms must be recognized. Women play an especially strong role in taking care of children and other family members, cooking, cleaning, as well as in farm work and other employment. Given these labour demands, for some women income-generating activities that would allow the household to buy more fruit and vegetables as well as other necessities may be a higher priority than managing a home garden. Nevertheless, even if a home garden may not be the preferred option for all families, efforts to support home gardens can serve to create awareness about sustainable production practices, nutritious and healthy diets and could stimulate local commercial production and consumption.

Commercial production

On family farms where fruit and vegetable production has a primarily commercial focus, both women and men provide labour, with women making substantial contributions. Dolan (2001) noted that in Kenya, where families who were growing tea and coffee and were also engaged in contract farming for green beans for export, women's share of labour for planting beans was over 80 percent, for weeding it was almost 90 percent, and for harvesting it was 60 percent. Men contributed a greater share of labour on tasks that were heavier (clearing and preparing the land) but these required less time and were not done continuously throughout the season. However, Dolan (2001) also observed that gender-segregated patterns in farm labour were becoming less pronounced. A more recent survey of small-scale farmers and vegetable traders in the United Republic of Tanzania found no significant gender division in the production process, although men had a more prominent role in managing pests and diseases, purchasing inputs and selecting seeds (Fischer *et al.,* 2018). This survey confirmed that staple crops (maize and sorghum) and cash crops (pigeon pea) are generally viewed as ''male'' crops, with men responsible for a significantly higher share of production management and allocation of the income. On the other hand, for leafy vegetables (amaranth, Chinese cabbage, Ethiopian mustard) and other vegetables (tomato, African eggplant, onion) the gender differences in production management and income allocation were not as pronounced, with women receiving more than half the income for some vegetable crops.

However, men's and women's roles in vegetable production can vary widely depending on the setting. For example, in many large cities in West Africa, a high percentage of urban farmers using informal irrigation systems to grow vegetables commercially are men, up to 90 percent in some cities, whereas in a smaller number of cities (e.g. Freetown in Sierra Leone, Banjul in the Gambia) this gender ratio is completely reversed (Drechsel *et al.,* 2006). A gender analysis of commercial vegetable production in the province of Punjab in Pakistan found that it was primarily male family members and hired male farm workers who were involved in the production of vegetables, with distinct gender divisions by crop. Men provided more than 80 percent of the labour for cauliflower cultivation and 100 percent for cucumber, whereas women's share of the workload for cultivating peas, onion, garlic and okra was higher (more than 40 percent) and involved mainly hoeing, weeding and harvesting (Taj *et al.,* 2007).

In female-headed farming families, labour requirements for fruit and vegetable cultivation are a constraint on production. This difficulty is compounded by the fact that, in general, women farmers face greater difficulties in hiring farm labour and have less access to land and credit than men (FAO, 2011b). A gender analysis of the perceived constraints to vegetable cultivation in Nigeria showed that 98 percent of women farmers stated that a lack of land was a constraint, as opposed to only 6 percent of men. Over 90 percent of the women farmers said a lack of credit was a constraint compared with 13 percent of men, and nearly 80 percent of the women said transportation was a constraint as opposed to 15 percent of the men (Deji *et al.,* 2013). It is noteworthy that the greatest discrepancy in perceived constraints in which men felt the greatest disadvantage was in marketing, with 90 percent of the men seeing it as a constraint as opposed to 23 percent of the women. Other perceived constraints, including inadequate supply and high prices of inputs, lack of extension services, access to water, control of pests and diseases and crop storage, were shared more or less equally by men and women.

Casual, temporary and seasonal workers

For farming families with fewer resources, working as wage labour on other farms or elsewhere can be a critical component in a diversified livelihood strategy. Although this document focuses on sustainable fruit and vegetable production by small-scale family farmers and local supply chains, some consideration must be given to medium sized family farms, as well as to large-scale commercial fruit and vegetable operations that produce for export and agro-industrial companies involved in fruit and vegetable processing. Their operations are also critical to the global supply and availability of nutritious fruit and vegetables. These larger commercial enterprises also have high labour requirements and the employment opportunities they offer can be an important component in the livelihood strategies of small-scale farming families. The income family members earn from waged employment, which is offered on a casual, temporary or seasonal basis, can help reduce poverty and food insecurity. In some cases, some of this income can be invested to support increased production of higher value crops, like fruit and vegetables. In Senegal, Maertens (2009) found that earnings from seasonal work on large-scale corporate farming operations (onion and mango) led to higher productivity, production and incomes for small-scale farmers. In another study of small-scale farmers in Senegal, wages from labour in large-scale commercial bean production accounted for 30 percent of the household income on average (Maertens *et al.,* 2012).

Dolan and Sorby (2003) note that in Guatemala, the money earned by women as day labourers on vegetable farms was more than they could make from artisanal work. In Mexico, wages for avocado packers were above minimum wage. In Kenya, exporters hire women, many of whom are landless, on a casual or short seasonal basis, to work in post-harvest facilities, for weighing, grading, cutting, washing and packing the vegetables. Wages are not high, but they are typically well above the government set minimum wage (McCulloch and Ota, 2002). In a literature review from several countries, Maertens *et al.,* (2012) found that women make up more than 50 percent of the workforce in the high value-added agriculture export industries of Chile, Ecuador, Guatemala, Kenya, Mexico, South Africa and Zimbabwe. They also point out that although the wages may be low, in some cases the gender wage gap in these export industries is less than it is for other sectors.

Many casual, temporary and seasonal workers on large-scale fruit and vegetable farms are migrants, moving from one farming area to another within a district or country or across international borders, in some cases as a family. In other cases, individual household members, often men, may travel alone, which increases the work burden on women who remain behind, making it even more difficult to sustain the production of labour-intensive fruit and vegetable crops. On the other hand, the remittances can be a part of the household strategy to increase financial resources that can be either invested in the family farm or used for other purposes (to purchase fruit and vegetables from markets, for example).

On large-scale farms, casual, temporary and seasonal employment arrangements are largely informal, and workers may be in precarious situations, unprotected and vulnerable to exploitation, and often without access to healthcare and other social protection measures. Women and migrant workers are particularly at risk. Employment conditions for labourers on fruit and vegetable farms often do not meet the standards of "decent work" as envisaged in SDG 8 (ILO, 2019). Even where wages exceed the minimum wage or local alternatives, they may not cover basic needs. Labourers work in the fields for long hours and risk exposure to pesticides. If fruit and vegetables are to serve as a driver for inclusive and sustainable economic growth, attention must be paid to ensure that the labourers, whose work is essential to the sustainable production, harvesting, post-harvest handling and processing of fruit and vegetables, receive fair wages, work in safe conditions and have adequate social protection (refer to ILO's website **https://www.ilo.org/global/standards/introduction-to-international-labour-standards/conventions-and-recommendations/lang--en/index.htm** for further information).

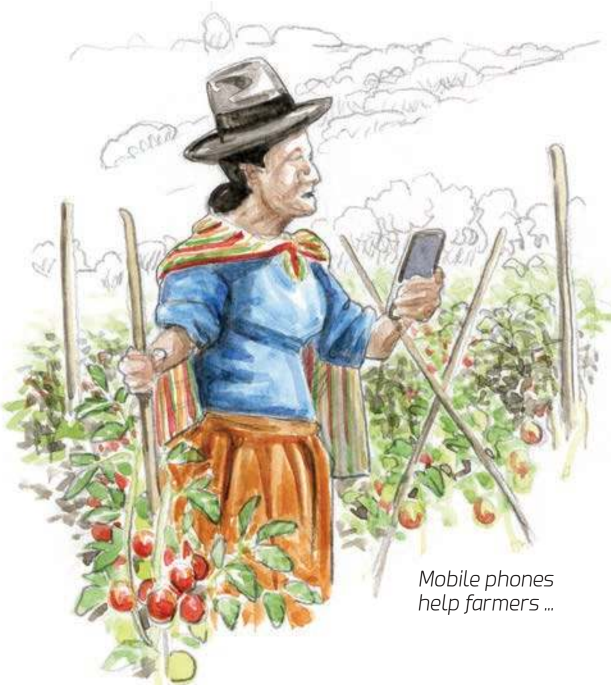
Small- and medium-sized enterprises

Fruit and vegetable production is not only labour intensive, it is also knowledge intensive and for many farmers this can be an obstacle. It is an obstacle that can be overcome through education, extension and capacity building. However, the high value that can be obtained for fruit and vegetables also allows some farmers to make use of services provided by self-employed entrepreneurs and small- and medium-sized enterprises with specialized skills and expertise. These include nurseries providing high quality seedlings and grafted seedlings, input suppliers for seed, plant health management products, drip irrigation systems and greenhouses, advisory services on soil health, crop diagnostics and plant protection, and businesses for harvesting and post-harvest services (FAO, 2018d; Liverpool-Tasie *et al.,* 2020).

The perishability of fresh fruit and vegetables requires efficient and stable value chains to maintain the quality of the produce and achieve its market potential. This creates opportunities for small- and medium-sized enterprises and for cold chain storage and transportation. The high value of fruit and vegetables, therefore, can be a driver for diversifying and developing local economies. These small- and medium-sized enterprises also offer employment opportunities to farming family members to diversify their livelihood strategies.

Information and communication technologies

The fact that sustainable fruit and vegetable production systems are knowledge intensive means that digitalization, data management and ICTs are of particular importance. Employment in this domain appeals to youth and can be a potential employment option for people with



Mobile phones help farmers ...

physical disabilities. ICT enterprises may be a component of the diversified livelihood strategies within a single farming household collectively managed by a group of farmers or operated entirely by entrepreneurs. The design and content of the ICTs need to be adapted to rural communities. For instance, illiterate users need a mobile application with images and pictures rather than text.

To increase their production sustainably, fruit and vegetable farmers and farmers' groups will need up-to-date information on weather forecasts and early warnings, pest and disease risks, diagnoses and management options, and on markets for produce and prices for inputs. Online networking is critical for improving the scheduling and the logistics involved in moving fresh seasonal produce through the different stages of the supply chain from rural areas to urban centres. This strengthened coordination will reduce food loss and ensure that production is responsive to demand. Through ICT networks, farming families, farmer associations and suppliers can create new markets for lesser-known fruit and vegetable crops and supply varieties that are better adapted to the local environments and preferred by markets. Time and money can be saved by ICTs that facilitate credit and financial transactions. ICTs and the data shared increase value chains' stability, profits, labour efficiency and provide off-farm employment opportunities that are attractive to young people.

Markets

Small-scale farmers need a secure market before investing in vegetable and fruit production due to the perishability and higher costs associated with their production, harvesting and post-harvest handling. These markets will in large part determine what to grow and how much and when, which standards of quality must be met, and which post-harvest services are needed. Satisfying these demands requires collaboration between farmers, farmer organizations, agribusinesses, governments, consumers and civil society groups.

The diversity of fruit and vegetables gives producers and suppliers a broad range of market opportunities. Ideally, for farmers and suppliers, these markets should be in as close proximity as possible, as this reduces their transport costs (and associated greenhouse gas emissions), lowers the risk of food loss, and potentially raises the quality of fresh products. Closer market connections also allow farmers and suppliers to establish direct relationships with consumers to build trust and adjust supplies based on feedback. Stronger local market linkages make the availability of fresh fruit and vegetables less vulnerable to disruptions in global supply chains brought about by a variety of risks, such as natural hazard-induced disasters, climate-related shocks, and stresses as has happened, more recently, with the COVID-19 pandemic. Fruit and vegetable production in urban and peri-urban areas is particularly strategic since it is the typical environment where small-scale farming is applicable and sustainable. Intensification is needed to make the best use of limited space and water resources in the overall context of an expanding urban population.

.... connect to markets

The diversity of fruit and vegetable value chains can be schematically represented (**Figure 7**) by crossing the distance from the producer to the last consumer, with the complexity of the chain explained by the diversity and number of actors involved in the value chain. The reported gradient does not follow real data regarding both the distance and the actors. What is relevant here is the relative position of the different markets on the graph. **Figure 7** expresses the huge diversity of fruit and vegetable markets, from reciprocity-based exchanges to the international trade of fresh fruit and vegetables and processed products. The idea is not to prioritize one type of value chain, but to orientate strategic choices and policies towards the most sustainable one.

The increasing proximity of markets to rural small-scale farmers is becoming a more widespread reality as urban areas expand and peri-urban areas become urbanized. A central element of integrating small-scale farmers into markets will involve adapting to this demographic transition by building and strengthening rural-urban linkages (e.g. through e-commerce). In Asia, a chain of large urban areas and smaller cities can be observed, described with the term "desakota" (McGee, 2009). This blurred division between rural and urban creates new opportunities for producers in rural areas to cater to the needs of the urban populations.

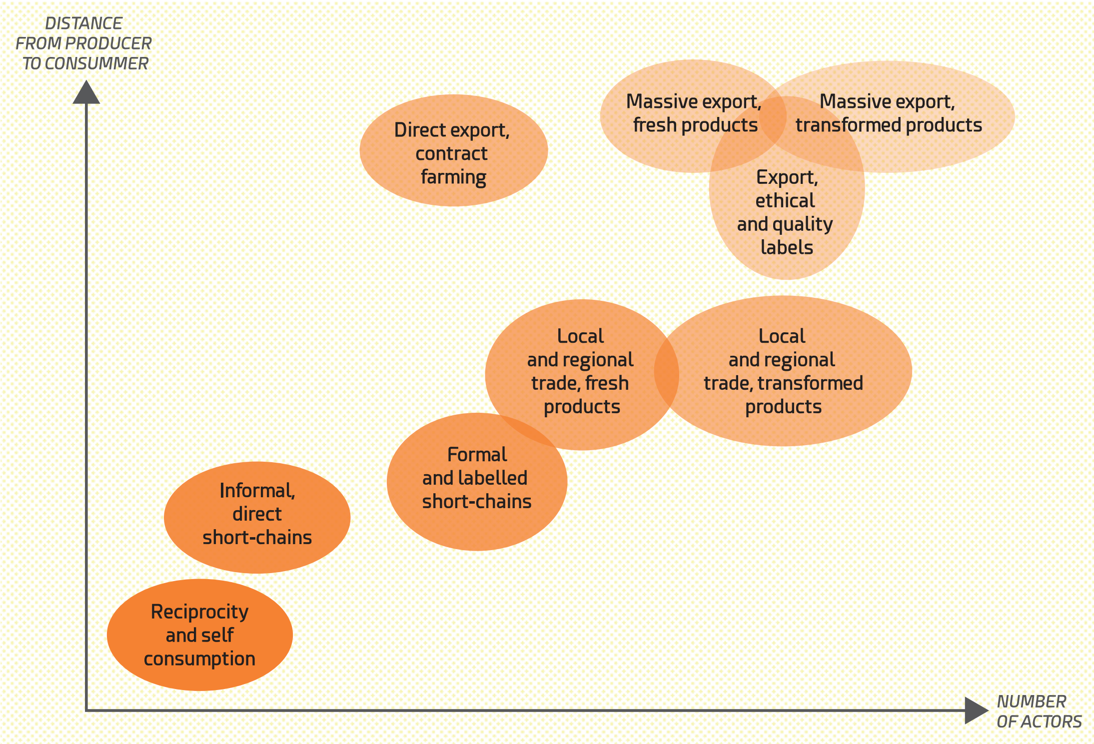


FIGURE 7
Vegetable and fruit diversity of markets
Source: Original mapping from J-M. Sourisseau, CIRAD

The overarching goal is to create sustainable food systems in which small-scale farmers can earn a livelihood in a way that is environmentally friendly, and for all consumers, no matter where they live or what their level of income, to have access to a reliable supply of safe and nutritious fresh fruit and vegetables.

Farmer organizations

Small-scale farmers can better compete and achieve market access if they are organized into groups or organizations (Markelova and Meinzen-Dick, 2009). The increased efficiency of the collective operation and economy of scale achieved enables effective input supply systems, provision of services and market linkages (FAO, 2012c). Farmer organizations aggregate farm products, perform joint sales and purchase of inputs, share knowledge and capacities and increase bargaining power with value chain actors and markets (Kelly, 2012).

Collective actions by farmers' organizations allow for reductions in transaction costs for accessing finance, mechanization technologies, market information and certification schemes. In support of collective actions through farmer organizations, members should have as much liberty as possible to create their own rules adapted to local contexts and market demands (Markelova and Meinzen-Dick, 2009). Farmers' organizations vary from country to country, yet some success factors are common: provide flexibility to adapt to local contexts and market demands; facilitate information sharing, training and technical assistance; generate new funding opportunities and ideas; and focus on core business before expanding to new areas (Kelly, 2012). In cases where farmer organizations are not sufficient to improve market connectivity, an alternative is to bring together similar groups to form larger producers' unions, federations and networks (Arias *et al.,* 2013).

Informal retail markets

In low-income countries it is common for consumers to purchase fresh produce from farmers and retailers at informal markets. These informal markets are quite diverse and resist a precise definition other than they possess certain qualities such as their lack of regulation and separation from large and formal retail markets (supermarkets, hypermarkets, convenience stores) (CFS, 2015).

In cities and towns, informal food retailers may have a small shop or a fixed stall in designated areas, sell from the pavement, or engage in itinerant selling. Generally, these informal traders source their produce from wholesalers, although in some cases they may purchase direct from farmers or farmer organizations. Often members of the farming household, usually women, will market their produce informally at local markets. Although supply chains underpinning the informal trade in food are often concentrated around a city region, they can also cover longer distances. For example, in sub-Saharan Africa, the supply of fruit and vegetables to urban markets can be international, involving informal cross border trade.

The importance of informal retail food markets to ensure food security cannot be overstated. Citing a 2013 World Bank survey, FAO (2017d) highlights that 95 percent of the fresh fruit and vegetables consumed in Kenya are cultivated by small-scale farmers and supplied through informal supply chains. In the region around the Zambian city of Kitwe, about 70 percent of the fresh produce was sold in traditional open-air markets (FAO and RUAF, 2018). Even in higher income countries, the amount of fruit and vegetables that are purchased from traditional markets can be high.

Fruit and vegetables are supplied in informal street markets....

Surveys in Chile showed that consumers obtained 70 percent of all fruit and vegetables from street markets (Arias *et al.,* 2013).

These informal food retailers can be more responsive to the needs of low-income consumers in both rural, peri-urban and urban areas. Their flexibility and mobility can allow them to sell at strategic points in the city that are convenient to low-income consumers (near public transit hubs, for example). They can sell smaller quantities and produce of odd sizes and shapes to accommodate tighter budgets. In some cases, they can offer credit to their clients. These informal retail markets provide something crucial to rural-urban food systems by offering access to markets for small-scale farmers, providing modest incomes for less-skilled rural and urban men and women, and by providing access to fresh produce to low-income consumers.

However, there are clear drawbacks to these informal markets and vendors. The quality of the produce may be low and the risk of food contamination relatively high as food safety standards may be non-existent or ignored and hygienic conditions may be poor. The vendor's inability to keep produce cool and to store unsold produce at the end of the day results in considerable loss, and the discarded produce can lead to sanitation problems. In crowded cities, informal food retailers can contribute to congestion.

For reasons connected to the environment, public health and other aspects of urban living, city planners have a responsibility to establish regulations over the informal trade of fruit and vegetables. Aesthetic concerns often come into play as well, as the presence of informal sellers may not match planners' vision for a modern city (as has been observed in Bangkok, Thailand). However, measures to formalize the informal system must also consider the critical role that upgrading these informal markets can play in stimulating farmers to invest in more productive and more sustainable production systems, and by extension, catalysing territorial economic development. These markets also make

.... as well as in organized wholesale marketplaces

key contributions to the economic livelihoods and food and nutrition security of rural, peri-urban and urban households. Informal markets may be the only way for vulnerable households to access fresh fruit and vegetables in low-income neighbourhoods. To avoid the food desert phenomenon and maintain healthy food environments for improved access to nutritious foods, the physical locations of these markets must be considered carefully by city planners.

Formal retail food markets

Supermarkets and other types of modern food retail markets have transformed food systems throughout the urban-rural spectrum. They have reduced the market share of traditional markets, altered dietary patterns, and changed food procurement practices. Because of food quality and safety concerns about fresh produce sold in informal markets, many consumers have greater confidence in fruit and vegetables from supermarkets.

In some ways, farmers and suppliers of fruit and vegetables are better placed than farmers and suppliers of other crops to adapt to the expansion of modern retail markets and to achieve some measure of market integration. Supermarkets can sell processed foods and cereal crops very cheaply because they are easily transported and stored and can be procured from global sources in bulk quantities, which makes it difficult for cereal farmers and those supplying dried and processed foods to compete. However, for producers and suppliers of perishable produce, the competitive balance is less heavily skewed, and opportunities exist for supply to supermarkets. Between 2006 and 2016, the share of fresh food distributed through supermarkets remained below 50 percent in high-income countries, below 30 percent in upper middle-income countries and around 10 percent in lower-middle income countries (The Global Panel on Agriculture and Food Systems for Nutrition, 2016).

Reardon and Gulati (2008) reported that fruit and vegetables tended to be cheaper in traditional markets than supermarkets, especially in countries where the expansion of modern retail markets is less advanced. However, they point out that India, which is still at a relatively early stage in the transition to modern retail markets, is exceptional in this regard, as vegetables can be 33 percent cheaper in supermarkets than in traditional markets.

There is a greater impetus for supermarkets to source their fruit and vegetables domestically because of the costs, complexity, greenhouse gas emissions and risks (such as loss due to perishability) associated with long distance fruit and vegetable supply chains. Battersby and Watson (2018) citing a 2014 report prepared for the city of Cape Town, South Africa, reported that the four largest supermarket companies in the city sourced 56 percent of their vegetables from within 200 km of the city, but only 5 percent of their grain. Although the proximity of local fruit and vegetable farmers to supermarkets places these farmers in a favourable position, they must overcome the practical obstacles of supermarket food safety and quality standards and deliver a steady supply of the volumes of produce required.

In Kenya, farms supplying to supermarkets were found to be on average five times larger (9 to 18 ha) than those participating in informal markets, and relied heavily on hired labour (Neven *et al.,* 2009) but remain smaller than the definition of true large-scale farms (FAO, 2017f). Farmers in Kenya who have become integrated into the formal domestic retail market achieved a 50 percent increase in household income (Rao and Qaim, 2011). In some contexts, supermarkets have called upon small-scale producers to meet their needs, such as in India where some supermarket chains have relaxed their standards in order to maintain their stock of fresh vegetables from local small-scale producers (Hampel-Milagrosa, 2016).

In Kenya, to meet with supermarket requirements for quality and volume, small-scale farmers of traditional leafy vegetables formed farmers groups with the support of Farm Concern International (FCI), a regional NGO, and entered into a contract farming arrangement with the Uchumi Supermarket chain. The farmer groups ensured that the terms of the contract were respected, and the supermarket staff carried out quality controls. After the initial contractual agreement with Uchumi, the groups signed other agreements with different supermarkets, grocery stores and even informal markets resulting in significant increases in production and incomes (Herbel *et al.,* 2012).

One of the most recent success stories of small-scale farmers' access to market has been the entry of Twiga Foods (**https://twiga.com/**) into the market in Kenya. Since 2014, it sources fruit and vegetables from small-scale farmers in rural areas and supply them to traders in the cities.

Export markets

This document stresses the importance of integrating small-scale fruit and vegetable farmers into nearby markets for increasing farm productivity and building robust local food systems that can ensure an adequate supply of nutritious fresh produce, especially in low-income countries where the prevalence of malnutrition is high and supplies of fruit and vegetables are insufficient. However, some consideration must be given to the opportunities available for small-scale farmers in low-income countries to participate in export markets. The long growing seasons and the low cost of labour in tropical countries offer small-scale farmers opportunities to earn higher incomes by capitalizing on the demand for off-season fruit and vegetables in high-income temperate countries. Increased incomes and higher productivity for these farmers would in turn contribute to local economic development and thus food security.

However, as with domestic retail markets, small-scale farmers in low-income and lower-middle-income countries face daunting challenges in participating in export markets. Governments in high-income countries have set strict food safety and traceability requirements (for pesticides, mycotoxins and quarantine pests, pathogens).

Small-scale farmers are limited by economies of scale, but contract farming is a potential mechanism to integrate them into export markets. In contract farming, small-scale farmers enter into contracts with buyers that lay out the terms and conditions for the production and marketing of farm produce, usually stipulating the price to be paid, the quantity and quality of the product, and the date for delivery. Contract buyers agree to supply inputs such as seeds, fertilizers as well as credit and technical advice plus post-harvest services to meet standards for GAP and good manufacturing practices (GMP). These contracts can contribute to increasing productivity, improving efficiency in the use of inputs and natural resources, which reduces environmental pollution, and ensuring food safety.

Contract farming has been shown to increase farmers' incomes for small-scale vegetable farmers in Kenya (McCulloch and Ota, 2002). However, a drawback with this mechanism is that contracts are made with the owners of the land, who are almost exclusively men. Even though women make significant contributions to production, the payment is made to the contractor, and this can lead to an unfair allocation of income and intra-household conflict, as observed in Kenya (Dolan, 2001). FAO has published guiding principles for responsible contract farming operations (FAO, 2012d). See FAO's Contract Farming Resource Centre (**http://www.fao.org/in-action/contract-farming/en/**) for further reading on contract farming.

A review of studies on the participation of small-scale fruit and vegetable farmers in export chains from seven sub-Saharan African countries showed how small-scale participation varies significantly by country and by crop (Maertens *et al.,* 2012). In Madagascar in 2004, 90 to 100 percent of the fresh vegetables grown for export were procured from small-scale farmers, whereas in Senegal it was 52 percent and in Zimbabwe in 1998 it was 6 percent. In Côte d'Ivoire in 2002 none of the bananas were procured from small-scale farmers, but 70 percent of the pineapples were procured from small-scale farmers. In Madagascar, contract farming for green beans (mainly exported to France) constituted about half the household income for contract farmers. In addition, the inputs and the support provided by the export company (the only domestic exporter in the country) also brought other benefits. Small-scale farmers have become Global GAP certified, and they have applied some sustainable practices, such as composting, introduced for green bean cultivation to increase the productivity of their other crops. However, in Senegal, large farms became Global GAP certified, while none of the contract farming small-scale farmers were certified. Moreover, contract farming households had notably more land and non-land assets. In Madagascar, although the contract farmers had holdings that were in line with the national average (less than one ha), they had higher levels of education. Contract farming for vegetables for export markets can increase incomes for small-scale farmers, but since these farmers tend to be already relatively well off, it may have a limited overall impact on poverty reduction, although it may support the diffusion of more sustainable farm management practices. Increased earnings from wage labour on larger fruit and vegetable farms and in agro-industries supplying export markets also reduced poverty (Maertens *et al.,* 2012). Some households however, may face important constraints to participate in this sector (McCulloch and Ota, 2002).

Niche markets

The great diversity of fruit and vegetable crops, including NUS, and their high nutrient content and economic value, offers entrepreneurial opportunities for developing profitable local niche markets for small-scale farmers. Niche markets can be created by reaching out to different communities that have settled in nearby cities and supplying foods that are part of their culinary traditions (that can be marketed as heritage crops). These foods do not need to be delivered only through retail markets, but can include direct sales agreements with restaurants, caterers and cultural organizations. In some areas, there are opportunities to supply fresh produce directly to hotels and restaurants catering to tourists and other international visitors, including distinctive and unusual local fruit, vegetables and recipes.

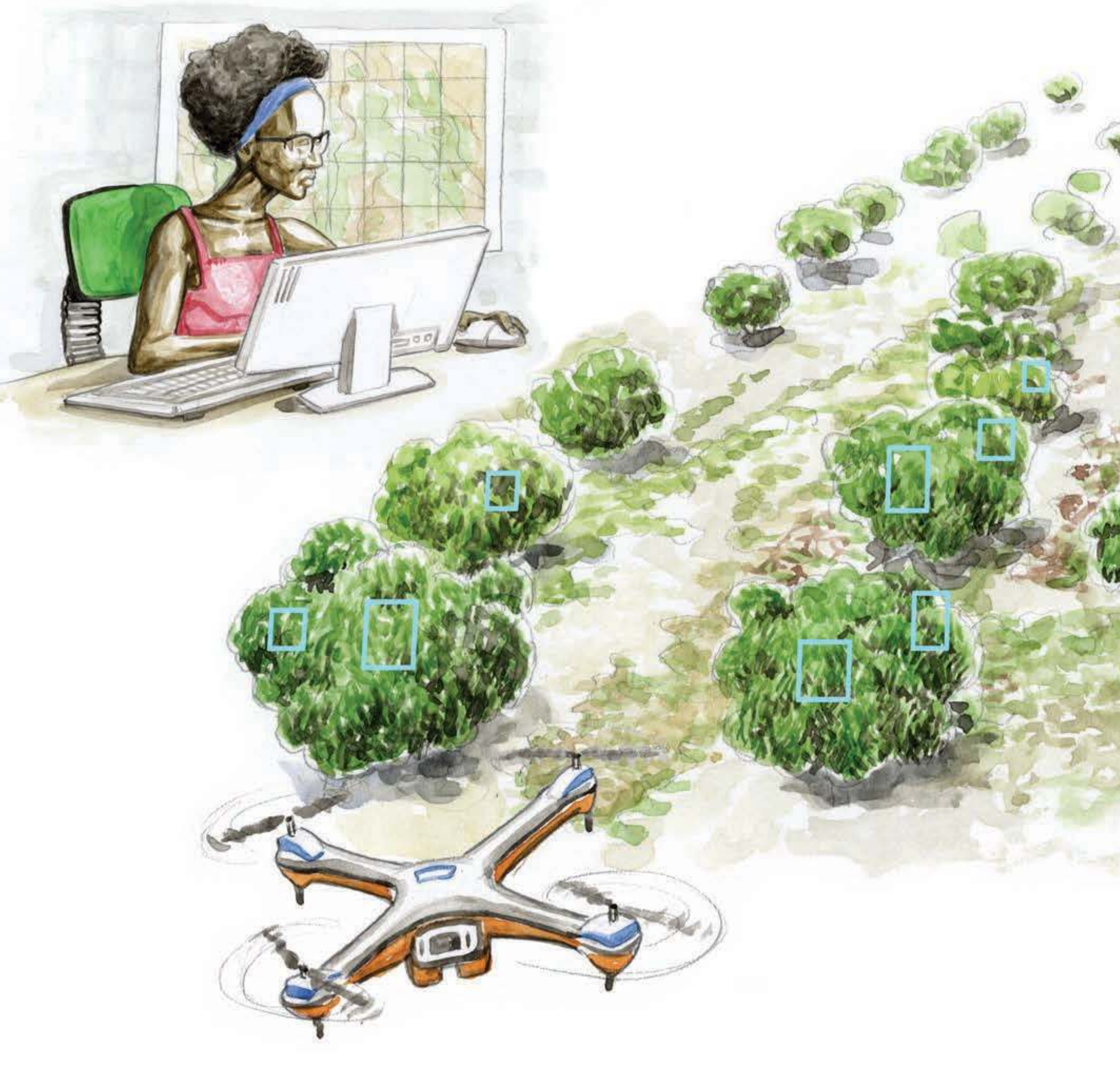
Another marketing option is the organization of community-supported agriculture groups, in which consumers who are committed to eating locally grown healthy seasonal foods pay an upfront subscription at the start of the season to a farmer or a group of farmers who then provide a regular basket of fresh produce throughout the year.

Participatory guarantee system

In general, small-scale farmers in developing countries face difficulties in complying with the standards associated with third-party certifications (GAP, Organic Agriculture and FairTrade, etc.) due to high costs and complex paperwork. Participatory Guarantee Systems (PGS) is an alternative certification suitable for small-scale farmers. Vegetables, fruit, and spices are the most common produce sold through such schemes. For PGS to work, it is important that there is market demand for safe and healthy foods and pioneer farmers who are willing to work together for increased economic returns (FAO and INRA, 2016).

PGS was originally used for small-scale farmers practicing organic agriculture and who were seeking to supply local and domestic markets. But PGS can also be adapted and used for all types of sustainable production. PGS is ensured by the direct participation of farmers, consumers and other stakeholders through farm visits and peer-reviews (IFOAM, 2008). This type of guarantee system is suitable for small-scale farmers as it lowers the costs of participation (which mostly takes the form of volunteering time) and reduces paperwork compared with third-party certification (FAO and IFOAM, 2018). PGS brings economic benefits to small-scale farmers because it identifies their products as safe and of good quality, which helps them to gain access to new and more stable markets.

In Namibia, where fraudulent claims about organic quality resulting from weak institutional infrastructure have been an issue, producers and consumers proposed a PGS. This resulted in consumer confidence in PGS-labelled products, higher economic returns and improved collaboration among farmers, value chain actors, markets and consumers (FAO and INRA, 2016).



CHAPTER 4

Enabling environment

Sustainable production and stable value chains for fruit and vegetables require technical, financial and political support. This is necessary for global agricultural production to go beyond meeting requirements for dietary energy and to achieve critical nutritional requirements. According to FAO, there is a nutrition gap between the foods that are grown and available and the foods that are needed for a healthy diet (Mason-D'Croz *et al.,* 2019; FAO *et al.,* 2020). One of the key messages that came out of the 2016 FAO/WHO International Symposium on Sustainable Food Systems for Healthy Diets and Improved Nutrition was that: ''There is a persisting misalignment between supply-side agrifood policies and investments and nutrition goals'' (FAO and WHO, 2017). Supporting small-scale farmers to increase their sustainable production of fruit and vegetables will help close this nutrition gap and correct this misalignment (FAO, 2014f).

An enabling environment is required to support small-scale fruit and vegetable production as well as other stages of the value chain and requires mainstreaming multi-sectoral and multi-risk sensitive development strategies that includes ministries of agriculture, environment, public health, food safety, trade, education and planning. Collaboration and partnerships are needed with intergovernmental organizations, farmers' organizations, private sector, civil society and international and national NGOs. FAO in collaboration with WHO has analysed the role of different stakeholders and elaborated a strategy framework to sustain national and regional initiatives on the promotion of fruit and vegetables for health (FAO, 2004).

Knowledge, skills and advocacy

Sustainable fruit and vegetable production is knowledge intensive, and small-scale farmers need access to technically sound guidance and quality skill development opportunities. Small-scale farmers also need access to a wide range of useful information related to weather, inputs and markets to help them to make appropriate decisions on when and what type of inputs to buy and when and where to sell their harvest. This requires engagement in capacity-building activities that introduce new risk sensitive practices, technologies and inputs (crops and varieties, water and nutrient management, soil and plant health), but also extend to commercialization. Collaboration will be needed among a particularly broad range of sectors, including agriculture, the environment, health and nutrition, water, sanitation and hygiene to provide the required education and ensure stable value chains for safe fruit and vegetables.

Gender-sensitive programmes to build the business skills of fruit and vegetable farmers and their service providers (for inputs, post-harvest options and market linkages) are critical. Gender-sensitive, socially inclusive programmes that can reach large numbers of beneficiaries with a wide range of needs will require coordinated support from different groups working collaboratively at the national, subnational and local level. It will involve building partnerships among government agencies, UN organizations and other multinational organizations, national and international NGOs, farmer organizations, civil society organizations, research agencies and the private sector. Education and training at tertiary and secondary levels requires upgrading.

At the same time, advocacy campaigns to promote the benefits of eating a variety of fresh fruit and vegetables are also needed. An increased consumption of fresh fruit and vegetables will not only have a positive impact on nutrition and health, it will spur consumer demand for safe, sustainably grown fruit and vegetables, which can create new market opportunities for local small-scale farmers. Nutrition education in and outside schools is elaborated on further in this document.

Agricultural extension and advisory services

Agricultural Extension and Advisory Services (AEAS) encompass the different activities to provide the information and services required by farmers and other actors in rural settings to assist them in developing their own technical, organizational and management skills and practices to improve their livelihoods and wellbeing (GFRAS, 2012). Agricultural Extension and Advisory Services are central to increasing sustainable crop production and need to be made more generally available (FAO, 2014d) especially for women (FAO, 2011b). Community dialogue is critical to encourage communication among farmers, practitioners, researchers and local government (David and Cofini, 2017). When designing training programmes, it is important to consider how best to encourage women to take part by considering, for example, the timing and location of sessions. Small-scale farmers struggle to access AEAS because publicly-funded schemes have a limited outreach. A diversification of AEAS providers has helped to bridge the gap between supply and demand. Sulaiman and Hall (2002) describe a range of experiences in India where diversification of AEAS providers has helped to bridge the gap between supply and demand by making better use of the private sector and civil society through input suppliers, export companies, NGOs and farmer associations, for example, and this has been further supported by advances in ICT development.

For fruit and vegetables, it is of particular importance that capacity exists to diagnose and manage pests and diseases in a sustainable manner through linkages to skilled networks (Miller *et al.,* 2009). For Uganda, the successful implementation of mobile plant clinics was dependent on creating a functioning plant health care system supported by national agricultural policies (Danielsen *et al.,* 2014; Danielsen and Matsiko, 2016).

Many seed companies, such as East-West Seeds, provide support services to small-scale fruit and vegetable farmers, including training and advice on pest management. However, private sector companies selling inputs and equipment mostly do not have access to small-scale farmers in remote rural areas compared with small, non-specialized retailers often selling a poor variety of inputs such as pesticides in villages. There are concerns that private input suppliers and agrodealers promote their own products, which may be more costly, less suitable for farmers than available alternatives, or pose a greater health risk to human and environmental health (e.g. agrochemicals). While such egregious practices exist, stronger regulation of approved products and introducing codes of practice are tackling the worst excesses of agrodealers. There is also a wider awareness that a sustainable supply of essential and affordable inputs is heavily reliant on a vibrant private sector.

One of the goals of sustainably increasing fruit and vegetable production is to ensure farmers have access to the information and services they need to accurately determine fertilizer requirements and IPM options. In one study in Southeast Asia, it was found that vegetable farmers obtaining crop protection advice from pesticide retailers spent 251 percent more on chemical pesticides than farmers obtaining advice from neighbours or extension agents (Schreinemachers *et al.,* 2017a).

The government has a continued role to coordinate advisory services provisions to ensure that they are environmentally, commercially and socially appropriate. There remains an important role for the public sector in providing extension and advisory services, particularly in areas where the prevalence of food and nutrition insecurity is high. However, delivering extension advice to large numbers of small-scale farmers is costly, and governments must weigh the environmental, economic and health benefits of this against the benefits that may be obtained from possible alternatives. There has also been a recognition that in these rural areas, educational initiatives must be more responsive to the needs of farmers and value chain actors, and not deal simply with on-farm production issues, but also address broader concerns related to market linkages, strengthening entrepreneurship, and improving access to affordable and high-quality inputs, credit and post-harvest options. Digitalization in extension and advisory services can enhance access, delivery, scope and impact of AEAS for agricultural producers and processors, including youth and rural women through digital innovations, both with emerging technologies (blockchains, artificial intelligence, the Internet of Things- IoTs) and accessible digital tools (mobile phones, knowledge management platforms, also known as e-extension, radio and TV programming).

Those working in fruit and vegetable value chains need better access to information and training. Fernandez-Stark *et al* (2011) identified the following priority areas for attention:

- training in food safety and how to satisfy compliance standards;
- incentives to firms to shift from flexible to a more permanent workforce to maximize the return on investment in training;
- increased partnerships between educational institutions and private sector firms to customize education programmes to meet the needs of the industry; and
- capacity development for the implementation of risk-sensitive measures within all aspects of the chain, including production, packing, storage and agroprocessing.

By themselves, public agencies cannot respond to the increasingly complex needs of farmers and value chain actors. In delivering rural advisory support, the public sector often works in partnership with other providers, which may involve different types of public-sector agencies, local, national or international NGOs, universities, private sector consulting firms or farmer organizations. Rural advisory services provided by NGOs and social enterprise models tend to be participatory and, therefore, effective in their approach but as they generally rely on donor support, longer-term provision can be a problem.

There is no single best method for providing extension advice that responds to different needs, purposes and targets. As FAO (2014d, p. 72) notes, ''A crucial problem facing governments and other actors in designing effective extension and advisory support is the shortage of empirical evidence to guide choices.'' To address this gap, FAO and the Global Forum for Rural Advisory Services (**https://www.g-fras.org/en/**) support the development and synthesis of evidence-based approaches and policies for improving the effectiveness of rural advisory services (Blum *et al.,* 2020).

Farmer Field Schools

FFS is a participatory process of group-based learning that was first developed over 30 years ago by FAO to promote IPM in rice fields in Asia. The FFS approach has since been adapted to support development programmes in Africa, Asia and Latin America, and FFS are now being implemented in over 90 countries. This is reviewed in detail in FAO (2019e). The focus of FFS has expanded to a broad range of crops, including fruit and vegetables, and to address issues related to land preparation, nursery management, irrigation, soil conservation, variety selection, fertilizer use, composting, IPM, value chains and marketing. In the Democratic Republic of the Congo, FAO organized FFS to reach more than 9 000 vegetable growers in five cities (FAO, 2010a). Basic economics of vegetables production were also introduced during sessions in Malawi, where the Ministry of Agriculture, Irrigation and Water Development prepared a nutrition handbook for FFS in 2015.

FFS facilitators receive training on gender issues and become familiar with the concepts of social inclusion and social vulnerability. Over the years, gender-responsive good practices and lessons learned have indicated that FFS can influence social dynamics and reinforce social inclusion. Using the concept of FFS as a model, FAO developed the Farm Business School approach to assist small-scale farmers take advantage of new market opportunities and has partnered with several organizations and initiatives such as Dimitra Clubs (**Box 10**). See the website of the Global Farmer Field School Platform (**http://www.fao.org/farmer-field-schools/home/en/**).

Food and nutrition education in schools

School food and nutrition programmes that teach children about healthy diets are important for addressing malnutrition and building future consumer demand for fruit and vegetables. FAO has worked with several countries and partners to develop materials and activities for professionally training nutrition educators (FAO, 2019f). A range of materials that make up the FAO planning guide for curriculum development on nutrition education in primary schools are available from the Nutrition Education in Primary Schools website (**http://www.fao.org/3/a0333e/a0333e00.htm**).

BOX 10. Dimitra Clubs for improved extension services. *Source: FAO-Dimitra project (http://www.fao.org/dimitra/home/en/)*

Dimitra Clubs are voluntary, informal groups for women, men and youth. Members discuss shared issues related to a broad range of topics, including agriculture production and marketing, food and nutrition, and small business development. They work together to develop practical approaches for solving problems using local resources. The approach is embedded in over 30 FAO field development projects. In 2019, there were more than 5 000 Dimitra Clubs with about 150 000 members (60 percent women) in eight countries of sub-Saharan Africa. In Niger and Senegal, Dimitra Clubs have developed close synergies with FFS. The FAO-Dimitra Programme facilitates their set up and provides training and coaching, but the clubs themselves are self-managed.

In 2014 in the Democratic Republic of the Congo, members of Dimitra Clubs, after consulting with a nutrition expert, were able to push for the end to a number of customary dietary restrictions that prevented women from eating certain foods. Addressing food taboos is important as they can be an obstacle in the way of increased consumption of fruit and vegetables (Beaudreault, 2019).

The clubs are a key element of the FAO-Dimitra Programme, which provides policy advice to government ministries on the adoption and integration of gender-transformative approaches in their policies, strategies and programmes to fight poverty and hunger. Special attention is given to the inclusion of groups that tend to be marginalized, such as women and youth, so that the clubs enable those voices that are seldom heard to be listened to. The clubs develop partnerships with local radio stations, which transmit member discussions through an accessible medium.

School gardens combine nutrition education with training on how to grow and prepare fruit and vegetables, along with didactic learning of subjects such as science, business, maths and art. This helps ensure that knowledge gained about the nutritional value of fruit and vegetables goes hand in hand with the ability to obtain a safe and secure supply at the household level. Studies have shown that school gardens can help to increase children's preference for fruit and vegetables, but so far have shown limited evidence on its impact to change consumer behaviour (Schreinemachers *et al.,* 2017c, 2019). Efforts are still needed to connect it to behaviour change, and to develop farming and entrepreneurial skills in children, which can guide the next generation of farmers and encourage them to grow crops sustainably and with nutrition in mind. FAO has prepared a set of training materials on establishing school gardens (FAO, 2005a) and has supported national school gardening initiatives in Armenia, Azerbaijan, the Bahamas, Brazil, El Salvador, Honduras, Kyrgyzstan, Nicaragua, South Africa and Tajikistan to stress the importance of fruit and vegetable consumption.

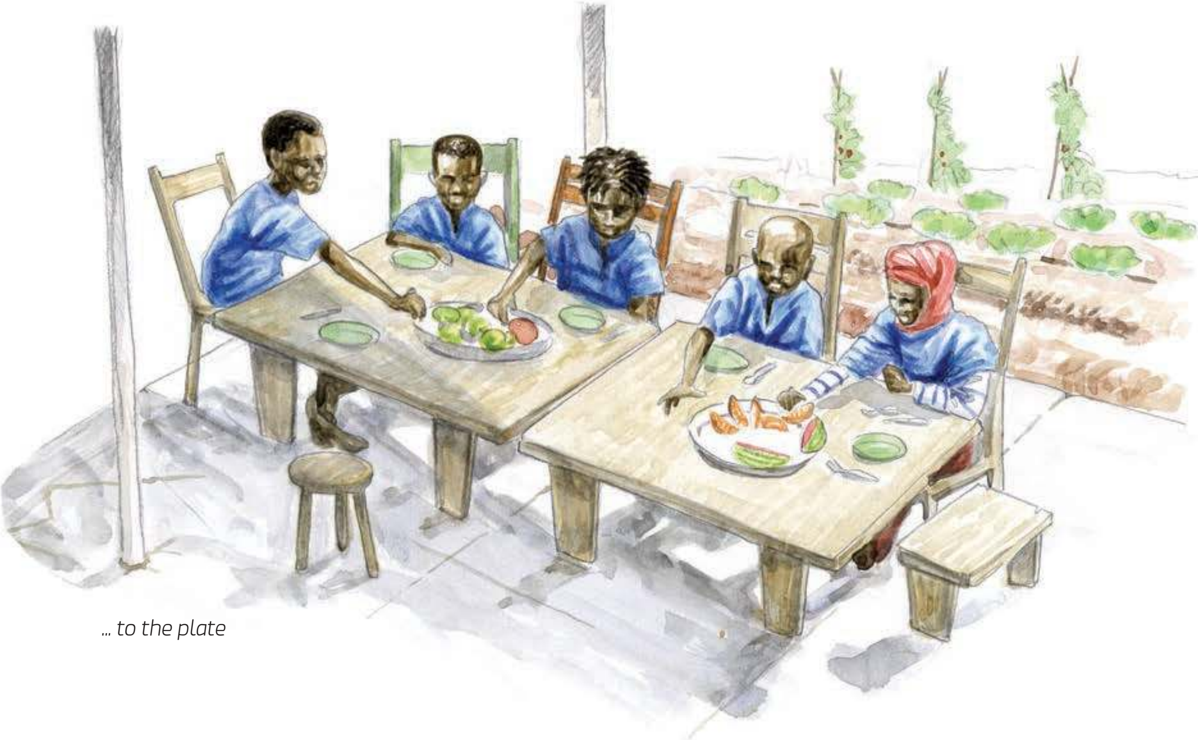
School gardening for continuous and enjoyable education from the field...

• Food and nutrition education outside the classroom

Because of the critical importance of addressing malnutrition among the most vulnerable, including adolescent girls, pregnant and lactating women and infants during their first 1 000 days, considerable effort has been made to reach out directly to vulnerable households and communities to raise awareness of proper nutrition and to increase the supply and availability of fruit and vegetables and other healthy foods. The Scaling Up Nutrition Movement **(https://scalingupnutrition.org)**, which is active in more than 60 countries and is supported by the UN Network, focuses its efforts on ensuring good nutrition during the first 1 000 days of life.

Participatory cooking sessions, which combine nutrition education with cooking skills, are one approach to promote the consumption of home-grown or locally available fruit and vegetables to reduce micro-nutrient deficiencies, especially targeting mothers and infants. FAO has produced practical guides and recipes for participatory cooking sessions and carried out projects in Afghanistan, Cambodia, Malawi and Zambia focused on improving complementary feeding, which infants require when they reach the age when breast milk alone is not enough to meet their nutritional requirements, using locally available fruit and vegetables and other ingredients (FAO, 2017g).

Promoting home gardens is one of the most common ways of combining nutrition education with food production, particularly vegetables. FAO



... to the plate

has worked with countries to support families to cultivate home gardens and has prepared training materials on improving nutrition through home gardening for field workers in Africa (FAO, 2001), Latin America and the Caribbean (FAO, 2014e) and Southeast Asia (FAO, 1995). FAO has also combined nutrition education with practical training in establishing micro-gardens for peri-urban and urban households, and with community gardens, often in areas that have been affected by crisis. There is evidence that home gardening and related interventions can promote the consumption of foods rich in protein and micronutrients (Hawkes, 2013). The World Vegetable Center household garden interventions have also sought to improve the nutritional status of people vulnerable to micronutrient deficiencies by increasing the fruit and vegetable production from a home garden and offering complementary training in nutrition and health. Approaches to home gardens have been comprehensively reviewed (World Vegetable Center, 2016).

• International advocacy campaigns for fruit and vegetables

The International Year of Fruit and Vegetables in 2021 will advocate for actions to strengthen the role of small-scale and family farmers in sustainable farming and production in order to reduce hunger and poverty, enhance food and nutrition security, improve livelihoods and contribute to better natural resource management. In particular, it will highlight the food system approach that links up field to fork, and farmers to consumers, for quality management to provide nutritious, safe and tasty fruit and vegetables, in a sustainable environment.

Since the first International Conference on Nutrition in 1992, many governments have launched campaigns to raise awareness of the importance of proper nutrition and daily exercise. In its 2010 *Global Status Report on Non-communicable Diseases,* the WHO listed public awareness campaigns about diet and physical activity as one of its best buys: ''actions that should be undertaken immediately to produce accelerated results in terms of lives saved, diseases prevented and associated economic costs avoided'' (WHO, 2010). Many of these campaigns, which are generally carried out by an alliance of government agencies, civil society organizations and the private sector, have specifically sought to promote the increased consumption of fruit and vegetables.

The Global Alliance to Promote Fruit and Vegetable Consumption "5 a Day", which was founded in 2012, unites 33 national campaigns. A review (Hawkes, 2013) of evidence on the impact of national fruit and vegetable campaigns in Australia, Chile, the United Kingdom of Great Britain and Northern Ireland, and the United States of America found that they contributed to increased fruit and vegetable consumption.

Ensuring access to resources

To support small-scale farmers to increase fruit and vegetable production sustainably, policy makers at the national, subnational and local level need to work with a range of different actors to ensure these farmers have secure access to land, water and financial resources.

Land tenure

Secure access to land is critical because farmers require longer time periods to test, adapt and eventually adopt technologies and practices for sustainable intensification. This is especially true for orchards and agroforesty systems with fruit trees. But vegetable farmers must make investments in land management, soil fertility and water management that cannot be recovered in one single year, or do not fully deliver the desired benefits in the first year. Lack of long-term rights to land, the absence of legal recognition of customary and other legitimate land rights, and competing tenure claims, all contribute to hinder the uptake of sustainable crop intensification practices. Many small-scale fruit and vegetable farmers, both men and women, have access to land under modern, customary or informal tenure and face the constant threat of being evicted or having their plots appropriated by others. Competitive

BOX 11. Tree tenure. *Source: FAO and ICRAF (2019)*

In many customary systems, tree tenure is distinct from land tenure – the owner of the land may not be the owner of the trees growing on the land. Tree tenure regimes can be very complex, distinguishing between whether the trees are planted or wild, and how the tree products are used (personal or commercial use) (Bruce, 1989). Certain trees may be accessed by all community members, while other trees may be privately owned or their use may be limited to only a few households. In Côte d'Ivoire, Ghana and Togo, farmers generally have exclusive rights to the trees that they plant, but trees that are naturally regenerated belong to the community. In sub-Saharan Africa, planting trees may indicate that the planter is making a claim to the land (Bruce and Fortmann, 1989), and some farmers avoid doing so to avoid conflict. This situation can inhibit farmers from investing in farmer-managed agroforestry systems. Also, tree tenure regimes that allow for multiple users of tree products can create disincentives for individual farmers with access to land to engage in agroforesty, as they will not see the full benefit of their investment. Policies to support agroforesty practices with fruit trees will need to clearly identify statutory rights for land, trees and tree products.

tenure arrangements may be systems built on traditional or modern social hierarchies that are discriminatory against women and other groups. Tenure for fruit trees can differ from land tenure in general (**Box 11**).

Overcoming the challenges related to formalizing land tenure arrangements and ensuring equitable access to land for men and women small-scale farmers is complex and challenging for many governments across the world. Solutions will depend heavily on the local context. *The Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security* provides support to countries in promoting secure tenure rights and equitable access to land, fisheries and forests as a means of eradicating hunger and poverty, supporting sustainable development and enhancing the environment (FAO, 2012f). FAO also published a technical guide to achieving gender-equitable governance of land tenure (FAO, 2013b). See the FAO Gender and Landrights Database (**http://www.fao.org/gender-landrights-database/en/**).

Financial services

Lack of secure land tenure compounds the constraints farmers face in accessing financial services and credit. Banks and other financial institutions will generally not offer credit to small-scale farmers unless they own land that can be used as collateral. Farmers' organizations can be an important source of credit (through the collection of financial contributions from members and provision to individuals) and other services, such as support for input purchases, advisory services, post-harvest services and connections to markets. However, membership in some farmer organizations may be restricted to farmers who own land or who have legally-recognized land tenure. Policies that can facilitate small-scale farmers' access to credit, particularly long-term loans, is essential to enable them to invest in natural capital such as soil fertility and good agricultural practices (GAP) and which will in turn boost sustainable production. Equally, access to credit, recent advances in mobile phone mediated banking, such as M-Pesa in Kenya and the United Republic of Tanzania, may enable farmers to access innovative techniques and technologies for more sustainable production and marketing strategies.

Urban agriculture planning

Insecurity over land access is particularly acute in peri-urban and urban settings where competition for land is intense and changes in land use can be sudden. For many urban and peri-urban farmers, secure long-term access to land does not often exist. In many countries, urban farming, which is dominated by vegetable production, is not acknowledged in agricultural policies and urban planning. Farmers often operate without permits from municipal authorities, or on land granted under customary law (FAO, 2010b, 2014b). The insecure tenure that characterizes horticulture producers reduces their capacity to invest in equipment and infrastructure (e.g. irrigation equipment) and makes them more vulnerable. In the context of land scarcity, the value of land for other non-agricultural uses is much higher and cultivations are seldom protected by secure tenure arrangements.

However, in many cities there is a considerable amount of underutilized open space and usable land, which could be allocated or leased for vegetable production (terraces along rivers or landslide-prone areas). Land use inventories and recent advances in geographic information system-based spatial mapping need to be undertaken in conjunction with research to determine tenure status and ownership, access to water and the different options for crop production (FAO, 2010b, 2014). However, there is evidence of how lessons learned from urbanization in such places as China can provide guidance to countries in Africa (Dercon *et al.,* 2019).

In many countries, there are no policies for land planning and management for long-term, sustainable agro-urban development. Land tenure arrangements for food production need to be considered by local authorities as part of an overall urban and territorial planning that includes land use policy that supports sustainable agricultural development. Through zoning and regulations, urban land policy should recognize and provide security for fruit and vegetable production in both rural and urban areas and build stronger connections between rural, peri-urban and urban producers and consumers. This will require multi-stakeholder platforms that include representatives from different ministries of the central government, municipal public health, education and land tenure authorities, representatives of producer but also consumer associations, inputs suppliers, water resources managers, NGOs and micro-finance providers (FAO, 2010b). The benefits of having green spaces and infrastructure in cities is largely undervalued. Apart from the aesthetic benefits, green spaces can be strategically placed in areas along rivers or on hillsides to reduce fatality risks during flash flooding or landslides in extreme weather, they can reduce the heat island effect, increase urban biodiversity and contribute towards improved air quality. A growing number of municipalities are recognizing the importance of having urban and peri-urban agriculture and forestry to increase resilience to disasters and climate-related shocks and stresses and farmers need to be incentivized to provide these environmental services.

There are examples of policies that cities have adopted to support access to land for urban fruit and vegetable producers:

- In the municipality of Rosario in Argentina, grant tax exemptions have been extended to landowners who allow low-income urban farmers to use vacant private lots.

- In Cape Town, South Africa, low-income urban farmers are given support in the form of secure access to irrigation water, tools and compost.
- In the Democratic Republic of the Congo, municipal consultation committees, representing local authorities and growers' associations, were set up with the assistance of a FAO project to process requests for secure leases to approximately 1 200 ha of market gardens (FAO, 2010b; 2014a).

The city region food system approach

A significant number of fruit and vegetable producers are located in peri-urban areas and associated rural hinterlands. In these areas, formal and informal farm units operate intensive semi- or fully-commercial farms and produce high-value crops given the proximity to urban consumers and markets. Food produced in peri-urban areas and rural hinterlands guarantee supplies for both urban areas and their rural surroundings, while urban areas supply the markets upon which agricultural livelihoods depend. Specifically, resilient city region food systems (CRFS) (**http://www.fao.org/in-action/food-for-cities-programme/overview/crfs/en/**) improve access to markets and promote recognition of alternative markets (farmers' markets, community supported agriculture). This includes promoting local and regional food hubs and shorter value chains and, more broadly, efficient and functioning agricultural supply chains that link hinterland producers to market systems. More integrated production and supply also means reducing food loss and waste, which is particularly significant for perishable products.

Nevertheless, considering the competition for land and water with other uses, the constant and rapid growing of urban areas, as well as the complex policy and tenure environment for production in these areas, farmers struggle to connect to markets and make a decent livelihood. In these contexts, promoting CRFS better connects farmers to markets and makes fruit and vegetables more easily available to cities.

The CRFS approach offers a concrete policy, including for ministries of agriculture and programming, and opportunities within which development issues can be addressed, and through which rural and urban areas and communities can be directly linked. CRFS improves economic, social and environmental conditions in both urban and nearby rural areas, promotes shorter value chains and recognizes the need to promote local produce for resilient food systems in response to the COVID-19 pandemic (**http://www.fao.org/3/cb1020en/CB1020EN.pdf**).

Food and nutrition security of a city depends on the integration of its food system within its region. Illustration inspired from FAO-RUAF (2015) http://www.fao.org/3/a-i4789e.pdf

Connecting to markets

It has been increasingly recognized that policies and programmes that focus exclusively on introducing farmers to sustainable approaches to increase or diversify their production of high-value crops are not enough to ensure that farmers will adopt the practices. The barriers to adoption are often related to the inability of farmers to deliver their produce to market or a lack of market demand resulting in poor returns on investments. Policies and programmes must include a sound analysis of proposed markets, and must also be gender-sensitive to ensure social inclusivity (FAO, 2014c; OECD and FAO, 2016; FAO, 2018c).

Farmers' organizations play a key role in supporting small-scale farmers to connect to markets because of economies of scale. Aggregated farmers can secure post-harvest services and market linkages that would be impossible if farmers operated independently. Policies designed to increase the production of sustainably grown fruit and vegetables, and to supply these nutritious foods to low-income consumers, can be achieved by promoting farmers' organizations, and post-harvest and marketing enterprises. International Fund for Agricultural Development (2016) developed an online toolkit that provides guidance on developing sustainable partnerships with farmers' organizations within its projects.

Infrastructure

For fruit and vegetable farmers, barriers to selling their fresh produce are often linked to poor roads, intermittent or non-existent power, a lack of a cold chain and limited mobile phone or internet connectivity to coordinate the exchange of information between suppliers and buyers. Investments in infrastructure such as roads, waterways, railways, electrical networks and ICTs can better link farmers, value chain actors, markets and consumers. In addition, infrastructures, particularly to improve storage, conservation and transportation are crucial to reduce food losses, which are significant for perishable products such as fruit and vegetables. These major public investments are costly and will necessarily be undertaken as part of a much larger territorial development plan, beyond horticulture.

Examples of policy for infrastructure and logistics can include:

- providing a reliable electricity supply and access to the internet;
- constructing or improving roads, rail or shipping links from farms to collection centres, storage facilities and marketplaces;
- building collection centres in remote areas near production sources;
- creating post-harvest facilities equipped for sorting, grading, washing, sanitation, packaging and storing;
- investing in technologies and facilities to process fruit and vegetables into value-added products with extended shelf lives while ensuring nutritional contents; and
- establishing regulatory frameworks for food safety and quality standards (FAO, 2015a).

Public procurement

Governments can provide a market for small-scale fruit and vegetable farmers by procuring fresh produce from them for social protection schemes that offer safe and nutritious food for vulnerable groups and public schools. Brazil's Family Farming Food Procurement Programme, established in 2003, purchases food directly from family farmers to supply institutions serving vulnerable populations and to replenish government stocks. In 2009, Brazil also launched the National School Meals Programme, which obliges public schools to dedicate at least 30 percent of their food budget to direct purchases from family farmers (FAO, 2015b).

To ensure transparency, avoid market distortions and reduce waste, public procurement processes can often be highly regulated and involve time-consuming bureaucratic procedures and complex accountability mechanisms. These pose significant obstacles to the participation of small-scale farmers in school-feeding programmes, as farmers' organizations may not be able to obtain recognized formal status. To overcome this constraint, governments can adopt policies that favour small family farmers in public procurement processes, including:

- allocating fixed percentages or quotas of public purchases to small-scale farmers;
- adopting tender processes specifically designed for small-scale farmers; and
- dividing up large purchases so that small-scale farmers can respond (FAO, 2015b).

At the international level, the World Food Programme (WFP) established programmes for procuring food from local farmers. Its Purchase for Progress (P4P) pilot initiative (2008–2013) sourced 10 percent of its food purchases from small-scale women and men farmers, provided them with training and assets to improve crop quality, facilitated their access to finance and promoted marketing. It also encouraged national governments and the private sector to buy food in ways that supported small-scale farmers. Another initiative was the Purchase from Africans for Africa (PAA) programme (2013–2016), which was modelled on Brazil's Food Purchase Programme. PAA worked to support small-scale farmers in growing, processing and selling produce, including fruit and vegetables, to meet WFP's quality standards for its school feeding programmes in Ethiopia, Malawi, Mozambique, the Niger and Senegal (FAO and WFP, 2014; Gyoeri *et al.,* 2016; Devex, 2016).

Government regulations and incentives

Pesticides

To protect the health of farmers and consumers, and the agroecosystems as well, fruit and vegetable production must be free as much as possible from any chemical inputs. Investment is needed in the development, registration and accessibility of biological control agents. National governments must establish and enforce regulations on pesticides, including effective systems of governance for registering and distributing pesticides as covered under the *International Code of Conduct on Pesticide Management* (FAO and WHO, 2014). See the complete set of technical guidelines (**http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/list-guide-new/en/**) for the implementation of the International Code of Conduct on Pesticide Management.

Any perverse incentives that encourage the misuse of chemical pesticides, such as price subsidies, should be eliminated, and governments should heed the guidance provided by the Rotterdam Convention (**http://www.pic.int/Partners/FAO/tabid/4392/language/en-US/Default.aspx**) on which pesticides should be excluded from registration or use. Policies should be considered to promote the judicious use of pesticides and even the reduction of them, through the use of, and access to, environmentally friendly biological pesticides and biological control methods.

Soils and fertilizers

A national policy framework and enforceable regulations are needed to promote sound land husbandry and to encourage farmers to adopt sustainable farming systems that maintain healthy soils. Government regulations are also required to promote farming practices that mitigate soil degradation and environmental pollution.

If direct or indirect fertilizer subsidies are provided for farmers, governments must ensure that the fertilizers that are produced and used as a result of these subsidies are managed in a responsible manner according to *The International Code of Conduct for the Sustainable Use and Management of Fertilizers* (FAO, 2019b). The use of organic fertilizers should be encouraged, as well as slow-releasing nitrogen fertilizers that make more nutrients available to plants and decrease greenhouse gas emissions, and fertigation systems that can deliver fertilizers with greater precision to ensure that the profile of nutrients supplied is the most appropriate for the types of fruit and vegetables being cultivated.

Policies should create incentives and support mechanisms to help farmers find organic alternatives to plastic mulch. In the absence of immediately available alternatives, governments should encourage the use of thicker types of plastic mulch that have a longer life and are easier to collect, recycle and dispose of. Governments should also create schemes for establishing private-public partnerships that can provide coordinated services to support farmers to deal properly with used plastics. Polices related to plastic materials and their reuse, recycling and disposal should also extend to other plastic inputs used in fruit and vegetable production, especially plastic materials in drip irrigation systems, and plastic sheeting in protected cultivation structures and plastic used for packaging.

Seed and planting materials

Governments have a responsibility to ensure that farmers benefit from seed security, i.e. they have timely access to sufficient quantities of the quality seeds and planting materials of their preferred and well-adapted crop varieties. Many low- and lower-middle-income countries have not developed or implemented effective seed regulatory frameworks, which weakens their capacity to provide small-scale farmers with the seeds and planting material they need (FAO, 2015c). In establishing seed policies, laws and regulations, governments need to strike the right balance between adequately protecting farmers and imposing undue restrictions on their access to suitable varieties of fruit and vegetables, farmer seeds in particular. Burdensome regulations can also make it difficult for seed companies and local seed associations to register improved varieties and supply low-cost seeds through local markets. The policy and regulatory framework must recognize the needs of different stakeholders from both the formal and informal seed systems and must be formulated in a participatory manner. To support countries in drafting seed policies, FAO has published the *Voluntary Guide for National Seed Policy Formulation* (FAO, 2015c). The very comprehensive review of the status of seed legislation and policies in the Asia-Pacific region demonstrates the need for governments to partner with the private sector (FAO, 2020b).

The costs of implementing seed laws and regulations can be high and governments may not have the resources to manage an effective seed quality control scheme. To provide governments with a lower-cost alternative that is flexible enough to accommodate crops that may not fit within a conventional seed quality control scheme, FAO has developed the Quality Declared Seed System (QDS) and the Quality Declared Planting Material System, which include many fruit and vegetable crops (**see Box 12**). However, it is a matter of concern that the informal status of most indigenous varieties and species of fruit and vegetables makes producers vulnerable to prosecution for illegal multiplication, use or marketing of seeds and plants.

Most national seed regulations were originally designed with cereals and other field crops in mind. Fruit and vegetable crops are significantly different and planting material and seed regulations need to reflect the specific characteristics of these crops. Certification is often obligatory for the major cereals, and roots and tubers, but is less common for fruit and vegetables. The growth of global and regional trade in plant materials and improved varieties, and the rapid release of plant varieties, means that an underfunded government-run testing system may block farmers from obtaining the latest varieties and create perverse incentives to find these varieties through unofficial channels, which increases the risks

BOX 12. Quality declared seed and planting material systems.

The Quality Declared Seed System (QDS) provides guidelines and protocols on the production of quality seed for small farmers, as well as seed specialists, field agronomists and agricultural extension services. Designed for countries with limited resources, it is a semi-formal system for seed quality assurance that is less demanding than full seed quality control systems but guarantees an acceptable level of seed quality (FAO, 2006). In the QDS, seed producers (contract farmers) who have been selected and trained in seed production and management are responsible for the quality control of the seed production, and government agents check only a small portion of the seed lots and seed multiplication fields (FAO, 2008). The QDS, which was developed by FAO in 1993 and revised in 2006, covers over 30 varieties (both open-pollinated and F1 hybrids) of vegetable crops and varieties. FAO has also developed the Quality Declared Planting Material System (FAO, 2010c), which sets out guidelines and protocols for multiplying planting materials for fruit crops, and has a section on bananas, plantains and other species in the Musaceae family.

of fraud. For vegetable seed obtained through private sector suppliers, information on plant performance and quality assurances are better provided through validation trials carried out by the breeder or importer, with less government control (FAO, 2020a).

Water management

Water management policies and governance to support fruit and vegetable production need to be based on sound water accounting, which is "the systematic study of the current status and trends in water supply, demand, accessibility and use in domains that have been specified" (FAO, 2012g). With accurate water accounting, policies can be adjusted to address any imbalances between supply and demand, as well as improve the efficiency, equity and sustainability of water allocation and use. These policies should support integrated water management and irrigation practices, which are comprised of four main elements: a system of water allocation, incentives to use water efficiently, the promotion of water-efficient technologies, and decentralization and partnership approaches to water management (FAO, 2011c).

To support fruit and vegetable production in peri-urban and urban areas where competition for water is high, policies will need to be integrated into a broader strategy for territorial development that includes water treatment plants, promotion of rainwater collection and storage, and will involve a consultative process that includes farmers' organizations and other stakeholders.

Wastewater use

Efficiency use and reuse of water resources are concrete measures to reduce vulnerability and increase the resilience of farmers by reducing the use of scarce water resources. The use of recycled or reused wastewater also helps to decrease the demand for fresh water supplies and the discharge of wastewater into rivers, canals and other surface water sources (Buechler *et al.,* 2006). Wastewater is a reliable supply of water that allows farmers to grow crops throughout the year. It also contains nutrients that can improve crop growth. Furthermore, it is often the only water available, so farmers, especially in urban areas, have no choice but to use this wastewater to irrigate their crops (FAO, 2012a). However, vegetable production in peri-urban areas can be compromised by contaminated or polluted wastewater. To reduce the risk of contamination, it is necessary to handle wastewater safely and select suitable crops. This includes treatment units that allow producers to irrigate horticulture plots with the greywater discharged from kitchens, showers, and if properly treated, from toilets. The guidelines by WHO (2006) describe the levels of treatment needed for agricultural uses.

Food losses and waste

In countries where food insecurity is high, policy makers should focus on actions that address food losses at the early stages of the supply chain, as this is where impacts on food security are likely to be strongest, whereas in high-income countries waste at the consumer level tends to be higher (FAO, 2019a).

Policy options include creating incentives for developing and promoting sustainable low-cost on-farm cooling technologies (evaporative pre-cooling, zero energy cold rooms and night-time ventilated cool storage structures) or more mechanical cooling technologies that use renewable energy resources generated from local off-grid or micro grid-based energy systems. A recent evidence synthesis provides policy guidance and details on specific post-harvest interventions shown to reduce losses for certain horticultural crops in sub-Saharan Africa and South Asian countries (Stathers *et al.,* 2020). Provisions could be made to assist small-scale farmers in purchasing cooling equipment powered from renewable resources (Kefalidou, 2016). Because a certain amount of volume and quality of food is needed for the private sector to invest in cold chain development, policies to support food producers to organize into groups or associations should be encouraged. Policies to expand the use of cooling systems to reduce fruit and vegetable post-harvest losses are more cost effective and deliver benefits to a wider number of people if they are targeted to off-farm post-harvest facilities where the produce of many farmers is aggregated and prepared for market (Kitinoja, 2013). In collaboration with the private sector and farmers' organizations, policy makers need to formulate strategies for cold chain development that are integrated with larger national development strategies and action plans, so that cold chains contribute to food and nutrition security, strengthen the livelihoods of small-scale producers, create off-farm employment and support agro-industrial growth.

To reduce losses of fruit and vegetables, governments at different levels should also consider providing incentives for public-private partnerships to improve dry-storage facilities, for example, by establishing systems that can supply farmers with sturdy stackable plastic containers that can be cleaned easily and reused for their harvested produce, or to improve transportation conditions of both cold and dry chains.

Social protection and risk reduction options

For small-scale farmers, there are many expenditures and risks associated with sustainable fruit and vegetable production. Enhancing risk-sensitive and shock-responsive social protection schemes contributes to the implementation of vulnerability reduction measures in order to prevent, when possible, and/or mitigate the impact, respond better and adapt to multiple shocks and stresses, and make it more feasible for small-scale growers to invest in new crops and new production methods. Many of the farm labourers who play such a large role in fruit and vegetable production, harvesting and post-harvest handling, and who work on an informal basis under casual, temporary or seasonal arrangements, have no access to social protection that could help ensure their employment meets the standard of decent work.

Social protection involves:

- social assistance (non-contributory programmes, such as cash transfers, public work programmes);
- social insurance (contributory programmes such as old age pensions, unemployment insurance, maternity leave); and
- labour market regulation (control of labour standards promoting decent work such as minimum wage and prohibition of child labour, and protection by training workers and providing benefits to unemployed) (Morlachetti, 2016).

In many countries, social protection legislation explicitly excludes agricultural workers and labourers hired under informal arrangements for seasonal field work such as fruit or vegetable harvesting. Also, in contributory social insurance schemes, the financial costs can be too high both for employers and employees, especially those with irregular incomes. Delivering social protection services such as health care to workers, especially to migrants who are often spread out over a large area, is costly and administratively complex. To address these challenges, policy makers need to consider expanding and adapting legal frameworks for social protection and integrating financing and contribution schemes that can accommodate a range of different types of employment, make contributory programmes more affordable for low-income workers (e.g. subsidized contributions) and enhance capacity to deliver services (Allieu and O Campo, 2019).

International instruments, such as certification schemes (Fair-trade or Participatory Guarantee System [PGS]) can be used to create markets and encourage producers and suppliers to follow labour standards that help ensure decent work. The high costs and paperwork involved in third party certification schemes needs to be addressed and opportunities for PGS explored, especially when supplying local markets. National legislation on organic agricultural production requirements can also include an adherence to labour standards, as has been done in Brazil, Costa Rica and Mexico. Some national legislation regarding specific commodities can also be used to ensure labour practices. For example, in Kenya, the horticulture produce legislation, requires producers supplying the export market to ensure worker hygiene and health, provide access to medical services, abide by the regulation of wages and conditions of employment, and maintain formal labour records (Yeshanew, 2018).

Index-based insurance

Fruit and vegetable crops are high-risk due to their vulnerability to pests, diseases, climate shocks and stresses, and perishability. Fruit and vegetable crops also face a higher risk of loss than other crops because appropriate cool storage facilities are not always available. Shipping delays, such as those that have occurred because of the COVID-19 pandemic, can also be a threat. Agricultural insurance in various forms is readily accessible to many farmers in higher-income countries, but they are rarely available for small-scale farmers in developing countries due to the high costs of verifying claims and the a poor understanding by insurance providers on risks faced by small-scale farmers. There are many climate- and weather-related risks faced by small-scale farmers in developing countries including droughts, floods, cyclones and erratic weather. Yet, financial and insurance services to reduce the vulnerability of small-scale farmers confronted with these shocks are limited. Weather index-based crop insurance aims to address the challenges of insuring small-scale farmers. Insurance providers no longer need to perform an in-field loss assessment when weather-indexed crop insurance is combined with automated weather stations, satellite imaging and geotagged small-scale farmers using mobile phones (Mattern and Ramirez, 2017).

There are factors limiting adoption of index insurance including incomplete risk coverage, high cost for farmers, lack of flexibility in making payments, lack of trust on the provider's side and misunderstanding of the insurance product (Carter *et al.,* 2017). Another reason is the limited amount of weather stations in many countries, especially African countries (CCAFS and CGIAR, 2013). It is likely that weather-index insurance will remain expensive for developing countries in the short term. It is important, therefore, to provide ready solutions to reduce farmers' vulnerabilities, in particular by ensuring that they have timely access to contingent savings, indexed emergency credit lines, and sufficient quantities of the quality seeds and planting materials of crop varieties that are tolerant to abiotic stresses and resistant to pests and diseases (Carter *et al.,* 2017). Governments and donors can support the uptake of this type of insurance by providing subsidies to poor farmers for equity reasons while having exit strategies for long-term financing (Hess and Hazell, 2016). New schemes can be piloted and tested for their suitability (**Box 13**).

BOX 13. Green insurance pilot. *Source: Global Index Insurance Facility (2018)*

In 2015, The Global Index Insurance Facility (GIIF) in collaboration with the International Finance Corporation (IFC) and Green Delta Insurance Company (GDIC) launched the Weather Index Insurance pilot for tomato production in Chitalmari, Bangladesh. A weather data grid was created by IFC and used by GDIC to design and monitor the Weather Index Insurance products even at the most remote location in the rural communities. To reduce transaction costs and build local networks at community levels, IFC and GDIC linked with farmers through organizations and institutions providing services or products to farmers during the production cycle (NGOs, farmers' associations, banks, seed companies and contract farming entities). Based on the input of the farmers and on weather data, IFC customized a Weather Index Insurance for tomato farmers in Chitalmari. More than 15 awareness-raising events about Weather Index Insurance, targeting more than 2 000 farmers were organized, yet only 200 farmers having 129 ha of tomato production bought the premium for 61 days (subsidized by 75 percent) in 2016. When unseasonal rainfall occurred, the farmers were notified within one week of the claim through the NGO working with them and received their payment within 15 days of the insured event. For the following season of cucumber and bitter gourd, 1 200 farmers bought the Weather Index Insurance product without any subsidy, and no claim occurred during this pilot. In 2017, 2 000 farmers bought the premium for the entire tomato cycle. During the tomato fruit development phase, the temperature fell below the trigger and farmers received the payment. The insurance claim helped compensate farmers for their economic losses. Since these pilots, farmers in Chitalmari growing vegetables, especially those producing tomatoes, are eager to purchase Weather Index Insurance.

Research and innovation

National agricultural research systems in many low-income countries are underfunded and are not as responsive to the needs and priorities of low-income small-scale farmers as they ought to be. A series of steps to improve research on sustainable crop production include:

- strengthening national research systems, starting at local levels and giving priority to small-scale farmers;
- increasing funding for research, notably on the most sustainable production systems;
- explore and make value of all farmers' traditional knowledge in combination with academic knowledge and science-based innovations;
- linking research with extension; and
- focusing research in areas with high environmental and social potential.

At the international level, research on fruit and vegetables has been largely neglected compared with staple crops. Although the Alliance of Bioversity International and The International Center for Tropical Agriculture (CIAT) does significant research on banana and to a lesser extent on fruit trees, the network of Consultative Group for International Agricultural Research (CGIAR) centres has historically focused on staple crops, with many individual centres devoting their research to one major staple crop. The World Vegetable Center, which was created outside of the CGIAR system, is the principal international agricultural research centre dedicated to vegetable research and development with a focus on small-scale farmers in lower-income countries. Nevertheless, given the tremendous diversity of vegetables, the World Vegetable Center cannot be expected to cover all vegetable cropping aspects and is necessarily obliged to make strategic choices about research priorities. A core partnership among the *Centre de cooperation internationale en recherche agronomique pour le développment* (CIRAD), FAO and International Society for Horticultural Science (ISHS) has raised the visibility of the sector and engaged civil society, scientists and policy makers through a global approach. An assessment of possible future strategies to better integrate fruit and vegetables into international agricultural research efforts suggests that international agricultural research should strongly focus on developing strategies for IPM, biological pest control and improved water use efficiency, in combination with the private sector. Moreover, publicly funded research could help find low-cost solutions for infrastructure-related aspects such as post-harvest handling and storage (cooling and drying), where renewable energy sources show substantial potential (Anderson and Birner, 2020).

As climate change and the decrease of biodiversity, including in the soil, are the two greatest challenges faced by fruit and vegetable farmers, research is needed on an environmentally-friendly integrated approach that:

- combines soil fertility and water management not only to lower the financial risk for the farmer, but also to ensure equivalent or higher incomes;
- is based on the use of bioinputs and cropping practices, such as genetic tolerance to climate shocks and stresses combined with plant associations and biopesticides for major fruit and vegetable pests and diseases that can replace the chemical approach ''one target – one pesticide''; and
- converts informal data and evidence-based experience or experiments into well-documented reports to influence policies, regulations and behaviours.

Knowledge gaps

The diversity of fruit and vegetables presents particular challenges to developing methodologies for compiling reliable statistics on production, area under cultivation, and yield. The fact that in many countries fruit and vegetables are often sold through informal markets means much of their economic value is unaccounted for. This scarcity of production and economic, social and environmental data makes it difficult to determine needs to target policies and public services and to monitor the impact of these. Improving statistical information about fruit and vegetable production in rural, peri-urban and urban settings, the role these crops play in sustaining livelihoods, and the contribution they make to local diets, is a research priority.

There are also large gaps in knowledge about the genetic characteristics of fruit and vegetable crops. Actions needed to address these gaps include:

- conserving genetic diversity in public genebanks;
- characterizing the diversity, especially the nutritional characteristics, through testing;
- understanding the fine mechanism of plant genetic regulation and the trade-off between plant growth and defence against biotic and abiotic stresses; and
- making this diversity accessible to farmers and countries through access and benefit-sharing schemes.

BOX 14. Digital Agriculture to meet the needs of small-scale farmers and value chain actors. *Source: Faye* et al. *(2019)*

Despite the importance of fruits and vegetables for food and nutrition security, the lack of reliable data in Africa affects all stakeholders of the value chains – from farmers to national and international institutions. On the field, farmers need accessible and accurate information for making decision pre-harvest; fruit yield forecasting, fruit size and colour grading, fruit set monitoring over the year are all key parameters for growers to better manage their crop by making the right agronomic or economic choices (Sarron *et al.*, 2018). Moreover, agricultural statistics such as mean yield and productive areas per cropping system are crucial for stakeholders all along the value chain to provide clear knowledge and extensive information on the sector. For governments, agencies and NGOs as well, agricultural data such as yield gaps and regional production per market are required for agricultural policy making and to evaluate the outcomes of these policies. Also, researchers need large scale and accurate data to measure the performances of cropping systems and to quantify the limiting factors (Carletto *et al.*, 2015).

In this context, digital agriculture, which relies on the use of technologies, is one of the pathways for data and value chain improvements in Africa. It allows data acquisition, standardization, availability and sharing between farmers and stakeholders. In particular, data acquired by farmers' participative monitoring using their smartphone will increase the availability of accurate information at the field scale on yields, sanitary status, water stress, etc. This is the challenge that CIRAD addressed by developing the project PixFruit in a co-conception process and user-centered design. PixFruit aims to provide a participative and digital data manager for estimating mango production in West Africa. By bringing together the latest artificial intelligence embedded in smartphones for real-time and cost-free fruit counting with remote sensing technologies and agronomic models, PixFruit attempts to address the needs of small-scale famers (yield assessment) and stakeholders of the fruit value chain (production statistics at the regional scale). Consequently, digital agriculture will overcome the challenge of data sampling and availability, thereby offering a direct contribution to poverty reduction and food security at large scale by strengthening the fruit value chain.

It will be particularly important to expand research programmes to include local varieties of fruit and vegetable crops, particularly NUS and how they can be further commercialized or contribute to adapt to the changing climate (FAO, 2018b).

Addressing these knowledge gaps is important for breeding improved varieties of locally adapted crops and for the conservation of threatened crop diversity. A major initiative in this area is being carried out by the African Orphan Crops Consortium (http://africanorphancrops.org/), which is working to sequence, assemble and annotate the genomes of 101 traditional African food crops with the aim of improving them genetically.

Participatory agricultural research and plant breeding

Because new varieties may take many years to produce, especially in fruit tree species, breeding programmes have to be stable, competently staffed and adequately funded. Both the public sector and increasingly private breeding companies must involve the farmers in order to develop varieties for sustainable cropping systems.

To enable small-scale production systems to respond better to the impacts of disasters and climate change, research needs to be done in collaboration with local farmers to identify crops and varieties that are tolerant to water or salt stress, floods, higher temperatures and greater climate variability, and at the same time can meet market demands. Participatory research and plant breeding are also needed to develop pest- and disease-resistant crops, which would reduce the need for farmers to apply chemical pesticides, promote biopesticides and lower their production costs.

Other critical areas of agricultural research for developing the resilience of small-scale fruit and vegetable production systems include investigating the range of potential cropping systems that incorporate crop rotations and crop associations adapted to the prevalent growing conditions, and that contribute towards maintaining healthy, pest-free soils and respond to market requirements.

Technological innovation

Research and development are needed to produce and test affordable biodegradable plastics that can replace the non-biodegradable plastic materials that are currently and widely being used for mulch and in drip irrigation systems and greenhouses. Biodegradable bio-based mulches that can be tilled back into the soil have been developed, but there are performance and cost issues that need to be overcome before they can be widely adopted.

High priority should be given to innovative low-cost technologies that use renewable energy for crop management, post-harvest storage and transport **(Box 14)**. In low- and low-middle-income countries, innovations in low-cost, low-carbon cooling technologies are needed to maintain a continuous cold chain for fruit and vegetables as they move from the farm through the supply chain to the consumer, especially for informal markets. FAO has developed a methodology (**http://www.fao.org/energy/agrifood-chains/energy-sustainable-technologies/en/**) to assess the environmental, social, economic and financial costs and benefits of investing in renewable energy for food chains, including vegetables.

Research and innovation also need to be directed to technologies for food processing to create products that safeguard nutrient content, taste, texture and increase consumer acceptance and market opportunities. Affordable and reliable practical tests for food-borne pathogens as well as pesticides and other contaminants are also needed.

Distributed ledger technology and blockchain

Distributed ledger technologies (DLT), which are often referred to as blockchain (although technically blockchain is one particular type of DLT) are an area where policy actions along with research and innovation can support small-scale farmers in general and fruit and vegetable farmers in particular. DLTs are used to create a digital database that records, tracks and monitors transactions of physical and digital assets in real time.

For example, DLTs can improve food safety by significantly increasing the traceability of products in agricultural supply chains, allowing for the rapid identification of the source of contaminated products and the mobilization of quick responses to minimize health impacts and financial losses (Mattern and Ramirez, 2017). By establishing transparent and secure records of provenance from producers to retailers, DLTs can increase consumer confidence in the safety of the produce and in the production methods that were used, and provide incentives to farmers and suppliers to adopt GAP.

DLTs can also overcome some of the major challenges involved in providing agricultural insurance to small-scale farmers. By establishing unalterable insurance contracts, linked to mobile wallets with weather data generated regularly by sensors in the field and confirmed by weather stations, DLTs can automatically deliver immediate pay-outs in the case of drought or flooding, which would eliminate costly verification procedures, reduce transaction costs, and increase transparency for both insurance providers and clients. Smart contracts used by DLTs can also provide secure digital payments in real time to reduce transaction costs between producers, suppliers, wholesalers and retailers.

The use of DLTs could also create greater transparency and security in land registration, especially for the rural poor, and would safeguard land records even during natural hazard-induced disasters or civil conflicts. Secure digital land titling can be linked to the creation of a broader digital ID that can ensure small-scale farmers and small- and medium-sized entrepreneurs are able to confirm their assets easily, and confirm the quality and quantity of agricultural products and their creditworthiness to financial institutions.

Using DLTs to support small-scale farmers and suppliers presents significant challenges, including an absence of enabling policies and regulatory frameworks, inadequate infrastructure, failures of interoperability and other technical issues, and the lack of digital skills in farming communities. Multinational agri-food companies will be the first to adopt DLTs. To ensure that all farmers can benefit from these technologies, governments and intergovernmental organizations will need to work together to raise awareness about the potential of DLTs, build the capacities of agricultural stakeholders and strengthen international cooperation between the public and private sectors and civil society groups to design and implement collaborative programmes to develop inclusive DLTs (Tripoli and Schmidhuber, 2018).

• Policies and incentives for sustainable production and food systems for fruit and vegetables

As a complement to this chapter on the required enabling environment for sustainably producing and marketing fruit and vegetables, Table 4 highlights guidance to policy makers on the regulations and incentives required. It is essential that ministries work together to develop and implement appropriate regulatory frameworks that provide a conducive environment for a thriving private sector, to include ministries of agriculture, environment, public health, education, trade, finance, planning and international cooperation.

TABLE 4
Policies and incentives for sustainable production and food systems for fruit and vegetables

COMPONENTS	POLICIES OR INCENTIVES
Crop and variety genetic resources	• Strengthen seed, field and *in vitro* genebanks to conserve, characterize, evaluate, document and make accessible the widest possible spectrum of the germplasm of the target species, including neglected and underutilized species. In particular, evaluate the accessions for tolerance to abiotic stresses such as salinity, heat, drought and flooding and biotic stresses (i.e. pests and diseases), for quality traits (especially micronutrient contents), and for post-harvest and marketing characteristics (shelf life, transport durability, suitability for processing, colour, shape, taste, texture). • Strengthen the conservation of wild relatives (usually the sources of desirable traits) in nature where the evolution of adaptive traits may continue. • Enhance on-farm intra- and interspecific diversity which will also help to improve the resilience of the production systems. • Develop and implement, according to applicable international norms and national legislations, equitable and fair access and benefit-sharing mechanisms in order to make accessions available to crop breeders and other scientists. • Develop international networks to increase the synergy between separate genebanks, phenotyping and breeding initiatives.
Genetic improvement	• Public or private crop breeders to develop varieties that are productive, nutritious, resistant to biotic and abiotic stresses, are well adapted to target agroecologies, and meet consumer preferences and market demands. • Broaden the genetic base of the improved varieties through pre-breeding, i.e. generating intermediate materials by crossing non-adapted germplasm that possess novel traits with standard breeding lines.
Seed delivery systems	• Enhance farmers' access to quality seeds and planting materials of traditional as well as modern varieties through: - Strengthening the institutional and human capacities along the entire seed value chain, from production and processing through quality control to packaging, storage, and marketing; - Strengthening the value of farmer seeds and confirming the seed sovereignty of farmers; and - Strengthening community-level seed production with suitable quality assurance regimes, including quality declared seeds and quality declared planting materials protocols.

COMPONENTS	POLICIES OR INCENTIVES
Seed delivery systems	• Developing and implementing national seed regulatory frameworks that enable the participation of a multiplicity of actors ranging from farmers to cooperatives and small- and medium-scale seed enterprises to the private sector opportunities. • According to the International Seed Testing Association, seeds meet the set standards for trueness to type, absence of physical damage, contaminants and diseases, and of optimal physiological status. https://www.seedtest.org/en/home.html
Land and water tenure	• Develop initiatives to ensure equitable access to land and water. • Implement schemes to recycle and reuse water and for organic waste recycling and composting. • Provide incentives to growers who conserve and enrich soils and who ensure clean water runoff (environmental service linked payments). • Implement regulations to monitor and prevent water pollution. • Develop an international network of facilities to test water. • Promote initiatives to allocate land and water in urban and peri-urban sites to growers to create shorter value chains for fresh and nutritious produce (and to reduce food loss and waste).
Good agricultural practices (GAP)	• Implement GAP that promote sustainable production and protection of fruit and vegetables. • Promote GAP through schools, universities, and extension services. • Certify education and extension agents providing credible advice. • Regulate quality of inputs such as fertilizers, crop protection products, irrigation, plastics and trellises. • Support farmers' access to inputs and appropriate technologies and mechanization (irrigation, greenhouse, machinery). • Develop standards for plastics based on biodegradability and use, and schemes for collection, cleaning and recycling. • Incentivize affordable extension services.

COMPONENTS	POLICIES OR INCENTIVES
Good manufacturing practices (GMP)	• Secure availability and access to quality tools and equipment especially those locally made in rural areas (front line hardware stores). • Implement GMP for post-harvest services, processing, distribution and marketing. • Implement GMP for sanitation and quality control. • Certify actors providing credible advice by third parties as well as in a participatory way.
Food safety	• GAP to include capacity to diagnose cause of disease in order to recommend best control options. • Integrated pest and disease management options developed and incorporated into GAP to avoid chemical pesticide. • Implement the international code of conduct on pesticide management. • Prevent use of dangerous pesticides through active engagement with the Rotterdam Convention. • Prevent distribution of quarantine pests and diseases through adherence to the International Plant Production Convention. • Prevent transfer of food-borne pathogens through appropriate sanitation (GMP). • Provide incentives to grower cooperatives and value chain actors that ensure food safety. • Develop international networks and laboratories with capacity to test and report food safety. • Establish and/or strengthen national food control systems harmonized with Codex Alimentarius.
Research and technology innovations	• Develop capacity for improved genebank management and breeding strategies, including farmers' ones. • Develop capacity to improve GAP recommendations for specific fruit and vegetable propagation and cropping systems. • Develop new environmentally friendly IPM strategies. • Develop international expert networks to monitor pest and disease impacts, new variants and incursions. • Develop capacity to improve post-harvest handling and reduce losses. • Develop food processing options (food technologies to preserve nutrients and market traits in processed products).

COMPONENTS	POLICIES OR INCENTIVES
Research and technology innovations	• Develop international expert networks and laboratories with capacity to test and report food safety issues. • Prioritize development of technologies and practices that target small-scale producers and existing extension services.
Market access	• Create reliable and risk-proof road, rail and water freight options to link growers to markets efficiently. • Develop cold chain, transport and storage systems. • Incentivize credit services and insurance mechanisms for growers and value chain actors. • Implement awareness campaigns to inform consumers of the health benefits of diversified diets containing fruit and vegetables. • Establish public procurement policies to promote supply from the most responsible small-scale farmers and encourage consumption in public facilities. • Promote the cost benefits of diverse and nutritious diets compared with health care costs from poor diets. • Foster dialogue between markets and producers on expected qualities and quantities of produce. • Create price monitoring schemes. • Support development of e-commerce platforms that link producers with consumers. • Promote and support short supply chains targeting local markets including support to traditional and territorial markets. • Promote market branding through certification standards for fair trade, sustainable practices, promotion of biodiversity, organic production, equitable returns and gender opportunities.
Entrepreneurial skills	• Develop capacity to empower individuals and small- and medium-sized enterprises in business acumen. • Target women and youth in off farm, value chain enterprises (input supplies, digitalization for data management, maintenance and repair services, post-harvest, storage, transport, processing, distribution, and marketing, as well as early warning systems). • Incentivize innovation and scale effective technologies. • Focus on entrepreneurship development for specialized mechanization hire services to overcome peak labour demands for planting, weeding, plant protection and harvesting with emphasis on job creation for youth.

CHAPTER 5

The way forward

A fundamental shift toward more nutritious crops in more diversified cropping systems is necessary

Previously, there has been a focus on single commodity supply chains with supporting agricultural policies, especially for carbohydrate-rich staple crops or for export, as the model to create wealth, targeting subsistence farmers to become businessmen. Recently, it is recognized that cultivating more nutritious crops in diversified systems is necessary to protect the environment, generate incomes and decent jobs, while adapting to changes in climate, and safeguarding nutritional security for the increasing global population.

To achieve SDGs 2 and 3, fruit and vegetables must be made available and affordable to consumers. Sustainable production of fruit and vegetables, combined with stable value chains, is therefore a national, regional and global priority to meet global nutrition requirements.

The immense diversity of fruit and vegetables offers small-scale farmers options for sustainable production by selecting species, varieties and combinations of each that are adapted to different environmental conditions (water and nutrient availability, length of growing season, for dealing with common pests and diseases), and for market access to achieve SDGs 1 and 15. It is relevant that the fruit and vegetables currently categorised in FAOSTAT only represent a fraction of the global diversity of fruit and vegetables and that many are labelled as neglected and as underutilized species. Yet fruit and vegetables have enormous potential to achieve multiple SDGs due to their high nutritive contents, adaption to cultivation under different environmental conditions, and their resistance to prevalent pests and diseases. Data collection and reporting mechanisms need to be strengthened to capture this potential and to inform agricultural policies and not overcomplicate this into agricultural policies.

Fruit and vegetables are high value. Cultivating them can be profitable because they can grow on relatively small amounts of land and with less water and nutrients than are required by other crops in rural, urban and peri-urban environments. They can move a country towards attaining SDGs 1, 3 and 11. The high-value and yet perishable nature of fruit and vegetables offer significant opportunities for new businesses and decent work. These include technical advisory services, input supplies (seeds, trellising, protected cultivation systems, drip irrigation, fertilizer, pest and disease management technologies), post-harvest services (grading, washing, sterilizing, packaging, processing, transportation, storage) and market linkages (food technologies, branding, marketing, participatory guarantee systems, digitalization, traceability schemes and blockchain). The labour and knowledge intensive demands from fruit and vegetable value chains can generate on-farm and off-farm employment opportunities, especially for women and youth, to achieve SDGs 4, 5 and 8.

Empowerment of the fruit and vegetable sector through technical guidance and public-private partnerships will increase the efficiency of value chains to reduce food loss and waste (to address SDGs 2 and 12), and to directly support women who are commonly responsible for fruit and vegetable production and marketing. Further, recognition of the importance of the need for high-quality agricultural inputs (including biological control agents for managing pests and diseases), and regulation of products, suppliers and distributors, is needed to encourage a thriving, innovative and private sector to develop. These benefits have been affected by the COVID-19 pandemic, which has demonstrated the importance of short value chains for fruit and vegetables to sustain regular supplies of fresh and nutritious food when imports and other global supply chains are disrupted due to travel restrictions for goods and labour. Natural disasters, biodiversity erosion, and climate change, have demonstrated the need for policies to support sustainable fruit and vegetable production. The impact of COVID-19 has also shown the importance to efficiently link small-scale farmers to markets, and for improved urban, peri-urban and rural planning such as through CRFS (FAO, 2020c; FAO, 2020d). Good practices and policies on natural resources, disaster and climate risk management are at the core of resilience building and are essential for the overall achievement of the development of economies in low- and middle-income countries (plus the continued success of higher-income countries).

The UN Decade of Action on Nutrition (2016–2025) and the UN Decade for Ecosystem Restoration (2021–2030) emphasize the need for land to be managed in a sustainable manner to increase the productivity and availability of nutrient-dense foods while providing livelihoods to support global communities. UN Member States have committed to undertake 10 years of sustained and coherent implementation of policies, programmes and increased investments to eliminate malnutrition in all its forms, while leaving no one behind and simultaneously protecting the continued productive capacity of natural environments. Furthermore, the UN Decade of Family Farming (2019–2028), is providing the international community with an opportunity to address family farming from a holistic perspective (Bosc *et al.,* 2018), in order to achieve substantial transformations in current food systems to contribute to achieving the 2030 Agenda for Sustainable Development (FAO and IFAD, 2019). Embracing the family farming model, while also recognizing the benefit of mid-scale, commercial and contract farming systems, require integrating strategies related to:

- food security and nutrition;
- crop diversification;
- the resilience of food systems;

- adaptation to climate change;
- the protection of biodiversity; and
- the creation of decent jobs, especially for women and youth.

Technical and institutional innovations are strongly linked to each of these areas; safe and nutritious fruit and vegetables benefit from a huge diversity of varieties, a wide range of cropping systems, ranging from open field with mulching and fertigation, to hydroponics or to plant factories with soilless systems.

Sustainable fruit and vegetable production is knowledge intensive, particularly with regard to the conservation of soil fertility, managing water resources, developing and implementing biodiverse strategies to control pests and diseases, and ensuring stable market linkages. Progress in ICTs and digitalization make access to knowledge possible and can strengthen local advisory services. Management of this knowledge for high value fruit and vegetables offer the opportunity for several off-farm businesses (e.g. for post-harvest services) that are attractive to youth and can provide decent rural employment to mitigate the migration to urban areas.

However, global investment in horticultural sciences is diminishing, both in high-income and low- to middle-income countries. Curricula, training courses and research investments need to encompass the rich diversity of fruit and vegetables and include NUS. A solution is to integrate fruit and vegetables into the global food system approach, as a key contributor to greater ecological, economic and social equilibrium to achieve the SDGs.

Participatory investigation involving scientists, producers and food system actors (both public and private) is needed to analyse multiple-criteria effects on sustainable production and stable value chains. Fruit and vegetables present a unique diversity of combinations of short- and long-cycle (perennial) cropping systems and opportunities for greater integration with other forms of agriculture. These pathways can generate higher incomes and decent work for family farming systems in low- and low-middle-income countries.

Policy support and business prospects to recycle grey water, compost manure and organic waste, development of environmentally compatible options to control pests and diseases, and to manage natural resources are critical, as is the equitable provision of land, water, inputs and access to finance and technical guidance.

A territorial approach is essential to link rural, peri-urban and urban communities and businesses to guide planning interventions to promote short value chains for local farmers to supply safe, affordable and nutritious fruit and vegetables and that involves all government ministries, civil society and the private sector. The benefits of fruit and vegetable consumption to create stable markets, and innovative and sustainable production practices, high-quality inputs and reliable post-harvest services need to be prioritized and incentivised for policy makers.

The fruit and vegetable sector has to drive the transition from food security to global nutritional security

To influence policy makers, credible evidence is required that is based upon scientific evidence and on policy briefs. Especially for the informal sector, improved efficiency is necessary for better connectivity, organization and visibility. For this more reliable data is needed, which is currently restricted to export markets. Investments are needed to capture the data on production, impacts on soil, water and nutrients, pests and diseases, processing, food loss and waste, and consumption to better inform management decisions. Reliable data linked to nutrition delivery through diets would encourage farmers to consider their production responsibility based on market opportunities and it would encourage consumers to reconsider their spending priorities.

In summary, it is necessary to incentivize the provision of sound technical guidance, high-quality inputs and services, and new business opportunities to enable the fruit and vegetable sector to drive the transition from food security to global nutritional security. This can only be achieved if there is market demand from consumers who are encouraged to consume nutritious foods, and if there are political incentives for industrial food manufacturers to distance themselves from unhealthy foods and to formulate appropriate media messaging.

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This book will convince the reader to care about fruit and vegetables, and to see that the small-scale production of these crops is fundamental to achieving the sustainable development goals. In five chapters, the reader will learn about the challenges and rewards for producers, sellers and consumers.

- **Chapter 1:** a working definition for fruit and vegetables, making the case for supporting small-scale farmers and value chains.
- **Chapter 2:** options for farm management to ensure that production is sustainable including genetic resources, seed systems, management of water, soil, nutrients, and control of pests and diseases.
- **Chapter 3:** options to integrate small-scale commercial fruit and vegetable farmers into socially inclusive value chains, including innovative post-harvest handling services, market linkages, and reducing food loss and waste.
- **Chapter 4:** options for practitioners and policymakers at different governmental, institutional and social levels to promote the sustainable production and consumption of safe, nutritious and affordable fruit and vegetables.
- **Chapter 5:** key interventions and innovations to facilitate the sustainable production of fruit and vegetables in low- and middle-income countries across the world.

This publication takes readers on a journey introducing them to a diverse array of fruit and vegetables through colourfully illustrated studies from around the world. It justifies the importance of these crops and it encourages readers to take an active role both in promoting fruit and vegetable production and in encouraging more people to eat them.

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