Postharvest interventions, key for improvement of food systems

Exploring the impact of postharvest interventions on increasing food availability, stability and income generation in developing economies

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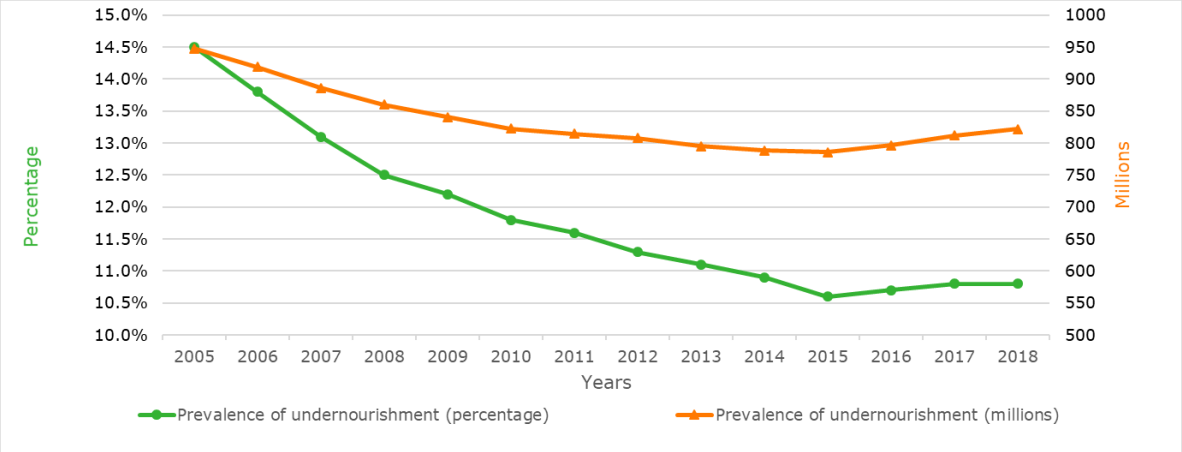
1 Summary

In many developing countries, population growth and urbanization rates are high. If the food systems in these countries are not developed in such a way that they can keep pace with the increasing population growth, millions of people will be affected. Food supply and food security are likely to decrease. Already, the curve of undernourished people in the last decade has changed direction and their numbers are increasing again [1], see graph below. Moreover, migration is bound to increase pressuring certain regions even more.

Graph 1: Development of the number of undernourished people



Source: [1]

Action is needed to prevent the disastrous effects as sketched above. We propose that a new way of thinking is needed to allow the local food systems to rapidly develop in an economically stable way, thereby allowing the market to keep up with local demands and the system to mitigate the issues arising from the rapid population growth.
In this paper, we propose an approach that ensures the strengthening of the food systems by taking the actual local circumstances into account. The main conclusions are that **a strong group of medium-sized enterprises is needed in each country/region to bring the local food system to a higher level, as is strengthening postharvest knowledge and technologies**. Moreover, we will show that the availability of affordable solutions in primary production and in post-harvest handling, storage and processing will provide the key to develop these stronger food systems. Wageningen University and Research has the tools and experience in bringing the food system in a certain context to the next level. For assessment of the enabling environment of food systems, we use a **country level analysis** aimed at advice on policy development and infrastructural investments. For feasible postharvest business development, a **company level analysis** to advise on aligning technology level and scale with food system and market is used.

The impact of current demographic developments is high: It has implications for developing countries (malnutrition, discontent) as well as for developed countries (migration). This means that Western donors and development banks as well as local politicians in developing countries have a (political) interest in improving food security, thus in applying proposed approach to improving food systems under the actual local circumstances, as the people involved are consumers as well as voters and the large numbers of people affected will stand for serious implications when the issue is not tackled.

2 Introduction

The UN General Assembly (2012) stated that all people have a right to adequate food that not only meets the minimum requirements for survival but is also nutritionally adequate for health and well-being. In 2015 the UN General Assembly presented 17 Sustainable Development Goals (SDGs), which are to be achieved by 2030.

The high-level panel of experts (HLPE) on Food Security and Nutrition (2017) stated that: 'The focus on nutrition and diets echoes similar calls to action by several international global goals setting agendas, including the United Nations Zero Hunger Challenge, the United Nations Decade of Action on Nutrition and the SDGs. Reorienting food systems to better support nutrition will be essential to meet – among other SDGs – goal 2 (zero hunger) and goal 3 (good health and wellbeing). Many recent reports highlight the need for a holistic approach and radical transformation of agriculture and food systems to tackle the multiple burdens of malnutrition and contribute to the achievement of the 2030 Agenda'

The HLPE presented a Conceptual framework of food systems for diets and nutrition, as provided in Figure 1. Dengerink and Brouwer describe that such food system approach '*offers a new, more holistic perspective on food and nutrition security, by broadening the focus of researchers and policy makers from the activities in the food system to the food security, social and environmental outcomes and the socio-economic and environmental drivers of these food system activities. In doing so, the food systems approach not only shows how food systems interact with other (ecological, economic or political) systems but also analyses how each of the elements within a food system interact with each other in producing food system outcomes.*' [2]

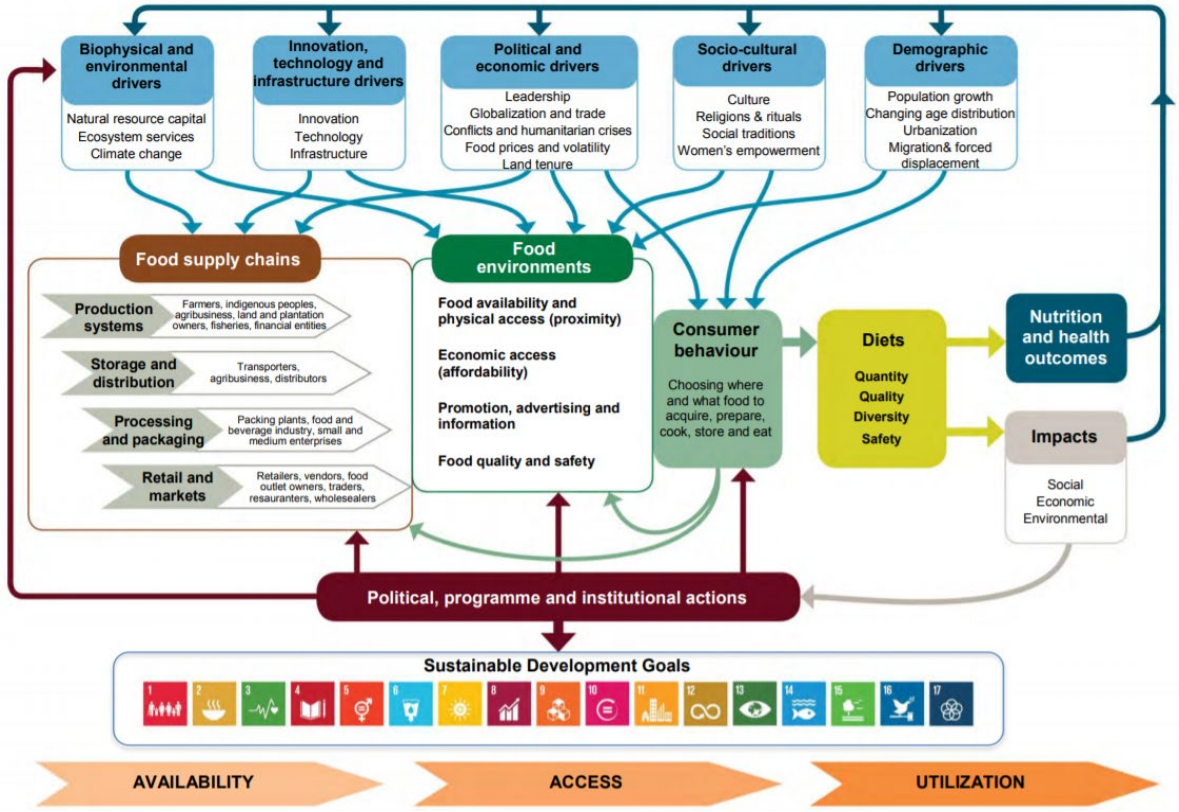


Figure 1: Conceptual framework of food systems for diets and nutrition

For the purpose of this paper we will highlight relevant trends in the food system in order to understand the issues that have a major impact on food & nutrition security. Furthermore, we will look at the role of postharvest management in the food system.

2.1 Food system trends

Food system weaknesses

Especially in Africa and Asia a major demographic shift is taking place and will continue to do so [3]. This concerns population growth as well as urbanization rate and migrations, and it impacts the structure of food systems. Current yield levels and production efficiency in the primary sector are too low, and food waste and food loss in the food supply chain are too high to sustain self-sufficiency in food production already now in many countries in Africa, let alone in the future [4]. This is the case in many countries and results in a high dependency on imported commodities like rice and wheat. Initiatives by several governments that focus on increasing local production of staples often had positive results but were not able to replace, or even slow down import increase of main staples, because (urban) population increase outruns the additional food production. In other words, dependency on imported commodities increases and tends to keep increasing. This makes countries vulnerable for price increase and fluctuations as well as disruption of international trade of which the current COVID 19 crisis could serve as a warning signal. Regarding nutritional value, also the production of fruits and vegetables lags behind.

Population growth and urbanization

With a growth rate of 2.56%, Ethiopia's 108 million population as an example, is expected to double in 28 years. Nigeria's growth rate of 2.53% leads to a doubling of its current 214 million population also in 28 years. For the African continent, the total growth rate until 2050 means a 1.3 billion population increase in approximately 30 years, roughly 43 million annually. At the same time, urbanization growth rates can be observed often exceeding 4% [5], Both trends occur in most developing countries and they occur simultaneously, amplifying each other. High rates of urbanization result in a lower percentage of people in the countryside to work on the land and to be partially self-sufficient by means of home-grown vegetables and household cattle. The food for increasingly larger numbers of urban populations needs to be produced by a relatively smaller rural population. The deficiency needs to be imported.

Food production limitations

Fragmentation of land in rural areas due to division amongst several children when passing to a next generation, frequently results in plots that are too small to support a smallholder's family, resulting in migration to cities. Moreover, these small plots make efficiency of production increasingly difficult. Less food producers (in percentage) that need to feed more urban non-food producers and the pace of this development, result in an urgent need for an approach to professionalize local food production systems including primary production as well as postharvest chain management. However, the professionalization often goes in stages based on the development level of the food system in place.

Current approach to improving food systems

Already for decades the issue of food security in developing countries is being addressed by development organizations, governments, development banks etc. and apart from successes, also failures in the approach have been indicated. Moreover, the current demographic developments as described earlier, accelerate the need for achieving significant impact as the food systems in place are not able to keep pace with future food demand.

Food systems have an impact on many issues, including primary production, environment, social aspects etc. and all these angles are connected and influence each other. It is therefore of utmost importance **to recognize the development level of a food system and address the issue of food security in the light of food systems instead of looking at one aspect of it only.** Basically, all links in the value chain that compose a food system, need to match each other in terms of development level as indicated in Figure 2. A key success factor for improving food security is in addressing the whole system in one approach. This may include hardware, software and orgware, adapted to each other and adapted to the appropriate level of development of the food system.

Food system level development related to market and technology development

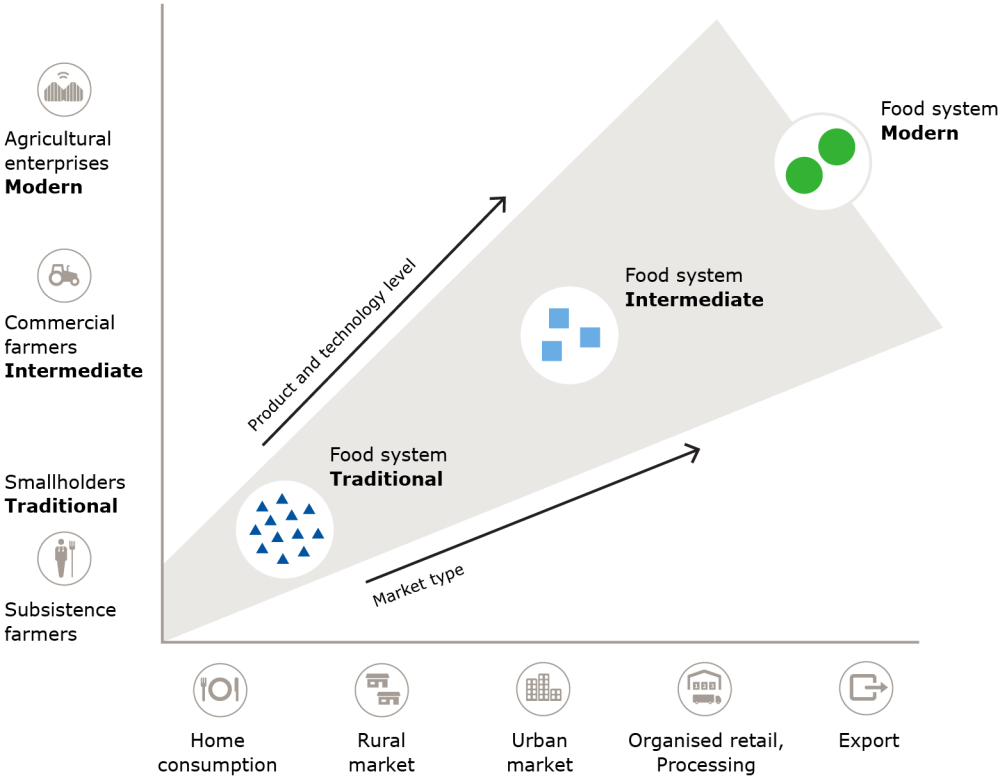


Figure 2: Food system level development related to market- and technology development
Source: Wageningen Research (Based on an original from: [6]).

Currently, often the focus is on a single issue leaving out the effects on other levels. For postharvest interventions there is often overemphasis on technical aspects at the expense of social, cultural, environmental and political issues, and economic feasibility. Increased food demand also leads to the use of less suitable, marginal lands. It often leads to damaging landscapes and increased erosion by wind and water. It may lead to conflicts between cattle breeders herding their cattle and farmers growing crops. It may lead to conflicts about water on a small scale like a mountain stream, up to large conflicts between countries. These aspects also need to be taken into consideration. Interventions are often not adapted to the level of development of food systems, leading to project investments that are not economically feasible for the market that is part of the food system and thus are not being used after the project ends. So called "White Elephants", unused technical facilities such as cold stores are often the only things that remains of these projects.

In general, it is concluded that current interventions are often too much stand-alone and do not take all aspects of the food system into account. Middlemen, traders and processors are often ignored although they are part of the food system. The required investments are not always in line with the needs of the food system [7].

Proposed approach to improving food systems

The best strategy for food systems strengthening requires an holistic approach. We propose a two level assessment of food system "maturity":

1. On country/regional level: in this assessment countries can be benchmarked on their enabling environment. Results can be used for policy development and guidance for infrastructural investments.
2. On company level: in this assessment companies are benchmarked on food system and market they operate in, to be able to align investments with expected profitability.

Beside assessments to guide governments and companies to make improvements, it is essential to make use of education, extension and research to implement proposed improvements.

On the level of general improvements of the agricultural sector in a given country, in Europe, and specifically in the Netherlands, the so called golden triangle is recognised to have played a significant role. This triangle refers to cooperation between business, government (grants) and knowledge to bring agriculture to a higher level. This model is proposed as model for food system improvements in other countries in which the cooperation and coordination between research, extension and education needs improvement and their focus needs to include entire food systems, their level of development and the local circumstances.

2.2 Postharvest management in food systems

After harvest, food needs to be distributed to the consumer, sometimes after a storage period. The management of this process is known as postharvest management. The HLPE described the critical role of cold chains to ensure the dietary quality from a food safety and food availability perspective [8]. In this paragraph we zoom in on the role of postharvest management in food systems, starting with Figure 3 showing the impact of postharvest interventions on the strategic development goals. Primary impact of the postharvest intervention (orange) is on its immediate position in the food supply chain and the direct stakeholders involved. Secondary the impact spreads further in and trough the food supply chain (blue) affecting more stakeholders and households. Thirdly the intervention impacts the larger issues on hand as described in the SDGs (green).

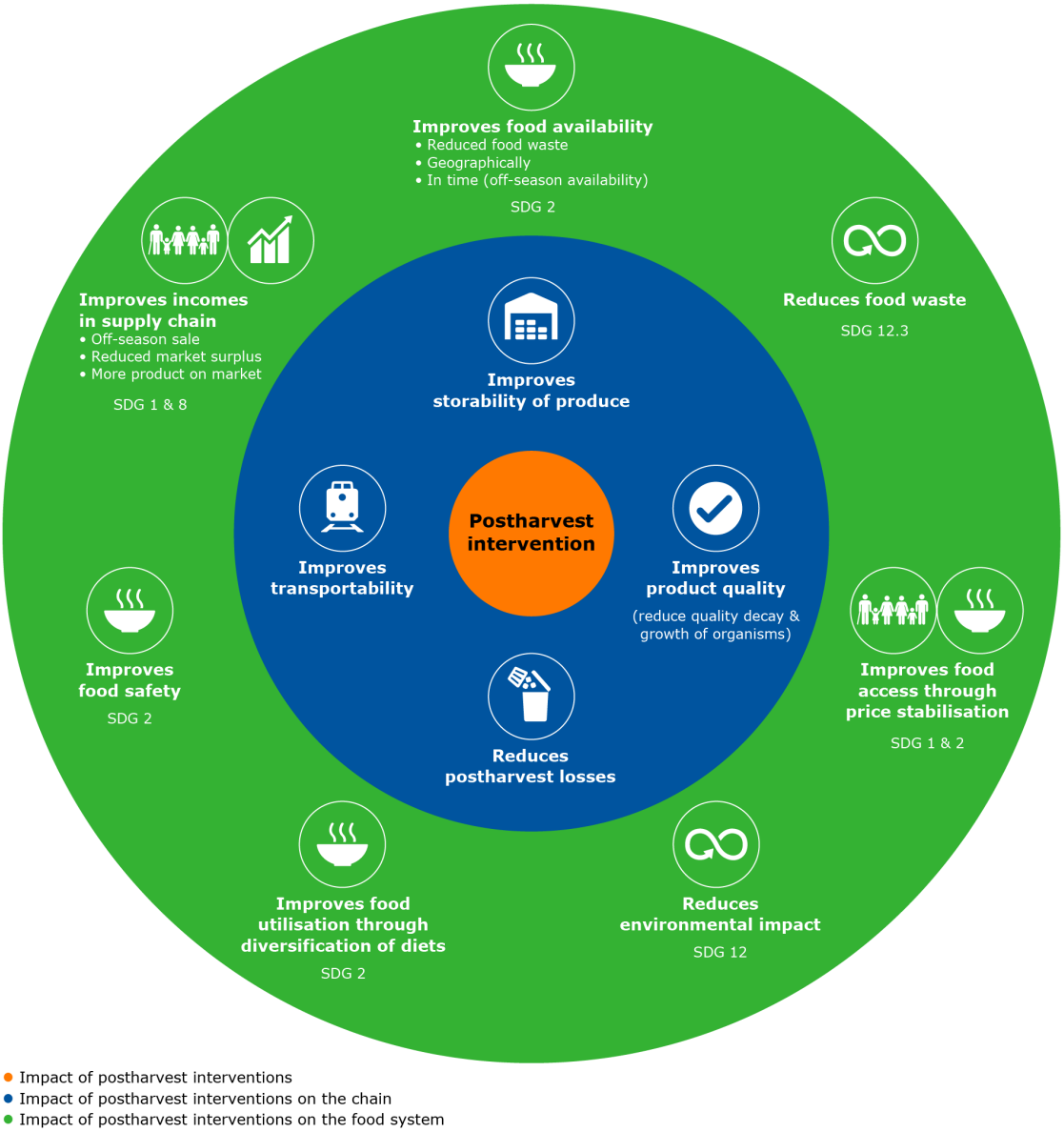


Figure 3: Impact of postharvest interventions on Strategic Development Goals

Especially for perishable products like fruits and vegetables, it is very efficient to invest in postharvest management and equipment because the return on investment can be significant due to savings on food losses. The more perishable a product, the bigger the effect of postharvest interventions on the contribution of that product on food & nutrition security (FNS). The effect of postharvest management in a food system is twofold: first, the time between harvest and consumption can be extended, meaning that markets further away can be reached and the product can be supplied over a longer

period of time instead of only immediately after harvest. Second, the amount of fresh products that is lost because of decay can be reduced, see Figure 4.

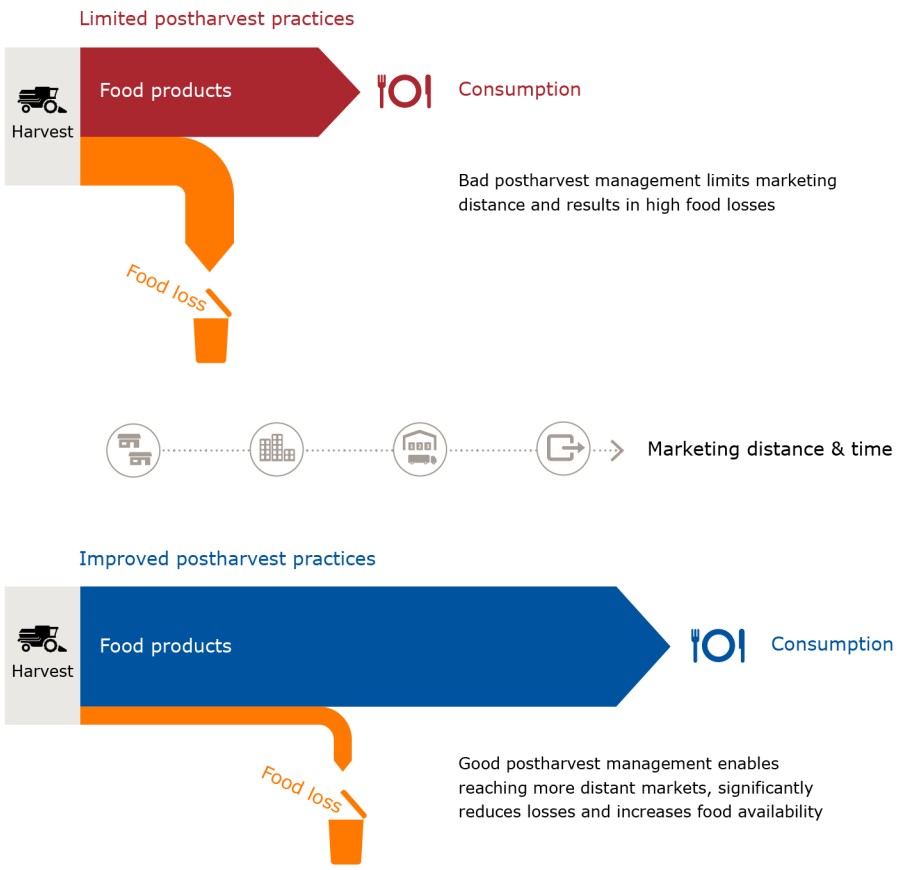


Figure 4: Effect of postharvest management on food loss in perishables

There are two different strategies in postharvest handling of perishable products. One concerns short-term cooling and logistical management to improve end quality of the product on the market, reduce losses and increase the marketing distance.
The second strategy focusses on medium- and long-term storage to be able to market the produce over an extended period of time and reduce price fluctuations (see Figure 5). The approach depends on the product and market situation but in both cases significant gains can be achieved.

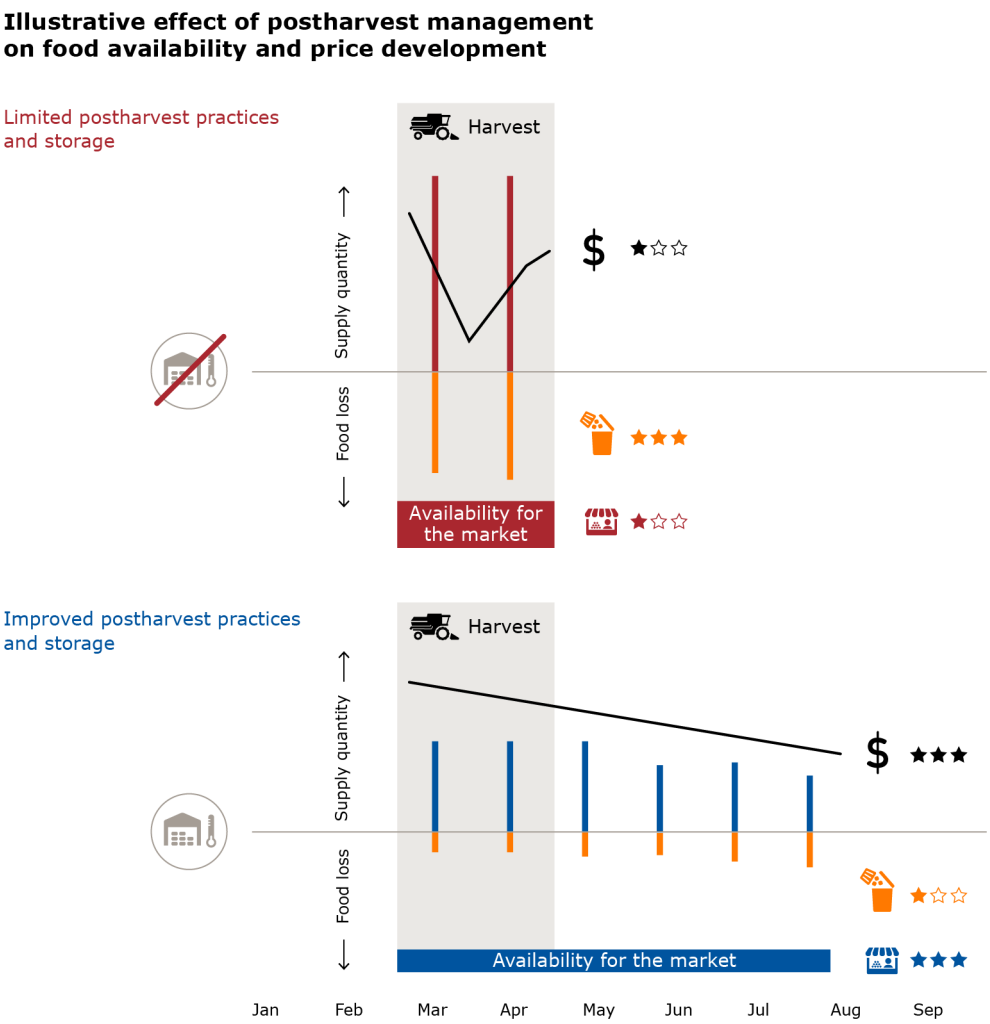


Figure 5: Illustrative effect of supply quantity and window on prices for fresh produce

Elansari *et al.* stipulate that the main objective of postharvest storage, as a component of the value chain, is to maintain produce quality as superior as possible for as long as feasible. They also stipulate the objective of storage considering the indicators below, [9]:

- Minimizes decay by slowing down microorganism's progression
- Lowers transpiration or water losses that otherwise promote unfavorable effects, such as wilting, elongation, rotting, greening, sprouting, and toughening. Such activities affect appearance, quality and texture
- Slows down the biological activity of fresh produce, such as the case of reducing the production and action of the natural ripening agent ethylene
- Minimizes the surplus sale in the market, thus guaranteeing good returns to the farmers
- Assures the accessibility of the produce during the off-season
- Reduces waste and spoilage of produce
- Normalizes the price of the produce during the season, as well as during the off-season

Translating the objectives of [10] in a food system perspective, the objectives of postharvest management aim to:

- **Improve food availability in quantities, by minimize food loss and food waste**
- **Improve food availability in time (availability in off-season market)**
- **Improve food access through price stabilization**
- **Improve income of supply chain actors (reduced waste and create a better market price)**
- **Improve food safety**

Considering postharvest management from a food systems perspective we complement the list above with the following objectives:

- **Improve income of supply chain actors through access (by transport and/or export) to higher value markets** (e.g. by applying postharvest cooling of perishables)
- **Improve food availability in geographical perspective, by the ability to transport it to distant markets.** (e.g. fresh tomatoes from northern Nigeria and Burkina to the urban agglomerations in the coastal areas)
- **Improve food utilization though improved dietary diversity [8]** (e.g. fresh fruits and vegetables to complement the diets of calories rich staples)
- **Reduce environmental impact, by minimizing food loss and therewith preservation of related inputs**

The interactions in the food system, may also create undesired trade-offs. As example, by storing the produce, the availability of food is more distributed, which may influence the price in both the harvest season as in off-season. This may lead to improved incomes for the supply chain actors, but the higher prices may simultaneously lead to negative effect on food access for low income consumers. The requirement for a holistic approach on food security is therefore also true for postharvest management, as it touches on all high-level outcomes of the food systems, including food security, impacts economics, social aspects (equity / inclusiveness) and environment.

3 Gap analysis

3.1 Introduction

In order to be able to substantiate an approach that significantly contributes to alleviating (future) food security issues in developing countries, a gap analysis of the current situation needs to be performed.

An analysis of the main gaps in food production and supply in developing economies will give an insight in where interventions are needed or most efficient. It will also show that different gaps need to be addressed simultaneously in order to avoid improvements in one part of the chain to be nullified by the situation in other parts: a food system approach is required.

An example of main areas of attention for such a gap analysis is given below, considering the major relevant issues.

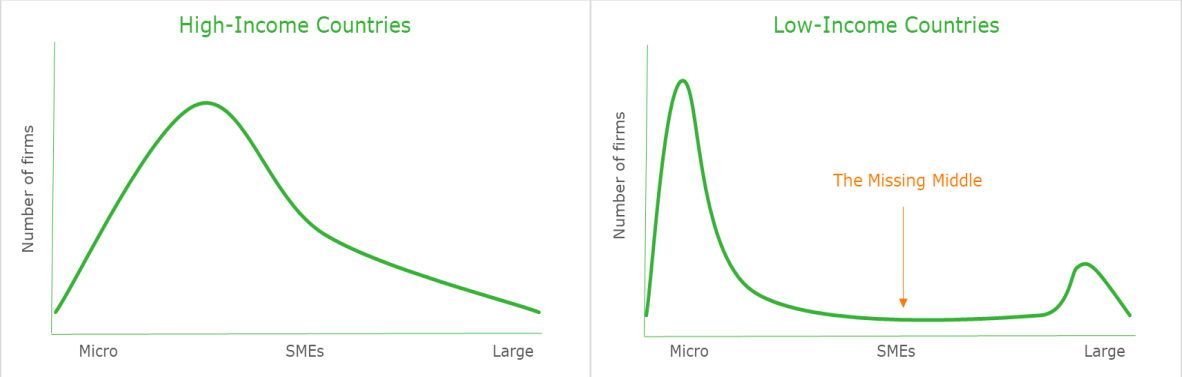
3.2 Gap 1: Smallholders feeding the cities

Gap 1 conclusion:
The micro farmers forming the majority the traditional agricultural sector will not be able to provide food security for a country alone. In emerging markets, relatively few SMEs exist. Facilitating SMEs is key to improve production and reduce postharvest losses.

Missing middle

When comparing emerging markets with developed economies, one can notice a clear distinction in the type of companies that contribute to GNP (Gross National Product) and employment. Whereas in developed economies, usually 50% or more of this contribution is realized by SMEs (Small and Medium sized Enterprises), this contribution is far less in emerging markets. This is the case for the economy in general but also specifically for the agricultural sector where many smallholder producers (Micro) are active along with a few very large enterprises and only a limited number of SME farms. **This phenomenon is known as the missing middle** [11].

A similar situation occurred in western countries when their agricultural sectors went through their stage of efficiency improvement half a century ago.



Graph 2: Size of companies and their share in contributing to GNP

Source: Based on original from [11]

Current food supply system types

Large agro and food companies in emerging economies often focus on export of commodities although also some new investments in large scale food production take place by local businessmen that made their capital in other sectors. These concern high level, capital intensive food systems including mechanization, efficient logistics and high-end markets.

In the middle segment, local and regional businesses are investing in mid-size farms, trade, storage facilities or processing. Usually this takes place near the bigger cities. Local food processors also get involved in the value chain because they need a secure and consistent supply of low-cost safe raw material in order to be competitive. All these developments are strongly influenced by the emergence of a middle class of consumers and concern mid-level food systems with some form of mechanization and a somewhat larger and more efficient production. These mid-level food systems mostly include logistics that are not optimally efficient and markets that are somewhat demanding but still mostly price driven.

Case 1: Kenya potato processing

Case Kenya

The middle class is increasing in numbers, which results in an increase of demand for French fries potatoes by restaurants.
Most of the fast food- and traditional restaurants in the world use pre-fried frozen fries for preparing their meals and these are supplied by a limited number of large companies like McCain, Farm Frites, Lamb Weston, Simplot etc. This has become a bulk product with small margins, requiring a large turnover of typically 50,000 tons annually per production unit to become economically feasible. In Kenya some pre-fried frozen fries are being imported from Egypt and South Africa but the market is way too small for an own processing facility.
Local processor Sereni Fries was aware of a business opportunity. By making fresh fries in a (labour-intensive) process with simple equipment, the company was able to supply restaurants in Nairobi on a daily and apparently competitive basis.

Wageningen Research helped with developing strategy, business calculations for processing, storage and raw material supply as well as food safety issues.

The company takes advantage of the local situation by using delivery scooters with an insulated box with 150 kg capacity that can move fast through congested traffic. Other advantages are non-dependency on a freezing infrastructure and a favourable processing coefficient for fresh (90 kg fries from 100 kg raw potatoes) compared to pre-fried frozen (50 kg fries from 100 kg raw potatoes)

The extension of the business is planned now via establishing small simple processing facilities in each provincial capital to enable fast logistics in supplying the end product and transporting the raw material to these facilities in trucks. In developed markets this works the other way around but this is an example where the processor adapts his technological level to the size of his operations and to the market circumstances. At the same time, the raw material supply can be organised to keep pace with the demand. A step to high-tech processing directly would be too costly for the turnover that can be realized and is therefore not feasible whereas an intermediate solution results in a profitable business.

Smallholders are usually part of low level food systems. They produce food for their own family but also sell surplus production for some income. This surplus is sold on local markets or purchased by middlemen and finds its way to urban areas. However, due to the size of the farms and the production, the value chains are long and comprise of many links involved in it. Efficiency is low and food losses are high. This leads at the same time to relative low prices being paid at the production part of the chain, resulting in the fact that hardly any money becomes available for investments in production- or quality improvement, efficiency or loss reduction.

Land pressure in densely populated areas is often caused by families who have subdivided small plots into even smaller parcels to pass land onto their descendants. As populations have risen, the average land holding size per household has fallen by one-third to a half since the 1960s [12].
Smallholders are not a homogeneous group but rather a diverse set of households with varying farm and household characteristics. Whereas some smallholders have the potential to shift from subsistence farming to commercially oriented and profitable farming systems, others have more opportunities to improve their livelihood strategies outside of the agricultural sector [13].

Jayne *et al.* extensively studied the development of size of African farms [14]. The share of national marketed crop output value accounted for by medium-scale farms rose significantly in sparsely populated countries like Zambia or Tanzania. However, this was less or not the case in densely populated countries such as Kenya, Uganda, and Rwanda, where land scarcity is impeding the pace of medium-scale farm acquisitions. This substantiates the need for a tailor-made assessment approach per country.

Table 1: Changes in the % of shares of national crop production value by farm size category

Farm size (hectare)	Countries with relatively sparsely populated areas						Densely populated countries			
	Zambia		Tanzania		Ghana		Nigeria		Uganda	
	1999	2015	2009	2015	1999	2013	2011	2016	2006	2014
0-5	79.6	66.3	82	70.7	78	56	93.9	88	84.2	95.3
5-10	13.7	18.9	12.1	17.8	11.8	25.9	5.1	6.8	7.6	3
10-20	5.1	12	2.1	9.3	6.4	12.3	0.7	4.9	3.3	1.6
20-100	1.4	2.8	2.3	2.1	3.5	5.5	0.3	0.3	4.3	0.1
100+	0	0	1.3	0.1	0.3	0.3	0.1	0	0.6	0

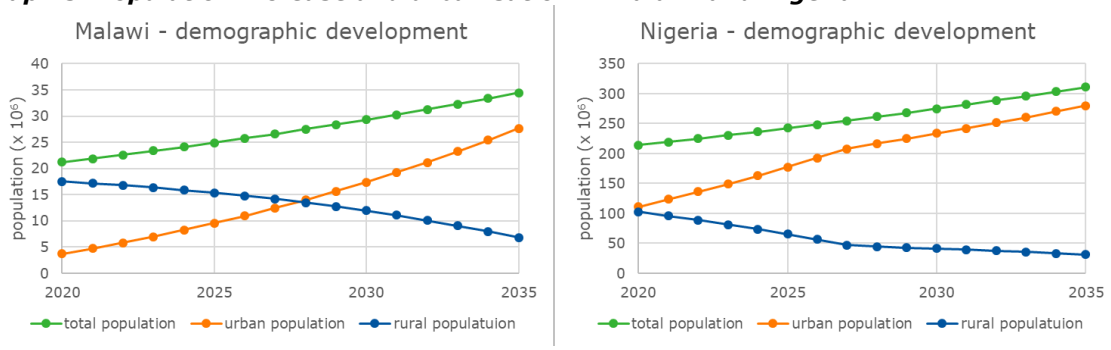
Source: [14]

NGOs support smallholders and also promote cooperation between them in marketing mainly. However, co-operative models that include large numbers of smallholders often work best where lots of hand labour is required (e.g. coffee in Ethiopia or paprika powder in Zambia).
In most countries, the demographic developments lead to market developments that require food systems to evolve to a higher level. In practice this will lead to upscaling in size by part of the small farmers either by themselves or in cooperation with others. Although postharvest efficiency is often not the main reason for upscaling, it does need a prominent role when upscaling takes place.

Limitations of smallholders feeding the cities

Rural populations still increase in numbers and result in pressure on land. However, the urban population increase goes even faster and requires more food to be supplied to the cities.
In many countries the rural population, and thus the number of smallholders, is expected to decrease in absolute numbers. To make this trend visible, as an example, the demographic developments for Malawi and Nigeria for the next 15 years are shown below (based on 2020 growth figures). These graphs is not exact predictions, future conditions may differ per country and growth rates are likely to decrease over time. However, the general trend shows a shifting balance between urban- and rural populations.

Graph 3: Population increase and urbanisation in Malawi and Nigeria



Source: Estimations based on 2020 population increase figures [5]

The smallholder surplus food production would need to increase significantly to satisfy the needs of urban population by local products. As plots get smaller, being inherited by several children when passing to the next generation, currently often becoming too small to support a family, and more marginal lands are taken into production, this is difficult to realize.

3.3 Gap 2: Postharvest supply chains

Gap 2 conclusion:
To move a step up to a higher food system level, one needs to invest in improved technology at both the production phase and at the postharvest supply chain to reduce food losses and improve market connection.

Yield levels of many agricultural products may increase by applying a right balance between improved techniques (mid-tech) and using improved inputs like seeds or planting material. But also including the appropriate level of logistics and marketing. In this regard, it is important to be aware of different levels of development of food systems and the need to include all parts of the food system in any approach.

On smallholder farms, production yield improvement towards the standard of large firms is difficult to realise without investing in improved technology. Small professional farms that are able to move to a higher food supply system level, can improve total available food volumes, create jobs and improve livelihood. Nevertheless, to realize an effective food supply system, the focus should be on production and on the postharvest supply chain as an indissoluble link that creates effective food supply systems. Otherwise, a large percentage of all additional food produced due to the higher yields will be no more than additional food loss or waste.

Moreover, when focusing on production and yield only, the market connection is typically weak. Production is not linked to market requirements like sourcing period, size, colour, brix levels, shelf life, etc. Therefore, farm-gate prices are low, resulting in low livelihood and limited capacity to invest in more effective food supply chains. Typically, these ineffective food chains can be identified by huge oversupplies and low farm-gate prices during the traditional harvest seasons, low supply during off-season periods and high prices, limited product quality and sales through wholesale markets instead of optimized logistics to final customers based on grading for specific markets (For example: quality A, quality B, etc.).

The challenge in optimizing a full food supply system, that optimizes both the postharvest chain and production yield, is the fact that all improvements need to be done at the same time to realize a solid business within the food system. If only one link is optimized, the total food supply system effectivity can't be expected to be significantly higher and does not justify any investment.

Besides the mentioned example of higher yield during typical harvest seasons that do not realize significant additional income or investment capacity, the same can be said for any supply chain optimization that does not include all links in the chain and aspects influencing it, for example:

- Planting better seeds to better meet market requirements is only worth the investment once post-harvest handling is effective as well.
- A farmer cooperation that wants to be taken seriously by powerful retail players can only be effective once uniform product quality is realized
- Investing in a capital intensive system such as low oxygen storage, is only smart once the production quality is sufficient and an effective model that organizes storage capacity and food safety requirements of the harvest of multiple smallholder farmers is implemented.

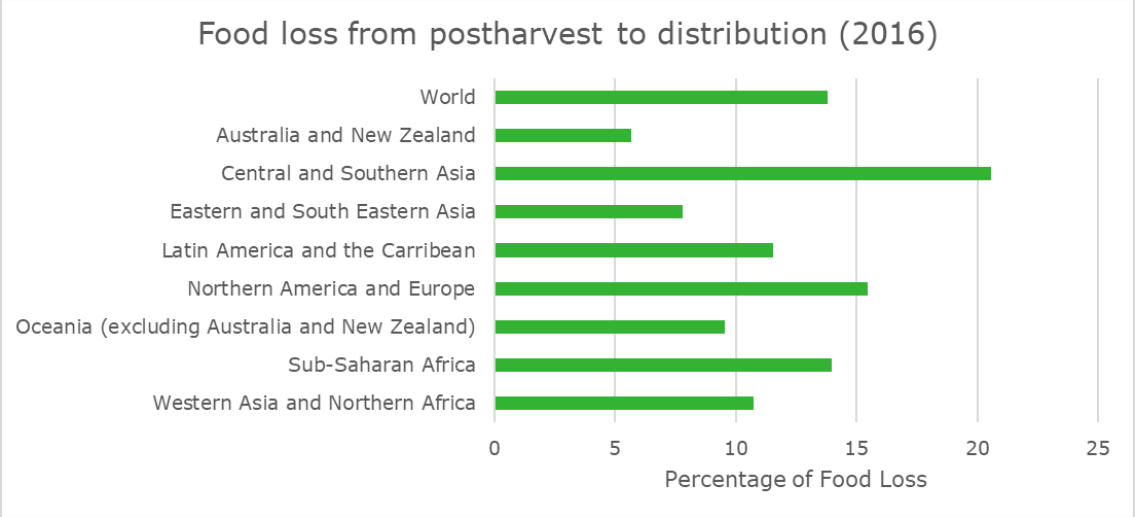
3.4 Gap 3: Food loss and food waste

Gap 3 conclusion:
Food loss worldwide is on average around 13% of food production. Lack of postharvest knowledge and facilities are underlying reasons for this.

FAO distinguishes between food loss and food waste [1]. Food loss is defined as losses occurring between harvest and supply to retail. Food waste is defined as losses in retail and consumer consumption. Together, they form the postharvest losses.

The percentage of food loss varies largely between regions but also between food chains. Losses between harvest and reaching consumers are substantial though.

Graph 4: Food loss from postharvest to distribution in 2016, % globally and by region



Source: [1]

Losses can be the result of many causes, depending on product, marketing, handling etc.
In developing economies food losses in post-harvest (excluding food waste) are a direct result of:

- Mechanical damage (rough handling, wrong packaging/stacking)
- Physiological damage (under-/over-ripeness, dehydration/wilting, loss of structure, browning)
- Decay (fungi or mycotoxins (e.g. aflatoxin), bacteria)
- Infestations (rodents, birds, insects, etc.)

Underlying reasons are:

- Lack of knowledge and/or awareness of farmers and staff about the effects of their (lack of) postharvest handling of a perishable crop on the quality, storability and shelf life of the product, especially in the first-mile between moment of harvest and arrival at the pack house.
- Lack of knowledge about the determination of the optimum harvest moment (level of fruit maturity/ ripeness) in relation to the market of destination.
- Lack of market (access).
- Lack of support in business planning. Developing a strategy based on SWOT, risk analysis and market analysis. Absence of business calculations.
- Lack of certification requirements (Hazard Analysis and Critical Control Points, HACCP) lead to food safety issues in postharvest handling and an underdeveloped awareness by management and staff regarding efficiency in production and food safety.
- Lack of (pre) cooling and conditioning facilities (mechanical cooling, curing/ventilation, drying) in the producer area lead to quality deterioration of perishable products but also lead to a weak position of the primary production in the value chain.
- Lack of (access to) processing facilities.
- Lack of rewards for quality improvements

3.5 Gap 4: Investment capacity, adapted to the right technology level

Gap 4 conclusion:
Finance and technology needed to develop the missing middle to bring food systems step by step to a higher level are sorely needed.

The investment capacity of smallholders is low. Due to the plot size and number of smallholders, food systems involving smallholders, consist of many links that make the chain less transparent, less efficient and that leads to low prices at the production side of the chain. This results in smallholders often just surviving, rather than being able to invest in production increase or waste reduction.
In low-income groups the major costs of living is food, see Figure 6. The nutritional value of diets in relation to food security is important. There is a lack of focus on food supply systems that include vegetables, nuts, fruits and pulses as a means to assure the availability of nutritional diets for future (urban) populations. Food prices and energy density seem to be important drivers and constraints of food choices [15].

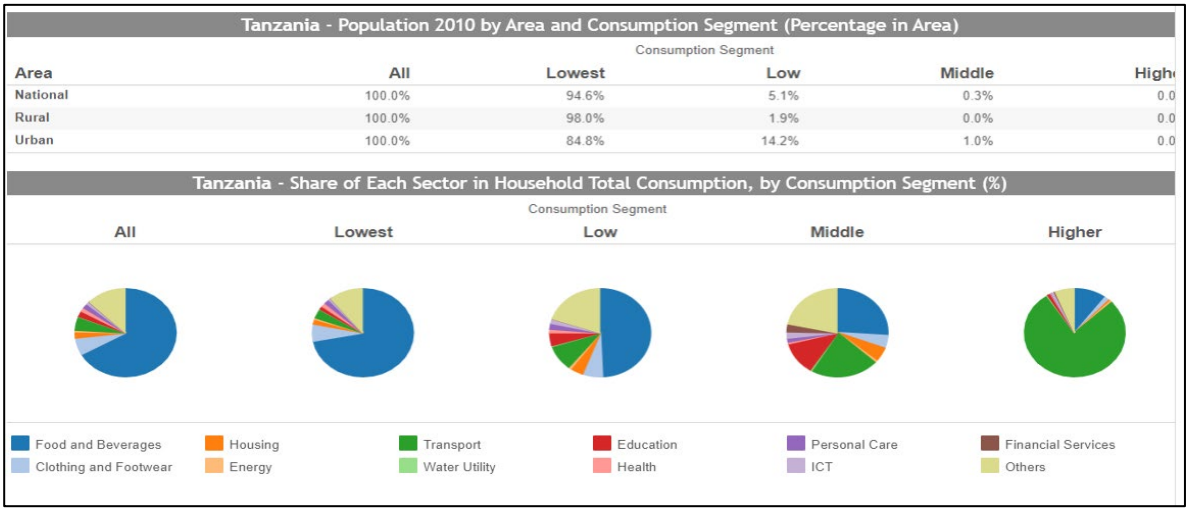


Figure 6: Household expenditure percentage on food per income group Tanzania

Source: [16].

Financing possibilities:

In general, big companies do have access to capital. During the past decade also part of the smallholders and small businesses have gained access to micro credits but IFC/World bank estimates that fewer than 10% have access, primarily those in well-established value chains dedicated to high value cash crops. Still large numbers of smallholders but especially SME companies and SME farmers lack possibilities to obtain financing, thus impeding development to a next level of food system.
Experience learned that there are several reasons for this:

- Lack of interest of local banks to invest in the agricultural sector
- Lack of knowledge and lack of service to develop sound business plans and business calculations
- Lack of knowledge at banks to interpret agricultural business plans
- Lack of collateral due to absence of clear landownership or a public land market

Investing in the appropriate technology level

It should be realized that lack of financing is not the only issue. **Even if financial means would be available, on company level it remains a necessity to align investments on the possibility to earn back this investment.** For the most part, local markets in developing economies are price-markets. The majority of households, especially in the lowest income groups, spend more than 50% of their household budget on food as shown in Figure 6 with Tanzania as an example. They do not demand the highest standards, or at least, they are not able nor prepared to pay a premium price for good quality.

Therefore, the limited additional price that can be obtained in the market for a better quality product does not justify large investments (in postharvest). In order to be able to adapt to seasonal price fluctuations or reaching higher-price markets, only rather modest improvements in techniques are

economically justified. These focus on either increased production capacity and/or storage possibilities often in combination with hand labour (which in many cases is cheap and available in abundance). This fact requires improvement of food systems step-by-step, from one level to the next, to which the level of technology, investments and chain organization needs to be adapted.

Focus on low-tech and high-tech solutions, lack of focus on mid-tech solutions

Many low-tech solutions are available for smallholders. These are mostly cheap and easy to make but need hand labour and are often not very efficient. From the side of NGO's there has been much effort to introduce low-tech solutions, but implementation of these solutions often proves to be challenging due to socio-economic constraints. The large companies in many cases do have the capital, knowledge to invest in high-tech solutions and market outlets to justify these investments.

Market opportunities, labour cost and availability basically determine the financial room to invest in more efficient production- and postharvest technologies. In many developing countries the availability of cheap labour and the limited willingness of consumers to pay additional prices for improved quality, limit the possibilities to invest in high-tech solutions.

There is a gap in the implementation between low- tech and high-tech that limits the growth of a middle development level in food supply chains and there is a lack of focus on this issue by project developers.
Despite the potential of mid-tech technology, the development is of low pace. Large farmers choose to invest in high-tech solutions, while smallholder farmers do not have the investment capacity to focus on mid-tech solutions. Mid-tech solutions meant to upgrade fresh food supply systems with smallholder farmers are investments for the long-term. Traditional investors consider these type of investments as less favourable due to lower benefits and higher risks. Additionally, consortia of governments, NGOs and research institutes that focus on mid-tech solutions seem to be rare.

3.6 Gap 5: Food security

Gap 5 conclusion:
To improve the probability of food security in a country, it is important to invest in a sound local food production system including focus on reducing postharvest losses and increasing storage capacity for grains, root crops and pulses.

Increasing population numbers and urbanization rates have already lead to an increased dependency on imported commodities in many developing countries. The FAO report on the state of food security and nutrition in the world [1], mentions an increasing dependency on imported commodities. This makes countries vulnerable to price fluctuations but also to disruptions in supply. It is advisable to develop a sound local food production including reduction of Postharvest losses and storage capacity for grains, root crops and pulses as buffers.

In many emerging economies there is a lack of good storage facilities to cover the time between harvest seasons and lean seasons. Especially the fruits and vegetables are highly perishable and therefor susceptible to substantial losses and low prices during the harvest periods. Due to that, food losses are substantial. So not only the total annual amount of available food is important, also the seasonality of food security must be taken into consideration. This affects rural populations, but also increasingly, the urban poor.

Initiatives by several governments that focus on increasing local production of staples often have positive results but were not able to replace, or even slow down import increase of main staples like wheat or rice, because (urban) population increase outruns the additional food production.

In the figure below is shown that Zambia is the only country on the African continent that produces more food than it needs to feed its population. All others are net importers. The same applies for South Asia and parts of Latin America.

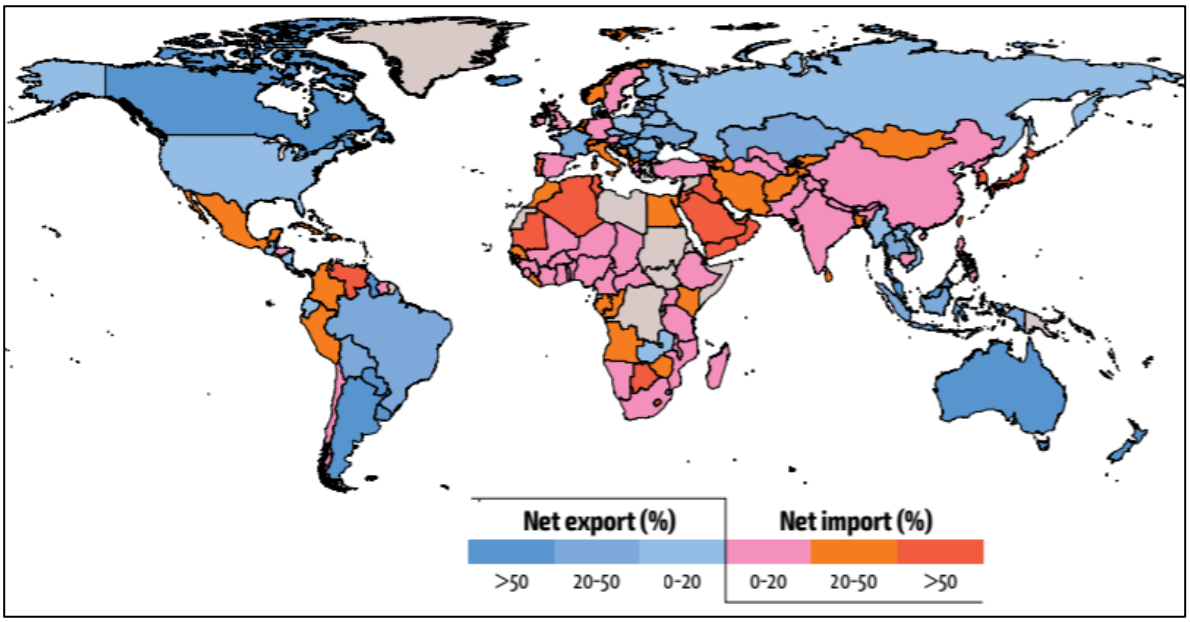


Figure 7: Percentage of net food imports in domestic food supply in total calories (2011)

Source: [4].

3.7 Gap 6: Food safety

Gap 6 conclusion:
Food safety should be an integral part of food production, yet food safety awareness and control is lacking in most emerging countries.

Food safety may only have a minor effect on food availability, still it is important that food is safe and safety is part of a food system. Hard- soft- and orgware to control food safety can also be adapted to the level of development of the food system concerned. For example, HACCP may not be required by law and/or market in some countries, still it is important to introduce its basic principles in food production.

Food safety is an issue that may have different causes that are related to pre- as well as postharvest;

- Agrochemical use prior to harvest but also during storage to protect storable grains and pulses from weevils or bugs are not sufficiently controlled and treatments may even be repeated when a commodity changes ownership leading to high residue levels.
- Aflatoxins are an issue in several crops and have both pre- and postharvest causes. Main examples are groundnuts, but also maize and spices like nutmeg may have aflatoxin problems. Aflatoxins hamper export possibilities of groundnuts but also pose a health risk for humans and animals.
- In processing, even simple HACCP awareness is mostly absent.

Food chain traceability is mostly absent in developing countries, especially when smallholders are involved in supply-driven non formalized chains. This means that there is also no feedback from the last part(s) of the chain to the producers, thus no incentive for chain quality improvements to reduce food loss and waste.

3.8 Gap 7: Access to knowledge and scalability of solutions

Gap 7 conclusion:
Access to knowledge on best practices is limited, but smart tech IT solutions could make a huge difference.

In Europe and other Western economies, apples can be stored up to a year, potato production yields went through the roof since the end of the second world war, strawberry pesticide usage has been lowered significantly, product perishability and quality has been extended significantly due to better

postharvest management, and cooperatives have been setup to distribute best practices and realize effective power distribution in food systems. These are example of best practices and knowledge that could significantly benefit smallholder farmers in developing and emerging economies if customized for their local food system effectively.

Nevertheless, the process of knowledge transfer to smallholder farmers is challenging. Governments try to facilitate smallholder farmers with free extension services, but in practice these governmental bodies lack significant capacity and (customized) knowledge. Therefore, smallholder farmers either hold on to traditional family farming practices or try to reinvent the wheel with the little investment capacity they have facing the life-threatening fact that any investment in innovation means less money to feed and educate their families.

The opportunities for an IT knowledge system that facilitates either or both knowledge transfer and mentoring of smallholder farmers without the need for extension services to be on site are endless due to the fact that smartphones have become very cheap and affordable for smallholder farmers. High tech on the IT platform side, requiring investments of governments or NGO's on technology and content, but a low threshold/costs tool for farmers or chain actors: this is sometimes referred to as smart-tech. The scalability of IT based knowledge transfer solutions makes this a powerful tool for food system improvements.

3.9 Gap 8 Cultural acceptance of innovations

Gap 8 conclusion:
Acceptance of food system interventions requires overcoming cultural obstacles. Involvement of local stakeholders and extension services is essential for successful implementation of interventions

Successful food supply system interventions must fit in the total food system. This requires acceptance by the wider society, which includes compatibility with the existing culture, with its social norms and values. Acceptability by the consumers as well as other members in the value chain for consumption, distribution and sales of a product or service, plays a vital role in the successful adoption of an innovation. The effects of food loss reduction interventions on social and environmental outcomes is often overlooked in studies: Stathers *et al.* found that only respectively 3% and 1.2% of related studies reviewed social or environmental outcomes and recommended more focus on these topics [17].
The largest obstacles in local acceptance of food system interventions are cultural. Every developing nation has different cultural heritages and customs, which must be approached in very different ways [7]. Local involvement is essential for acceptance. Besides involvement of stakeholders, also local extension services should be involved to tailor interventions to the local social and cultural situation and improve acceptance and implementation, for example by organising demos.

3.10 Summary

Main examples of gaps in food production and supply in developing economies are: smallholders not being able to feeding the cities, underdeveloped postharvest supply chains, high food losses, lack of investment capacity adapted to the right technology level, food security- and -safety issues, lack of access to knowledge and scalability of solutions and issues with cultural acceptance of innovations. These different gaps need to be addressed simultaneously in order to avoid improvements in one part of the chain to be nullified by the situation in other parts, so this requires a food system approach. Improvement of postharvest management, stimulation of SME actors in the postharvest chains, and embedding of extension and IT solutions seem key in closing most gaps.

4 Approach for identifying solutions

From a good analysis, the bottlenecks and the low-hanging-fruit or area where the biggest results may be expected, will become clear in detail. With food losses of over 20%, fruit and vegetables, roots tubers and oil bearing crops [18] seem the commodities with highest potential for improvements, but based on local analysis also cereals, pulses and meat or other animal products could be targeted.

In previous chapters the role of postharvest in improving food system outcomes has been described. Recognizing that improved postharvest management positively contributes to the food system outcomes, pathways should be explored to stimulate improvements on postharvest management. To facilitate for this, the postharvest department of Wageningen University & Research envisions that

> *stakeholders are facilitated in improving the postharvest management through postharvest assessment tools that helps them to identify easy-to-adapt solutions, provides them with suggestions on the implementation of those, and aids them in this way in reaching the next level of their local food system. In our vision governments should facilitate development of SME's in order to increase food security and food safety while reducing postharvest losses.*

4.1 Postharvest assessment tool

The postharvest assessment tool is a concept which facilitates supply chain actors and governments to assess the maturity of the postharvest management from their respective view and develop interventions adapted to the right context. Ericksen *et al.* recognizes the contributions typologies can have for researchers and policy makers dealing with food systems [19].

Wageningen Research proposes to develop a postharvest assessment tool, building on the fundament already laid down in literature (see Addendum: Foundation of postharvest analysis tool), with the following guiding principles[1]:

- The postharvest assessment tool is a process maturity grid designed to assess the maturity of the postharvest management and gives clear indication on how to improve to reach the next level of maturity.
- The postharvest assessment tool consists of elements or sub-processes that make up the entire process. For each of the elements, a maturity scale has been created; ten levels of maturity, starting from basics in step 1 and culminating in state-of-the-art in step 10. By assessing the maturity level of each of the elements, organizations can establish a 'maturity profile' for the postharvest management and gain an insight into the steps they need to take to move further.
- The postharvest assessment tool serves as a basis for benchmarking the progress of postharvest development; within the organization in time or chains in other geographical areas.
- Postharvest management interacts on multiple scales; per department, organization, chain and country. Further to this, it is recognized that the role of different actors, such as policy makers and the private sector in developing the postharvest chain might differ. The postharvest assessment tool caters for such scaling and the role of the users.

Figure 8 and Figure 9 show a visualization of the postharvest assessment tool, with a central role for the postharvest chain, and differentiating the role of private and governmental bodies.
Figure 8 shows the assessment of the food systems on country level with focus on government policy development and investment strategy. It analyses the types of food systems and their numbers as well as bottlenecks for sector development.

[1] Inspiration of the postharvest assessment tools is drawn from other maturity assessment tools, such as the Michigan State University (MSU) Purchasing Excellence model and the EFQM Process Excellence models

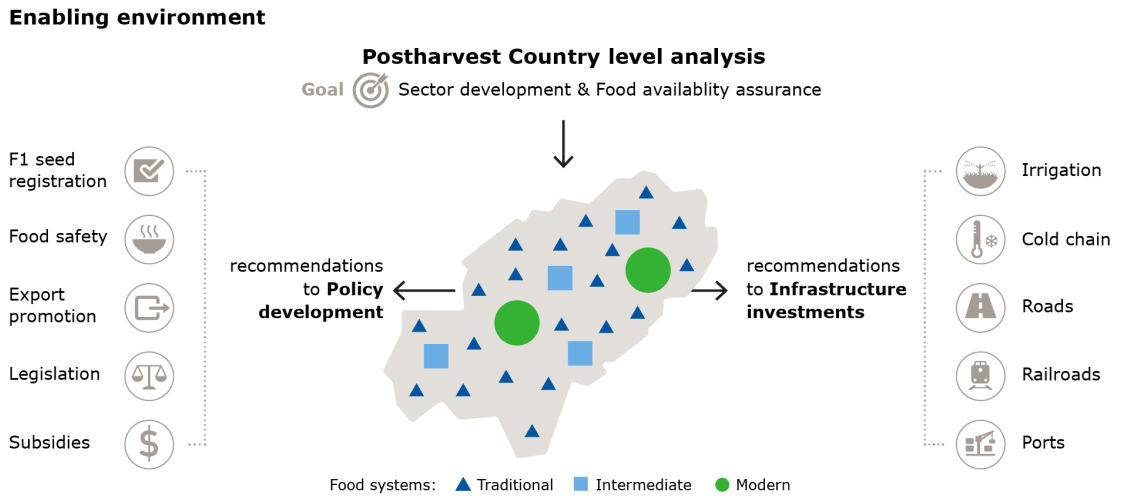


Figure 8: Assessment of enabling environment at country level

Figure 9 shows the assessment at company level. It determines the type of food system, market opportunities and leads to a business planning that determines the feasible size of operations and the corresponding technology level (as well as strategy, SWOT, risks analysis, financial analysis, investment plan, etc.).

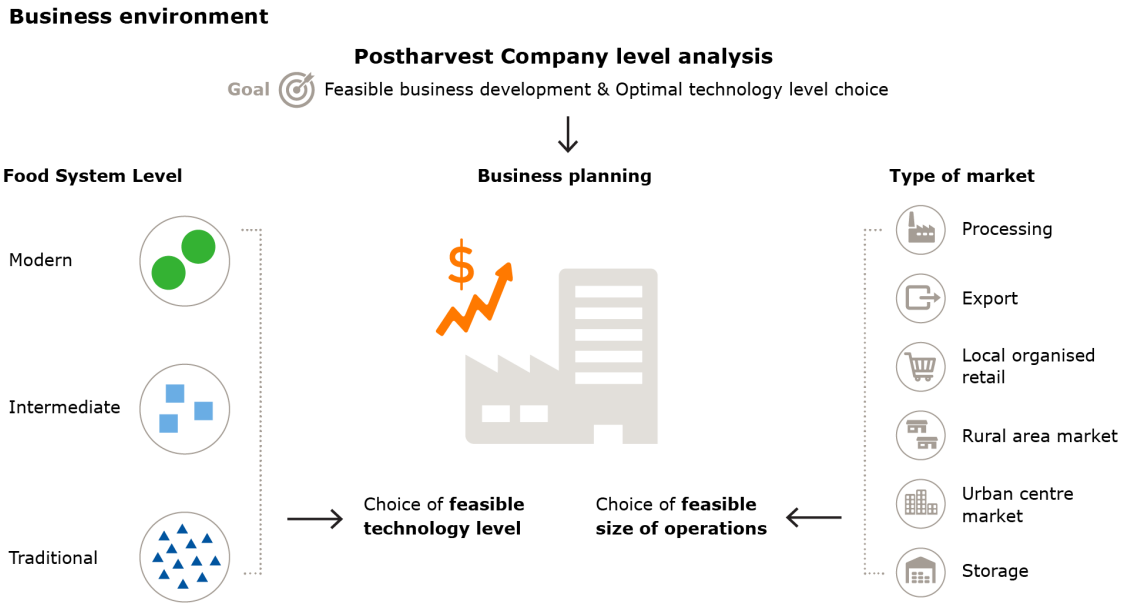


Figure 9: Assessment of the business environment at company level

4.2 Focus on mid-tech solutions

It is likely that in many instances food system improvement to a higher level will need a step from low-tech solutions towards mid-tech solutions, a step from micro level (smallholders) to SME farmers that can significantly contribute to sustainable food system development in emerging economies.

Smallholders lack the possibility of significant efficiency increase in production and storage. Their large numbers affect the number of links in supply chains. This in turn negatively affects the prices being paid at the producer end of the supply chain and therewith the capacity to invest. SME farms have

potential for professional development with incremental improvements in production, quality and postharvest management, keeping investments in line with potential profits. By gradually implementing improvements, the required knowledge and skills level of the farmers can also keep pace. Local processors do have an interest in chain development that include SME farms as they are in need of a consistent supply of raw material (consistent in quality, amount and supply).

A food supply chain involving SMEs can improve yield and quality, handle larger amounts of fresh products, invest in quality or loss prevention/reduction, includes less links in the chain and therefore has a potential to substantially increase supply while reducing food losses in the chain.

Nutritional value of the food must also be taken into consideration. Fresh fruits and vegetables in the diets are typically products that could easier be supplied to large parts of the population by local food systems rather than by import, as the latter requires a complete cold-chain to be maintained to obtain the extended shelf life for perishables that is required when the product comes from far.

Especially mid-tech storage technology can be fruitful to initiate a fresh food system optimization, because the main challenge in fresh food systems is perishability (or product quality over time). The aim will be to develop and implement mid-tech technology that costs for example 20% of the high-tech solution and leads to 80% of the high-tech results. Often realized by technically improving existing storage principles or by implementing new techniques under less optimal conditions. Once implemented, the supply chain buys itself time to optimize other aspects of the food system (production and postharvest supply chain): more fruitful markets can be assessed, logistics can be optimized, organization of farmers cooperatives can be realized, grading and sorting can be implemented, branding can be done, etc. Moreover, 20% of the high-tech costs can justify long-term investments.

The observation that the missing middle brings about opportunities to develop the agricultural sector of developing economies and the observation that this development is likely to benefit from a step-by-step improvement of postharvest handling are key conclusions of this white paper. Any project approach should be aware of this when developing possible solutions.

Knowledge within Wageningen University and Research is abundantly available to find mid-tech solutions for existing postharvest problems and to implement these. An example could be to combine the use of a computerized control box reacting on temperature and relative humidity (RH), with local materials to optimize cooling or ventilation of crops in storage. Another example could be to use non-chemical insect control to sanitize grains and pulses before or during storage.

Another good example of this can be seen in primary production of vegetables and their postharvest handling. Only in countries with a large high-end market, demanding good quality and offering high prices, investments in high tech-greenhouses take place from scratch (examples are Russia, Saudi Arabia (KSA), Arabic Emirates (UAE)). The production in these countries is meant to replace existing imports. In all other countries this development usually takes place step-by step. Starting with a simple plastic tunnel and slightly improved seeds. At a certain moment, investments are made in an improved plastic greenhouse, fertigation system and better seeds/varieties and in a later stage investments are made in improved climate control in the greenhouse and hydroponic cultivation systems. Quality and yield levels increase with each step but so do the investments. These investments are in line with market demands, financial possibilities and knowledge level of the producer.

When investments in postharvest are required, the same mechanism is in place. It is no use to make high investments in the newest postharvest technologies if the primary production and basic quality of the produce is at a low level still and the market does not require the best of the best quality yet. On the other hand, it is not wise to use cheap seeds or low-level postharvest techniques if the primary production facilities are at a high level. In other words, investments in postharvest, and the costs of these should be in balance with market possibilities /requirements and level of primary production to be sustainable.

To indicate the effect of different levels of food systems on investments and cost prices, a rough sketch is given below for 3 crops: (Irish)potato, onion and tomato. In these examples, we sketch a potential scenario. This is just an indication of the possibilities; there are many different situations and possibilities to optimize the food system by adapting to a higher level, even sometimes making combinations of technical solutions and labour input.

Case 2: Agro-logistic sector development Mexico

Wageningen Research developed the National Agro-logistics Program Mexico. A policy program which includes a roadmap with actions on agro-logistics that will safeguard food supply on the long term and an improved export position of Mexico.

In 2014 the Mexican Ministry of agriculture, requested Wageningen Research to perform an agro-logistic analysis for Mexico in order to support the implementation of the National plan for Agro-parks. The Agro-logistics program was developed in a co-design process with local stakeholders from the public sector (Ministries, agencies and services) and private sectors in the agri-food chain (primary production, processing, trade, wholesale, retail) and international experts. The goal of the National Agro-logistics Program is to define public policy measures that contribute to accomplish the potential of exporting agro-products, which will result in a transforming legacy for the sector. The horizon of this Program is the year 2030.

Mexican private and public stakeholders in the agri-food chain supported by 6 international agro-logistics experts formulated the ambition to become a world leader in export of agri-food products by the year 2030. This ambition includes also the growth of Mexican consumption of high quality agri-food products in the next decades. Although Mexico is already a big player in the production and export of tomatoes and avocadoes, this position can be improved for also other commodities as other fruits & vegetables, meat, sugar and fisheries. However, in general Mexico produces low added value perishable products using trucks as main transport means. To change that an extra effort is needed in improving infrastructure and multimodal transportation, standardization in logistics and quality and food safety standards, improving custom procedures, collection centres and adding value to the products, new business models to include small holders to formal markets, expertise development on postharvest and supply chain management. Only an integrated approach of different governments and private sector together can realize that.

The vision of the program is transferred in a roadmap with 5 program guidelines: governance, regulatory framework, infrastructure, investments and innovation. Each guideline is translated to actions. In total 15 concrete actions will be taken by Mexico in the next 4 years (2015-2018) to improve the agro-logistics. The benefits of the National Agro-logistics Program are:

- *Increase in agri-food trade*
- *Reduction of cost in supply chains*
- *New jobs in agro-logistics sector*
- *Improved position on LPI index*
- *Improved export position in agri-food*
- *Reduction of food losses in agri-food chains*
- *Reduction of lead times at borders by aligned inspection and custom services*

Increased effectiveness of public policies to strengthen agri-food chains

Example 1: Potato

Potato is very well storable, especially above 2100 m. where cool night air can be used for ventilation. Large price differences between harvest- and lean season, often justify investing in storage. The size of the operations is closely related to the level of development of a food system it is part of. The yield levels determine to a great extend the cost-price per unit product, but investments require a minimum quantity turnover to be feasible.

Figure 10: Examples of different level food systems in potato
Photos: Wageningen Research

Low-tech food systems in potato have very low yields, due to the absence of using good planting material. All work is done by hand and storability is limited to a few weeks.

Mid-tech: Less advanced investments making use of labour, mostly justify investments on a smaller scale because of increased yield and improved storability.

High-tech: For potato, the investments in high-tech partly affect the yield but also the labour requirement and quality. Mostly, high-tech investments require a minimal scale (e.g. 52 hectare for center pivot irrigation or 250 hectare for mechanized harvesting). The same applies for automated bagging.

Table 2: Indication of yield- and costs comparison of different level food systems in potato

tech level	yield (ton/ha)			investsment (€/ha)	operational costs	investment costs (10% interest, 6% depreciation)	total costs	cost price (€/ton)			storage losses	remarks
	low	high	average			16%		low	high	average		
low-tech	4	10	7	200	600	32	632	158	63	90	5 to 40 %	< 2 ha; much labour but non-paid
mid-tech	20	35	27.5	1,500	2,500	240	2,740	137	78	100	1 to 3%	2 to 50 ha; much labour (hired)
high-tech	45	65	55	10,000	2,500	1,600	4,100	91	63	75	1%	> 50 ha; little labour, large buyers

Source: Expert estimation R. Oostewechel, Wageningen Research

As there are many different factors influencing yield and cost price, Table 2 shows low- average- and high yield estimations per food system.

Example 2: Onions

For onions to a large extent the same mechanisms are valid as for potato.

Figure 11: Examples of different level food systems in onion
Photos: Wageningen Research

Low-tech food systems in onions have relative low yields, due to losses during production and storage. Often, small land holdings lead to lack or absence of crop rotation, gravitating this. All work is done by hand and storability is limited due to limited crop quality.

Mid-tech: Less advanced investments making use of labour, mostly justify investments on a smaller scale because of increased yield and improved storability. The size of operations may facilitate the introduction of crop rotation.

High-tech: For onions, the investments in high-tech partly affect the yield but also the labour requirement and quality. Mostly, high-tech investments require a minimal scale (52 hectare for center pivot irrigation or 250 hectare for mechanized harvesting). The same applies for automated bagging.

Table 3: Indication of yield- and costs comparison of different level food systems in onion

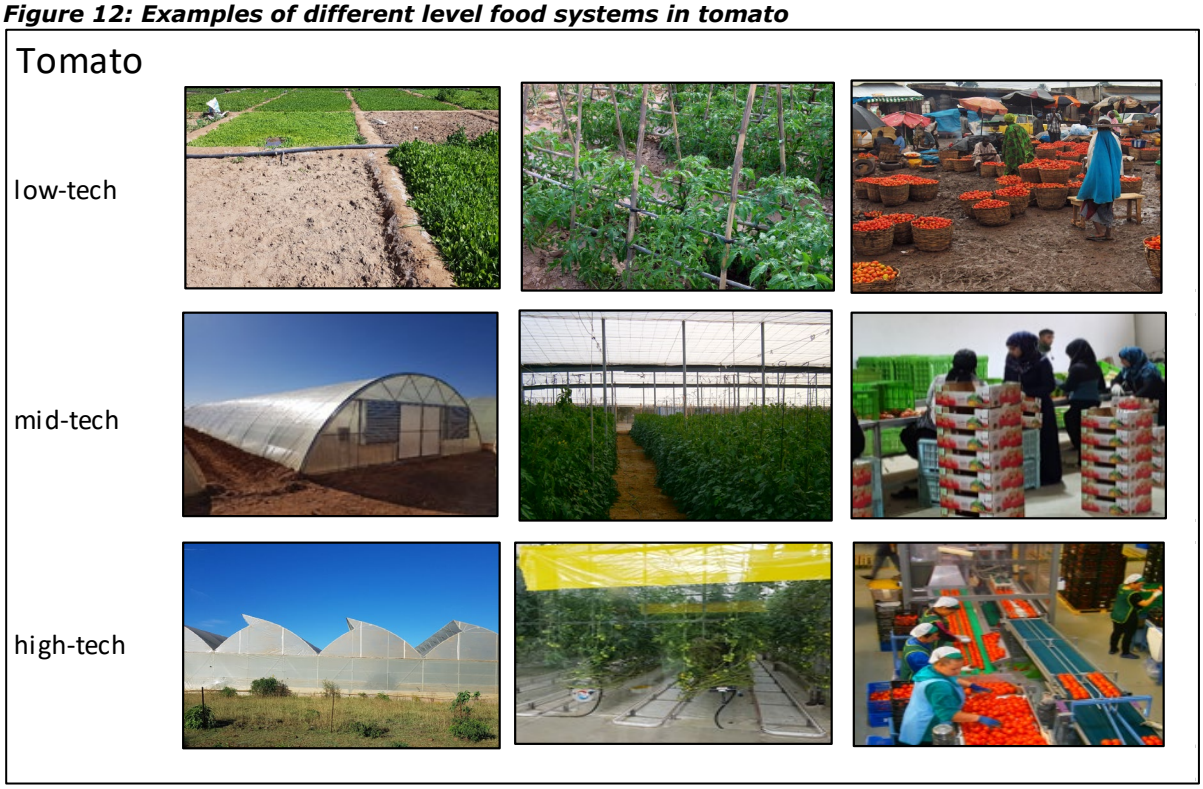
tech level	yield (ton/ha)			investsment (€/ha)	operational costs	investment costs (10% interest, 6% depreciation)	total costs	cost price (€/ton)			storage losses	remarks
	low	high	average			16%		low	high	average		
low-tech	5	14	9.5	600	500	96	596	119	43	63	up to 20%	< 2 ha; much labour but non-paid
mid-tech	14	45	29.5	1,500	2,000	240	2,240	160	50	76	6 to 15%	2 to 50 ha; much labour (hired)
high-tech	45	65	55	10,000	2,500	1,600	4,100	91	63	75	upo to 6%	> 50 ha; little labour, large buyers

Source: Expert estimation R. Oostewechel, Wageningen Research

Example 3: Tomato

For fresh tomato, high-tech investments serve to produce year round high quality product needed by well-developed markets. The investments are not primarily meant to reduce labour requirements and the production cost price per kg does not decrease. Production capacity- and quality increase are the main drivers as well as meeting market demands. However, a step from low- to high-tech is too big for most markets. Therefore there are many intermediary sub level food chains.

Figure 12: Examples of different level food systems in tomato



Photos: Wageningen Research

Low-tech food systems in tomato often have very low yields, due to the quality of the seeds that are used and disease pressure. All work is done by hand using cane poles for trellis in outdoor cultivation Absence of cooling and rough handling lead to huge postharvest losses and limited marketing distance

Mid-tech: Investments in small tunnels or improved tunnels enable climate regulation and increase yields. The crop remains labour intensive but quality improves and investments in simple postharvest handling facilities with cooling enable the supply to more distant markets, reduced losses and increased profits.

High-tech: For tomato, the investments in high-tech significantly affect the yield level and quality. However, the markets needs to be developed as well in order to realise high prices that justify the high investments, especially in greenhouse structure, climate control and soil-less cultivation. Mechanised grading to realise uniformity in size and colour are a must to serve high end markets.

Table 4: Indication of yield- and costs comparison of different level food systems in tomato

tech level	yield (kg/m²)			investsment (€/ha)	operational costs	investment costs (10% interest + 6% depreciation)	total costs	cost price (€/kg) At different yield levels			storage losses	remarks
	low	high	average			16%		low	high	average		
low-tech	2	5	3.5	3,000	2,500	480	2,980	0.15	0.06	0.09	5 t0 40 %	< 1 ha; much labour but non-paid
mid-tech	10	45	27.5	200,000	20,000	32,000	52,000	0.52	0.12	0.19	1 to 3%	> 1 ha: much labour (hired); large buyers
high-tech	50	80	65	1,300,000	260,000	208,000	468,000	0.94	0.59	0.72	1%	> 1 ha: much labour (hired); large buyers

Source: Expert estimation R. Oostewechel, Wageningen Research

Case 3: Jordan tomato handling

Many small vegetable growers cultivate tomatoes and peppers in plastic tunnels in the Jordan valley. One standard tunnel is approximately 400 m² and basically a mid-tech cultivation level is being applied. Production levels can be much higher and the application of different cultivation techniques is possible. This requires investments in technical installations, use of improves seeds and an increased knowledge level for its management. It all needs to be in balance. Higher yields decrease the cost price per kg, but the management risk increases and a stable market to send substantial quantities is required. The general way forward is step by step. This applies to the postharvest as well. Harvest is manual and some exporters collect fruits to send it to markets on the West-bank or Gulf states. Because of transport time and required quality and shelf-life, they do use cold storage and nice packing. However, all the rest of postharvest technology is simple, designed to make use of hand labour that is abundantly available. As profit margins for Jordanian tomatoes and peppers are small in the destination markets, investments in mechanical sorting and grading are hardly done.
A major reason for the low prices of Jordanian produce are however the uneven sorting and grading. Adding a simple mid-tech grader would already put the exporter in a position to achieve better margins.

Mid-tech solutions do include the choice of (existing) technology and the investment costs that are involved. However, the mid-tech solution also concerns organizational issues and training. Especially in the first-mile from tree/field to pack house. Much improvement can be realized using simple techniques and organizing the product-flow in an efficient way. The precise choice for which mid-tech technology to adopt depends on local circumstances.

Concerning the mid-tech technical solutions, these are mainly to be realized in storage and conditioning of produce rather than in grading, sorting and packing. This addresses the main gap of storage losses and lacking storage capacity that are a big contributor to seasonal food insecurity in developing countries as well as product price fluctuations and low farmer income. There are 2 main approaches:

1. Redesign high-tech solutions to low investment-cost solutions
2. Upgrade existing low-tech postharvest techniques to perform better

Ad 1: For this redesign, postharvest specialists must have a good understanding of low- mid- and high-tech solutions, so they can translate local requirements to appropriate postharvest solutions. For example, how much can we reduce technical specifications in order to still have sufficient positive effects on quality? E.g. aiming for 80% of optimal quality retention for 20% of the costs by using non-optimal but sufficiently effective technology/materials.

Ad 2: Many existing low-tech technologies are based on just cooling or just drying for example, by putting a product in a certain place. However, there are usually physiological processes in a product that need finetuning to optimize the conditioning. This requires measuring (temperature, relative humidity, air flow, etc.) and automated actions based on these measurements. Especially in the field of combining low-tech or existing storage solutions with measuring and control equipment, significant added value may be expected.

The mid-tech technical solutions may be developed for any crop but the expected focus will be on technologies for staples like grains, rice and root-crops and mid-tech solutions for postharvest storage and handling of fresh fruits and vegetables, nuts and pulses since these types of crops are expected to play a prominent role in addressing food security from a food nutrition point of view in the near future.

Case 4: Off-grid Mobile Fruit Packing Unit Haiti

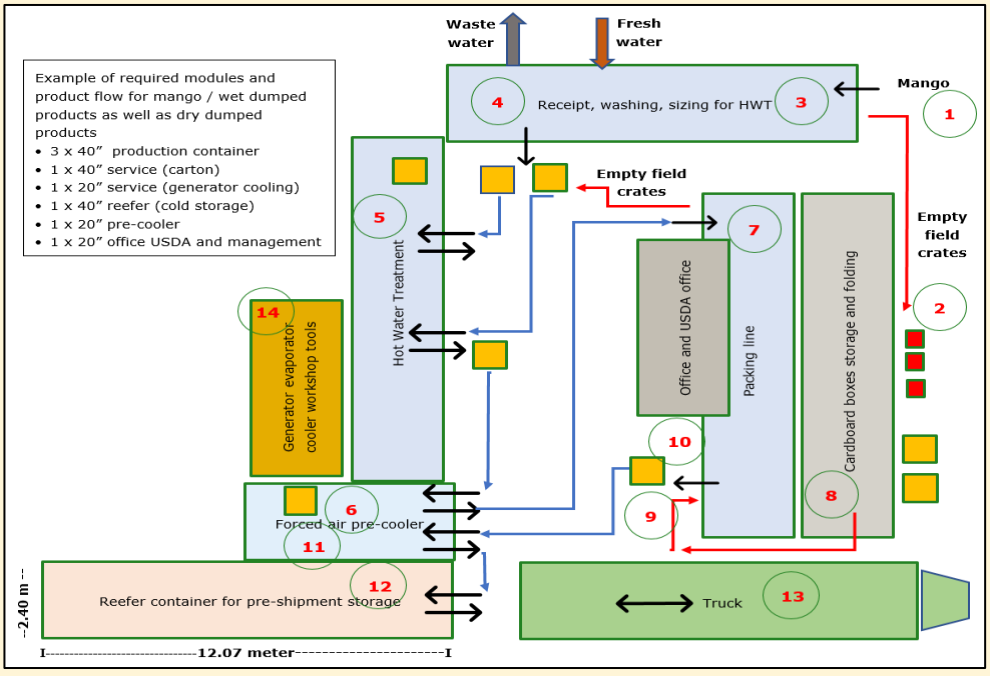
The 'first-mile', the time and handling between harvest and cooling, is important in the quality preservation of most fruits and vegetables. However, the infrastructure to cool and pack at a short distance from the production area and the ability to handle the produce within a limited time after harvest, is often absent in Low- and Middle Income Countries (LMICs). An off-grid mobile packing unit (MPU) with cooling facility could therefore be of enormous added value to farmers in many parts of the world, producing quality fruits at relative large distance from the main cold storage infrastructure. This would allow them to enter higher priced markets.

In Haiti, like in so many developing economies, one of the major risks encountered in practice when implementing new initiatives, is the economic interest of the established trading network in countries. They often see change as a threat to their own interest and do not like to see a shift in the power balance. At the same time this established network controls some of the critical infrastructure. A simple but effective and reliable unit to treat, pack and cool fruits can be a game changer and do justice to other investments in the field of farmer empowerment.

On request of World bank, Wageningen Research developed an outline for an off-grid mobile packing unit for mango, avocado and other (sub) tropical fruits and vegetables. It was designed in a modular approach, based on all activities that need to be performed for exportable mango and other tropical fruit crops and required capacities. The main features of a (semi) MPU are its relative low price, its flexibility and short time-span to realise the infrastructure and the low risk from project point of view, as the unit can be collected and placed in another location within several days.

In order to assure that the MPU is optimally being used in a sustainable way there are a number of criteria that are important to consider:

1. *Confirmation of the additional value for the product that can be obtained in (export) markets*
2. *A feasible technology- and investment level from the point of view of performance, investment- and operational costs*
3. *Independent and reliable electricity supply*
4. *Reliable (clean) water source or tank*
5. *Ownership by farmers with an interest in innovating their horticultural sector*
6. *Accessibility for farmers to bring produce to the scheduled MPU venue*
7. *Management of the MPU by a dedicated and trained team*
8. *Connection to a network of shipping companies and exporters*
9. *Consistency of both supply and quality provided to the market*
10. *Standard Operating Procedures (SOPs) for product handling are respected, including the audit component*
11. *Knowledge transfer of new expertise to farmers, management and MPU handling staff*
12. *Meeting (future) market demands in terms of varieties, grading, packing etc.*



Layout of mobile packing unit

4.3 Financing / Business planning

Smallholders may have access to microfinancing. Large companies mostly have access to (foreign) capital and government funds. It is the farmers that need more financing capacity than microcredits can provide because they want to invest in production increase or storage that often have problems with financing their investment plans. The gaps that were analysed were following:

- Lack of interest of local banks or other funders to invest in the agricultural sector
- Lack of knowledge and lack of service to develop sound business plans and business calculations

A solution to overcome these gaps may be found in:
Assistance in the development of business plans and business calculation: This helps SME famers to develop the right strategy and to choose the right investment approach that justify the level of investment by sustained additional income. First of all such a business plan is needed for the farmer him-/herself. Secondly for obtaining credit.

4.4 Scalability of solutions

As the approach in this paper does not primarily focus on smallholders, there is no capacity needed to reach millions of subsistence farmers. Rather a capacity is called for to reach emerging SME farmers and entrepreneurs. This can be achieved with community events and demonstration farms but especially by high level extension services with a multiplier factor build in. A well trained group of professional advisors may be asked to each form a group around them to give second tier training. Thus a multiplying factor of 10 can be achieved. This is important in order to create sufficient kick-off power at the start.

4.5 Development of tools

Wageningen Research offers a thorough analysis of the current state of development of food systems and based on that, a plan of action that takes all aspects that directly or indirectly influence a food system, into consideration. Wageningen Research is able to identify the correct level of food system development and the corresponding hard- soft- and orgware requirements needed for sustainable improvement.

Wageningen Research offers capacity building programs as well as train-the-trainer programs for local institutions, education and research.

Tools that are part of the full-concept approach in mid-tech solutions are following:

1. Quick-scan / gap analysis of the current level of development of food systems in a given area (for a given product group) with focus on postharvest technology use, losses and seasonality of food supply.
2. Tailor-made approach toward a sustainable solution for step-by-step development of a food system and overcoming existing gaps
3. Market analysis, determining opportunities and market performance indicators (success factors)
4. Business planning, including DESTEP analysis, strategy, SWOT analysis, risk analysis and mitigation measures, marketing plan, production plan, investment plan, calculations, Ratios (IRR, ROI, Cash-flow) and sensitivity analysis
5. Postharvest consultancy for functional design specifications
6. Training modules for determination of optimal harvest moment
7. Training modules for optimal postharvest technology use (including visuals that clearly show actions and results, focused on lower-education trainees and that can be used remotely)
8. Product specific postharvest training modules
9. SOPs (Standard Operating Procedures) development per product for each step from determining the harvest moment to supply to the market
10. Setting up local knowledge centres to investigate feasibility of improved postharvest technology and creating local SOPs
11. Advise on type of technology, capacity, location based on the SOPs
12. Food safety model development for postharvest- or processing facilities and functional design including a Aflatoxin prevention plan (groundnut and maize)

5 Conclusions

The main conclusions of this white paper are:

- There are many types of food supply systems in place in developing economies, of several different development levels from low-tech based through various stages of mid-tech to high-tech.
- Medium-sized enterprises are needed in each country to bring the local food system to a higher level.
- Development of the agricultural sector as a whole is needed to cope with food requirements of fast growing urban populations. The logical way for development of food systems is step-by-step from one level to the next.
- Availability, affordability and adoption of mid-tech solutions play a key role in the emerge of a food supply system improvement that allows professional SME farmers to invest in a financially sustainable way, allowing them to decrease production costs and increase production.
- To realize an effective food system, the focus should be on production and postharvest supply chain as an indissoluble link that creates effective food supply systems. Otherwise, a large percentage of all additional food produced due to the higher yields will be no more than additional food loss or waste.
- In order to avoid "White Elephants" and inefficient use of development funding, a thorough assessment of the current situation in a given country or region is needed as a starting point for an action plan. This analysis should be on country and/or regional level and include all aspects that directly or indirectly influence food systems.
- A separate assessment must be focussed on company level and address its specific needs, gaps and opportunities.
- For a sustainable development model it is imperative that local institutions (e.g. research, education, extension) will be key drivers and capacity building and train-the-trainer programs should be targeted to enable them to perform their role accordingly
- Wageningen Research has the knowledge and capacity to play a key role in sustainable development of agricultural food systems in developing countries.

6 Literature

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Addendum: Foundation of postharvest analysis tool

Building on the concept of the food system typologies, the high level panel of experts on food security and nutrition provides an overview of them available in literature [8]. For the purpose of their report they identify three broad types of food systems, namely: traditional, mixed and modern food systems. Focusing on postharvest typologies, Mrema and Rolle introduced a classification of country's postharvest technology level, differentiating between traditional, intermediate and high technology levels [20]. They further describe that '*all levels of technology are generally available in any one particular country'* and that it is generally linked to the economic status of a country.

The latter is recognized by Van der Lee, Helder and Groot, when they introduced the agri-food system development model [6]. In their model a link is established between the sophistication of the market and the product(ion) sophistication. Based on case studies they are providing a more clear link between the economic status (market sophistication) and the technology level (production sophistication) in agri-food systems.

Evaluating current postharvest typologies and performance indicators, we found indicators and typologies as stipulated in Table 5.

Table 5: Current postharvest typologies and performance indicators

Measure	Description	From
Country's postharvest technology level	Typology in traditional, intermediate and high technology levels	[20]
Agricultural infrastructure	Weighted score of indicators below left.	Food Security Network (The Economist Intelligence Unit) *https://foodsecurityindex.eiu.com/*
Availability of adequate crop storage	Qualitative binary indicator assessing if the government has made investments to improve or expend crop storage within the past 5 years.	
The availability of adequate transport	Qualitative indicator measuring the quality of infrastructure Likert scale between 1 and 5.	
Percentage of cultivated agricultural area which is equipped for irrigation	% of land equipped for irrigation	
Food loss		Food Security Network, using FAO Data *https://www.fsnnetwork.org/*
Food Loss (vegetables, fruit, cereals, pulses, livestock, fish)	Measure of postharvest and pre-consumer food loss as a ratio (%) of the total domestic food supply.	FAO, *Food Balance Sheets*

Zooming in on the availability of adequate crop storage facilities, the Economic Intelligence Unit analysts provide measures of agricultural infrastructure as part of the food availability measure. The agricultural infrastructure (number 2.3) is an indicator that measures the ability to storage and transport crops to the market. This indicator score is calculated based on elements 2.3.1 – 2.3.6 as per the table above.
The existence of adequate crop storage facilities is a binary indicator, assessing 'if there is evidence that the government has made investments through national funds, multilateral/donor funding or the private sector to improve or expand crop storage within the past five years'. The indictor score is either no (=0) or yes (=100). The results of 2019 shows that in 102 countries investments were made (100% score), whereas in 11 other countries no evidence of such existed.

Analyzing the current postharvest typologies and performance indicators, it becomes clear that postharvest management is considered to be of importance for food security (food availability), however, it remains unclear to what extend these indicators contribute facilitate policy makers, researchers and the private sector to improve the postharvest management in their countries and agri-food chains. What is fully lacking, is a tool to perform an analysis at company level that enables the disclosure of concrete requirements for feasible and sustainable actions and support.

To explore the potential of nature to improve the quality of life

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The mission of Wageningen University and Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 6,500 employees (5,500 fte) and 12,500 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.