Post-harvest loss reduction

A value chain perspective on the impact of post-harvest management in attaining economically and environmentally sustainable food chains

Bart van Gogh (ed.) [1], Henry Boerrigter [1], Maryvon Noordam [2], Ruerd Ruben [3] and Toine Timmermans [1]

[1] Wageningen Food & Biobased Research

[2] RIKILT

[3] Wageningen Economic Research

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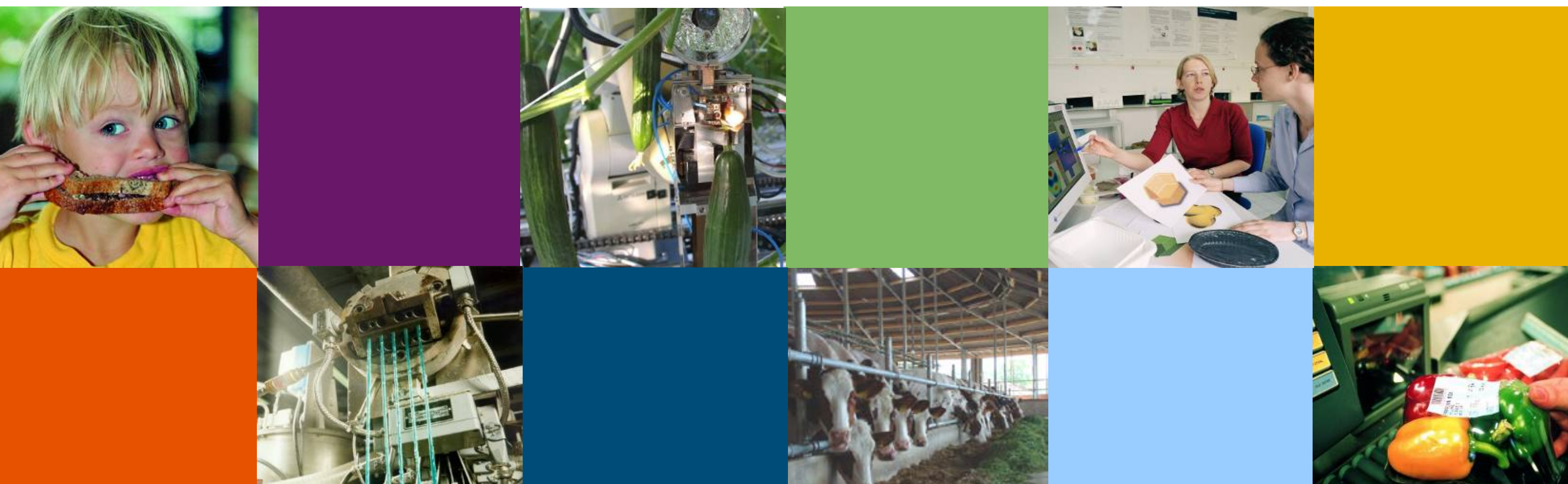

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Authors	J.B. (Bart) van Gogh (ed.), H.A.M. (Henry) Boerrigter, M.Y. (Maryvon) Noordam, R. Ruerd) Ruben, A.J.M (Toine) Timmermans
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Wageningen Food & Biobased Research
P.O. Box 17
NL-6700 AA Wageningen
Tel: +31 (0)317 480 084
E-mail: info.fbr@wur.nl
Internet: www.wur.nl/foodandbiobased-research

Preface

This paper was written by experts from Wageningen University & Research (WUR), representing their combined expertise on food chains, post-harvest technology, sustainability, food security, economics, and food safety. The paper was drafted at the request of the Dutch Ministry of Economic Affairs in co-operation with the Ministry of Foreign Affairs to give insight in the potential impact of post-harvest management (PHM) on a selected number of societal themes. The themes that are considered relevant within the domestic and international political context for global economic development and social stability, are successively: 1) food security, 2) food safety, 3) economic revenues, 4) employment, and 5) climate footprint. This paper presents the outcome of an exercise to combine the relevant expertise[1)] related to the topic of post-harvest management and in the context of reducing food losses in the post-harvest chain. The objective of the paper is to provide insight in the effects of the deployment of resources for the strengthening of post-harvest management on the mentioned themes.

[1)] *Wageningen Food & Biobased Research, Wageningen Economic Research and RIKILT.*

Content

1 Context and characteristics of post-harvest management

1.1 Introduction to the paper and its topic

Food systems are changing rapidly with important consequences for changing diets. The evolution in diet is influenced by higher incomes per capita, but: food prices, individual and socio-cultural preferences and the development of the cold chain play a role as well (EU, 2015). The food chains that supply consumers are growing longer, with global trade increasing the distance between production and consumption, as well as the diversity of foods available to consumers. In developing economies value and power in food systems are shifting towards the middle of these food chains (processing, storage, wholesaling and logistics), with agricultural produce becoming ingredients for processed products. Decisions by large agri-businesses, manufacturers and retailers are playing a growing role, relative to the public sector, in the availability, affordability, safety and desirability of foods (Reardon, 2015).

At the same time a substantial share of the world population is facing a nutrition crisis. According to a report from the Global panel on Agriculture and Food Systems for Nutrition 3 billion people have low-quality diets (GloPan, 2016). Overweight, obesity and diet-related chronic diseases are no longer symptoms of wealth and abundance but are increasing in every region and most rapidly in low- and middle income countries. Estimates suggest that by 2030 the number of overweight and obese people will have increased from 1.33 billion in 2005 to 3.28 billion. At the same time more than 800 million world inhabitants are still chronically hungry. 156 million children under 5 suffer chronic undernutrition affecting not only these children's physical abilities, but also their mental and learning capacities (UNICEF, 2017). More than 2 billion lack vital micronutrients (e.g. zinc, iron, vitamin A), which affects their health and life expectancy. Food systems therefore need to be repositioned from just supplying food to providing high-quality diets for all.

Food waste as 'nutritional disease' of advancement

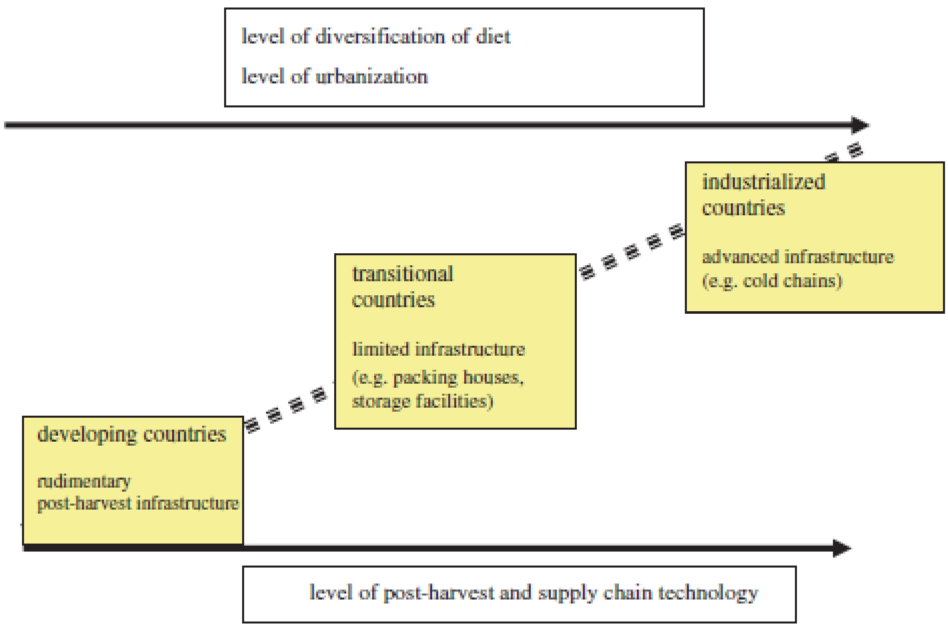
There is a trend that food waste in the consumer part of the FSC is increasingly becoming an issue in developing countries as well when the levels of expendable incomes will rise. This is particularly the case in the larger cities where income and welfare levels are relatively higher. Simple interventions at household level could contribute to the reduction of food spoilage and waste (storage and preparation). The focus in this paper lies on the post-harvest chain and the losses incurred in that particular part of the chain.. Food waste will therefore not be dealt with, except within specific contexts in which post-harvest losses and food waste have a combined effect (for instance on global GHG emissions).

The efforts to provide these high quality diets for all cannot be seen apart from the food supply chains' (FSCs) ability to deliver sufficient quantities of food products to consumers. This becomes evident when comparing the performance of supply chains for fresh produce in developing and developed countries in terms of incurred food loss, including food quality loss. A multitude of different definitions are used to refer to post-harvest food loss. In this study the definitions are aligned with the CFS HLPE report "Food losses and waste in the context of sustainable food systems". Food quality loss refers to the decrease of a quality attribute of food (nutrition, aspect, etc.), linked to the degradation of the product, at all stages of the food chain from harvest to consumption. The term post-harvest loss refers specifically to a decrease, at all stages of the food chain from harvest to consumption in mass, of food that was originally intended for human consumption, regardless of the cause. Food waste refers to food appropriate for human consumption being discarded or left to spoil at consumer level.

Food loss and food waste have significant economic, social, and environmental consequences. According to the Food and Agriculture Organization (FAO), food loss and waste amounts to $940 billion in global annual economic losses. It contributes to hunger. And lost and wasted food consumes about one quarter of all water used by agriculture, requires cropland area the size of China, and generates about 8 percent of global greenhouse gas emissions (FAO, 2013).

In both developing and developed countries on average 35 percent of fresh produce is lost or wasted. For developed countries the major part of this loss originates at the consumer stage of the chain (23 percent), while the various stages in the post-harvest chain account for the remaining 11 percent. In developing countries this is the other way around: 21 percent of the produce loss occurs in the post-harvest chain and 12 percent at the consumer. The difference in FSC performance is correlated with the difference in the level of the post-harvest and supply chain technology. FSCs in developing countries are characterised by a rudimentary post-harvest infrastructure with simple technologies, traditional storages and poor integration with local markets. Developed countries have a high penetration rate of cold chain technology, integrated systems between growers and supply chains, servicing high-end markets with strict standards regarding food quality and food safety. It is likely that the lack of post-harvest infrastructure in many developing countries is a major element in the generation of food losses (Parfitt et al, 2010; BIO Intelligence Service, 2015).

Figure 1 Schematic development of FSCs in relation to post-harvest infrastructure



Source: Parfitt et al., 2010

Figure 1 shows the FSC development path from a technological perspective. Post-harvest infrastructure is considered part of the post-harvest management system. Post-harvest management (PHM) is here defined as the whole of processes and measures that contribute to the flow of agricultural products (crops) which have been harvested, or are suitable for harvesting. In other words, PHM is more than the upgrading and use of an adequate technological infrastructure. It concerns also a range of non-technological issues, such as specific FSC knowledge, skills, communication and also organisational, institutional, financial and procedural aspects related to FSCs (Van Gogh, 2016).

Post-harvest management provides an important contribution to the outcome of the process of repositioning of food systems from not only supplying food but also to providing high-quality diets for all. In order to pinpoint the impact of investing in PHM systems it is necessary to assess the effects of PHM on the societal indicators as food security, food safety, economic revenue, employment and climate footprint. The underlying purpose of this paper is to obtain a quick-analysis of the contributions of post-harvest management (PHM) to a sustainable food supply. The subtitle of this paper refers to the impact of post-harvest management in attaining economically and environmentally sustainable food chains. In the context of the topic of PHM the experts have interpreted 'impact' as PHM attaining effects on the five before mentioned themes.

The next section will provide an brief overview of what is meant by post-harvest management and of its relevance or meaning for current food supply chains. Where appropriate the content of this paper is further scoped and boundaries of the paper are specified.

1.2 What is post-harvest management and what is it relevance?

The post-harvest chain comprises the organisations that are responsible for the handling and storage of crops after harvest (growers), processing (industry) and distribution of vegetable and fruit products (middlemen, auctions, wholesalers, importers and exporters, retailers, street vendors, food services). Processes and measures in the post-harvest chain are directed towards meeting customer requirements and satisfying the requirements imposed by other stakeholders such as government (new rule and regulations such as the General Food Law) and the retail community (e.g. Global Food Safety Initiative) (Vorst & Snels, 2014. Post-harvest management refers to the organization and coordination of these processes and measures in order to achieve the targeted objectives.

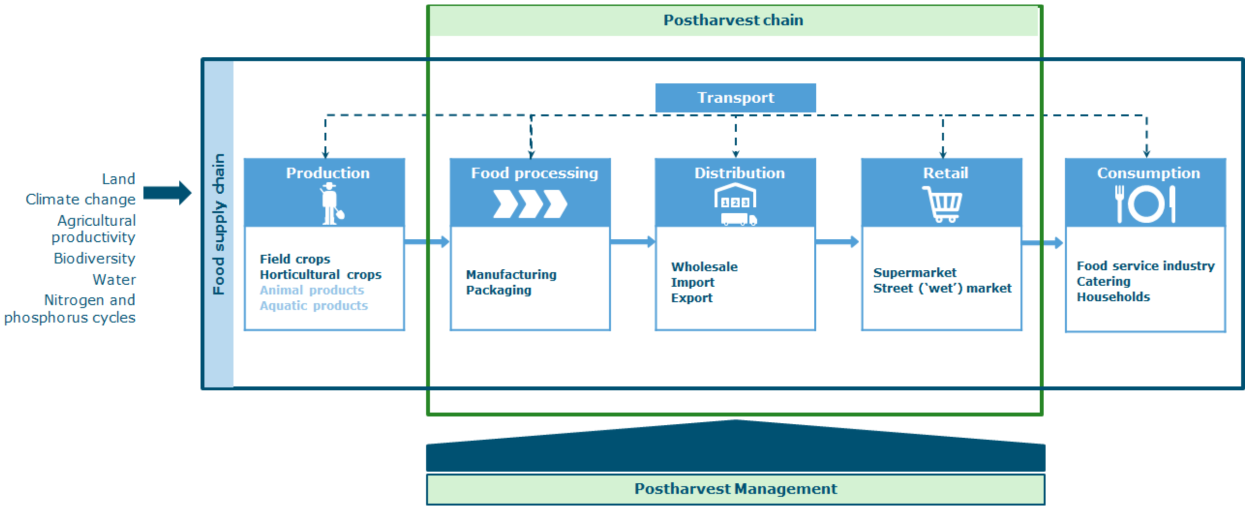
In this paper 'produce' refers to perishable crops (vegetables, fruits, roots and tubers) and other perishable food commodities (grains and pulses). Figure 2 shows a graphic display of the food supply chain from primary production to the consumption of food by households and out-of-home. The boundary of the post-harvest chain is indicated by the green frame. This frame encompasses all activities and above-

Definition post-harvest management

The postharvest chain comprises the interconnected activities from the time of harvest through crop processing, marketing, until the moment of sale to the consumer. Postharvest Management is the whole of processes and measures that contribute to the flow of agricultural products (crops) that have been harvested or are suitable for harvesting.

mentioned chain actors from harvest until the purchase of food by the consumer. This includes also the transport of product within the FSC.

Figure 2 Graphic display of the food supply chain, incl. the system bounday of the post-harvest chain



(based on Berti & Mulligan, 2015)

In Figure 2 also food categories from animal– and aquatic origin are displayed, but these product categories have not been taken into account in this paper (textbox). This does, however, not imply that animal and aquatic products do not have an impact on the performance and sustainability of the FSC. In fact the consumption of animal protein is expected to increase in the near future. Moreover, the production and consumption of protein at the beginning of this century has significant impacts on the environment (Forum for the Future, 2014). This will highly affect the design of food systems when an increasing number of people with a higher income will likely favour animal products.

Product scope

Animal-based products (meat-, dairy- and fish product) have not been taken into account in this paper for reasons of limiting the scope of the analysis. A similar value chain perspective on the impact of these products will require more elaborated research.

In recent years post-harvest management (PHM) has gained increased attention on a global scale from public and private parties as a solution for curbing post-harvest losses. This attention can be explained from the need and ambition to improve global food security. International campaigns and initiatives such as FAO's Save Food Initiative and Champions 12.3 coalition (a direct global spin-off from the 2015 conference No More Food Waste organised by the Dutch government), have successfully set an agenda to putting effort in the lowering of losses in the food supply chain. The definition of the UN Sustainable Development Goals (SDGs), and specifically SDG target 12.3, which seeks to halve per capita food waste and reduce food losses by 2030, has accelerated agenda setting efforts.

SDG 12 aims at building a more responsible and sustainable consumption and production system, “doing more and better with less”. SDG 12 is about promoting resource and energy efficiency, sustainable infrastructure, and providing access to basic services, green and decent jobs and a better quality of life for all. Its implementation helps to achieve overall development plans, reduce future economic, environmental and social costs, strengthen economic competitiveness and reduce poverty. It requires a systemic approach and cooperation among actors operating in the supply chain, from producer to final consumer. It involves engaging consumers through awareness-raising and education on sustainable consumption and lifestyles, providing consumers with adequate information through standards and labels and engaging in sustainable public procurement, among others. SDG12 gives an overarching context and perspective for scoping future PHM focus areas.

Also last year’s established EU Platform on Food Losses and Food Waste is exemplary for the increased political awareness of the vast volumes of food that are lost for human consumption, and of the negative effects of these losses and waste on (future) food supply and global warming. The Platform, as well as the Save Food Initiative and Champions 12.3 coalition also incorporates the need for mutual engagement of partners from public and private sector, as well from scientific communities in order to make steps towards decreasing food losses and food waste.

The attention for PHM is also fed by the increased understanding of the effects from post-harvest losses as a source of GHG emissions on climate change. In a fairly recent study FAO (2013) calculated the environmental footprint of food losses and waste for eight major food commodity groups in seven global regions. The study highlighted the magnitude of the environmental impact of the combined food losses and waste, allocated to the different stages in the supply chain, including the post-harvest chain. Investing in PHM measures could generate positive climate effects by lowering post-harvest losses, on the condition that these measures will not pose additional negative effects.

The relevance of post-harvest management is twofold. First of all, there is the existence of a considerable share of food losses in developing countries’ post-harvest chains. The term ‘post-harvest losses’ (PHL) refers to the losses between the harvest and the onward supply of produce to markets (the post-harvest chain) (Hodges, Buzby & Bennet, 2010; Buzby & Hyman, 2012). The volume of these PHL is subject to debate as empirically registered data on PHL are scarce. FAO studies on PHL currently form the main source of data, stating a staggering size of global post-harvest losses of 30 percent (and for some products even more). At this point we do not want to argue the existence of PHL although getting a better insight in the actual size of the problem within the context of a particular value chain (product- and country specific) should be considered priority for the design and

Data limitations in PHL calculations

Estimates of the size of PHL greatly vary. This is partly due to different definitions, but mostly because field data that empirically register PHL are scarce. FAO estimates that about 1,3 billion tons of food is globally wasted or lost each year, while PHL are also equivalent to 6-10 percent of human generated GHG emissions. Other studies on PHL by IFPRI and World Bank indicate considerable lower losses. The fact that data on PHL are debatable shows the need for a consistent methodology and practice for recording data on PHL in the value chain.

implementation of effective measures.

Secondly, post-harvest management creates the opportunity to elevate the performance of the entire FSC by investment in post-harvest added value activities. This is illustrated by the Dutch agro and food chains that have evolved from a supply-driven surplus producing sector into a demand-driven network of activities that are geared towards adding value and lowering of costs.

Traditionally the focus within FSCs lays on food, but in view of the political ambition to increase the efficient use of resources the valorisation of biomass, product side-streams are becoming increasingly important as well. The possibility to use post-harvest losses as a resource for the generation of electricity from biogas through anaerobic digestion can create opportunities for remote production areas with no access to a central power grid (Puri, 2016).

1.3 Basic characteristics of crop value chains

The value chain for food crops has a number of characteristics which relate to post-harvest management. The availability of specific technologies has had an effect on the design and development of crop value chains. The following paragraph highlights some of these characteristics.

Local climate, global markets - Food crop production starts where climate and growing conditions are most favourable. In past decades research and development in know-how and technical innovation have shaped the current horticultural landscape considerably. The application of agro-technologies in plant labs and soilless greenhouses, but also in open-air cultivations (such as inundation, drip irrigation, anti-frost sprinklers, anti-insect netting, mulch films etc.), have enabled growers to exercise control of the growing environment for producing high value horticultural crops. Other success factors are the availability of skilled (low cost) labour, of packing and storage facilities and the availability of a logistical infrastructure that enables connectivity between production locations and markets.

Growing global value chains – The sourcing for our daily food diet has increasingly become a global matter. Stimulated by the growing consumer demand for safe and preferably fresh products with a high nutritional value, worldwide trade of fruit and vegetables (F&V) has experienced an annual growth in trade volume of 4-5% in the period 2004-2014, resulting in a growth with more than 50% (F&V-Facts, 2015-2016). (Wealthy) consumers that desire year-round availability of fresh products and not only during a particular time of the year, have fuelled the international sourcing and trade of perishable and processed food, thereby creating a pallet of production areas that are seasonally complementary. It must, however, be realised that still more than 90% of all produced F&V is consumed locally (FAO estimation).

PHM as nursery of product quality?

Quality is made in the field and in the orchard. Improvement of the post-harvest chain therefore starts pre-harvest. Quality of fresh produce declines throughout the value chain. Post-harvest management and technologies slow down this process but will never yield an improved quality.

Quality is Value - An impo rtant feature of crop value chains is the challenge to maintain the value of quality throughout the chain. Plant products after harvest are still alive and therefore plant tissue breakdown (senescence), dehydration and ripening (and quality decay) starts immediately after a product is separated from its rooting system. This is an irreversible process. At higher temperatures products need more energy to survive, hence the deterioration occurs much faster, and so the quality decay is very fast. Other aspects that determine deterioration speed negatively is rough handling and/or the infection of products with pests or other diseases. To tempt consumers with good quality products with a long shelf life, current supply chains bring in a range of technologies to maintain quality of the products. This may be disinfection treatments, precooling systems, protective packaging, refrigeration and controlled atmosphere storage. Decay, senescence and ripening processes can be slowed down by the available technologies. Due to this typical characteristic of none processed (perishable) food products, supply chains are forced to permanently monitor the quality and the decay during storage and distribution in order to prevent post-harvest losses and unnecessary distribution costs. The monitoring of quality in the different stages of (fresh) food chains is therefore important.

Cold chain – The cold chain is the uninterrupted temperature controlled transport and storage system of perishable goods between producers and consumers. For this an array of technologies is available (e.g. precooling, refrigeration, air conditioning) which to a different degree can slow down the process of quality decay. The significance of product cooling and of having a cold chain in place from harvest until inside the consumer's home is paramount. Most crops grown in parts of the world with a temperate climate must be stored at 0°C to maintain quality. The optimal storage temperature for crops grown in (sub)tropical zones is considerably higher: 12°C. At any temperature lower than the optimal storage temperature the product will be damaged (chilling injury), while at temperatures higher than optimal temperature product decay will be accelerated. Vital links in an effective cold chain are cooling and storage at production sites, refrigerated transport and implementation in retail outlets (IRR, 2009). It must be realised that there is no perishable (plant based) product that can be fully stabilized by supply chain measures.

Impact of cold chain on food loss reduction

The calculation of benefits from cold chain technology (improved product quality, food safety and revenues from increased sales) would provide supporting information for the substantiating of investments in cold chain solutions. According to the international refrigeration industry a lack of cold chain technology accounts for 20% of the global losses of perishable food in the postharvest chain (for developing economies 23%) (IRR, 2009). A British scientific study states that even more than 50% of global food loss and waste consists of commodities that can benefit from refrigeration (Winkworth-Smith, 2015). Despite these numbers, determining the actual measured effect of refrigeration on the reduction of food losses, however, is hampered by a lack of data. Alternative data that could back-up these percentages are not available, as a result of which the little data that are available are recirculated in different publications. Research into the impact of specific refrigeration technologies on food loss reduction would provide valuable insights in the economic and environmental trade off.

Other post-harvest technologies – Improved prolongation of the post-harvest life of some F&V can be achieved by changing the atmospheric conditions around the product. This technology is available in various systems: CA (controlled atmosphere), ULO (ultra-low oxygen), DCA (dynamic controlled atmosphere) and MAP (modified atmosphere packaging). It is sometimes postulated that this technology might replace refrigeration: this is incorrect. Whereas these technologies contribute to maintaining product quality, they all require having a perfect temperature management system in place. Hence the priority of having a closed cold chain first before investing in these additional (and cost adding) measures. Another available post-harvest technology is the use of a gaseous ripening blocker. The agent 1-mcp (Smartfresh™) is capable in blocking ripening processes in sensitive (climacteric) products like apples, pears, plums, avocado's, kiwis, stone fruits, bananas and others for a relatively long time.

For many products, transformation and processing can be a way to reduce post-harvest losses and increase shelf life. Most developing countries, however, lack adequate processing facilities and are therefore unable to process large volumes of agricultural produce. This situation is aggravated by the seasonality of many perishable products.

Post-harvest management is strongly interlinked with pre-harvest aspects and with market circumstances. A more holistic approach towards post-harvest solutions is therefore needed, addressing not only the hardware, but also the software and orgware aspects (Van Gogh, 2013). An example of this is the Kenyan potato sector. Potato is expected to become the most important crop in Kenya, because demand is rising, both for fresh consumption as for processing (crisps). The price elasticity is relatively high and introducing effective potato storage can realize high economic returns, enabling the selling during low-season (low supply, high demand) periods. The current local potato varieties used, however, have limited storage potential, and to meet the growing high end markets, specific varieties should be grown. Also, the set-up of an organisation within the supply chain through which smallholder farmers are connected to adequate potato storage facilities requires a different business and operational model.

Strengthening of supply chain networks

One of the observations in a study on post-harvest losses in the potato sector in Kenya was that the inefficiencies in the current marketing system (fragmentation in the value chain, lack of market transparency, dominance of small brokers, high transaction costs, the little co-operation between value chain agents) combined with poor storage facilities, is one of the causes of product losses. A staggering figure of 65% of the harvested potatoes is recorded as damaged or lost. (Waudo & Schripsema, 2015). Investing in postharvest solutions will, in other words, require an approach that will include also the 'soft' side of PHM, i.e. the organisation of sectors and markets.

1.4 Contribution of post-harvest management in the value chain

In the debate on food losses the promotion of post-harvest management technologies and locally adaptive technologies are often mentioned as one of the recommendations for addressing post-harvest losses in developing economies (FAO, 2016). Supporting post-harvest management as a solution-based approach for reducing post-harvest losses in developing economies is one thing. Building a successful business case for investment in specific post-harvest measures is something different, in particular when investment in post-harvest loss reducing measures in one part of the chain may yield revenues in a different part. This may give little incentive for individual stakeholders to engage into this type of investment.

To illustrate the potential impact of investing in post-harvest measures one should calculate the potential revenues by assessing the value that is added in the post-harvest chain. Unfortunately, data that illustrate the distribution of value over the different activities in the supply chain are scarce. This makes it difficult to determine what the share or contribution (in terms of share of value in the supply chain) of post-harvest management measures in the total value chain is. When considering investments in specific post-harvest measures it will, however, be necessary to gain insight into the distribution of the added value within a specific chain in order to make an assessment of a fair distribution of the investment costs. This is particularly important in many countries in Asia and Africa where chain actors add costs, but not necessarily value. Ultimately, this creates a value chain model in which the price does not reflect added value but rather costs and scarcity.

Market inefficiencies

Inefficiencies along the entire chain result in high consumer prices. Marketing systems in developing countries are often complex and fragmented with multiple layers of middlemen that broker horticultural transactions. In the case of India this is almost 90% of the transactions in which middlemen take a commission in the range of 2,5-6%. This can lead to a cost inflation of over 250%. (Winkworth-Smith, 2015)

A study by Verhoog in 2015 gives an overview for the Dutch agro complex of the added value per chain activity (primary production, processing industry, supplying industry and distribution) and the share of GDP during three consecutive years. This gives us an indication of the relevance or importance of the post-harvest chain in terms of added value and revenues created. Table 1 shows the value that is added to agricultural products that have been produced and harvested in the Netherlands, but does not include the products that were imported for further processing and distribution. One can therefore assume that the added value by processing and distribution will be higher when also the added value of the foreign flow of products is taken into account.

Table 1 – Added value of the Dutch total agro complex in billion euros (2010-2012)

Agrifood sector activities	**2010**	**2011**	**2012**
Total agro complex, domestic+imported agricultural production flows	43,7	44,1	45,6
Agro complex, imported agricultural production flows	15,0	15,2	15,3
Agro complex, <u>domestic</u> agricultural production flows	28,6	28,9	30,4
Of which:			
• Primary production	9,6	8,7	9,3
• Processing industries	3,8	4,1	4,6
• Supplying industries	12,0	12,2	12,5
• Agrologistics	3,2	3,9	4,0

Source: D. Verhoog, 2015

One conclusion from the data in the table is that while the total value of the agricultural value chain increased in the consecutive years 2010, 2011 and 2012, the share of the processes and measures that we have defined as post-harvest management has increased (from 24,5% in 2010 to 28,3% in 2012) while the share of primary production in the value chain decreased from 33,6% to 30,6%.

In an older study on the Dutch agro complex in an earlier timeframe (1995-2008) this is even more obvious (see table 2). Here the data, that also included the agricultural flow of products from abroad, show a significant growth of the entire agro complex with more than 55%. This growth is mainly attributed to the activities in processing industries and agrologistics. This illustrates the potentially beneficial effects from investment in the post-harvest chain.

Table 2 – Added value of the Dutch total agro complex in billion euros (1995-2008)

Agrifood sector activities	1995	2003	2008
Total agro complex, domestic+imported agricultural production flows	32,3	41,4	50,5
Of which:			
• Primary production	9,4	9,3	9,3
• Processing industries	8,6	10,9	13,5
• Supplying industries	8,8	12,4	15,6
• Agrologistics	5,5	8,7	12,0

Source: Agricultural Economic Reports, Wageningen Economic Research

In a study by WUR on post-harvest losses in developing economies a wide variation of causes for these losses were reviewed and categorized as follows (Van Gogh, 2013):

Cold chain – lack of cold chain infrastructure from producer until consumer (incl. storages, transport, refrigeration equipment);

Post-harvest handling - absence of knowledge and equipment, and poor methods for sorting and grading of product; poor pre- and post-harvest crop protection;

Packaging – inadequate packaging of product in storage and during transport;

Infrastructure & connectivity - poor quality of roads and of public utilities (water, energy) hampering the movement and storage of food;

Market – poorly functioning marketing systems with a lack of information on market supply/demand and prices; fragmented market structure creating market inefficiencies;

Processing capacity - lack of adequate facilities for processing of second and third quality produce;

Quality standards – poor product quality, but also a lack of knowledge (understanding) of food safety standards, product quality and quality monitoring;

Education / R&D – workers in post-harvest chains lack skills and training to operate technology in accordance with post-harvest (quality) protocols; lack of R&D facilities for local post-harvest research; poor extension and information services;

Investment capacity – absence of (affordable) capital for investment in PHM measures.

1.5 Approach and structure of this paper

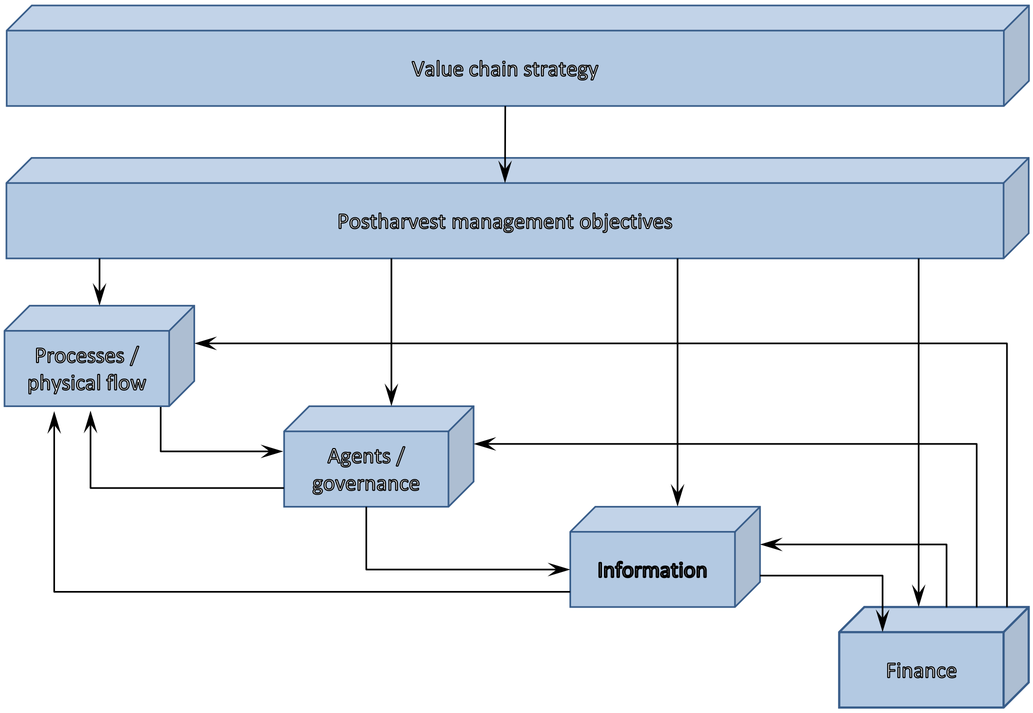
In the chapters following this introduction the researchers will pinpoint the relation between PHM and five societal themes. These themes have been selected for having a direct link with PHM and the post-harvest chain (Figure 3): food security (chapter 2), food safety (chapter 3), economic revenues (chapter 4), employment (chapter 5) and climate footprint (chapter 6). The purpose of these chapters is to present a value chain perspective on the effects of post-harvest management in attaining economically and environmentally sustainable food chains.

Figure 3 Graphic display of interaction between post-harvest management and the 5 societal themes.

In order to structure the content and outcome of the analysis in these chapters a value chain strategy model was developed and applied. In this model post-harvest management is addressed as a strategy for safeguarding product quality and reducing post-harvest losses throughout the value chain. Specific post-harvest management objectives may relate to specific strategies, e.g. increased food security, improved food safety, higher economic revenues, etc.. The relation and effects of PHM on the mentioned themes are then described by addressing PHM measures in relation to 1) the physical processes, 2) chain agents, 3) information flows and 4) financing. The model is based on the assumption that all elements have a specific correlation with PHM, and as such have an effect on the performance of the value chain. In Figure 4 the coherence between the elements in the model is graphically illustrated. A following step in this approach (which is not part of this paper) would be to identify performance indicators that will measure the performance of PHM measures and their effect on the specific PHM objectives.

The effects of PHM will be qualified and where appropriate and possible quantified as well. Regarding the latter, however, a large restriction has to be made, as data on post-harvest losses (or rather the lack of) form a major impeding factor in the evaluation of the effectiveness and profitability of post-harvest measures (as mentioned earlier in this chapter). In chapter 7, finally, a number of observations and conclusions will be made, specifically addressed to the reader as challenges for policies.

Figure 4 Post-harvest management assessment model



(inspired by ‘‘the integrated logistical concept model’ by Van Goor et al., 1996)

2 Food security

Value chain strategy

Food security is defined as the availability of and access to sufficient, safe and nutritious food for all people at all times to maintain a healthy and active life. It combines the elements of food availability (consistent supply), food access (purchasing power) and food utilization (storage and preparation). PHM influences in principle all three dimensions, but most importantly it modifies the consistency and predictability of food supplies and the nutrient composition and diet quality in food consumption. After all, this consistency and predictability is augmented when methods and technologies that preserve the quality of crops after harvesting are applied. Many preserving technologies can be applied to perishable foods (e.g. drying, salting, heating, irradiation, high pressure processing, pulsed electric fields, chilling and freezing) but also packaging (large/small, containerised, aseptic, etc.) is to be considered as a method for preserving nutritional quality and safety of a food product. Refrigeration combines the ability to extend product shelf life without altering its initial physical, chemical, nutritional and sensory properties (Fellows, 2009).

Relation PHM and food security

PHM can contribute to improved food and nutrition security through three different pathways: (1) increasing the availability of food at farm-gate and market level, (2) reducing the price of food and thus enhancing potential access, and (3) reducing the volatility of and the quality of food availability. PHM thus requires a careful combination of technical tools and behavioural incentives that stimulate agri-food chain stakeholders to invest in tools and supply chain networks while reaping the fruits of these investments. Many PHM investments are usually made at midstream value chain level at relatively high logistical costs, while large gains can also be reached through simple, small and affordable investments in PHM interventions at upstream farm level (drying, handling).

In addition to the PHM impacts for food security, it is considered increasingly important to assess possible effects on human nutrition. This refers to opportunities for improving food quality, diet diversity and food safety through better PHM. In this respect, promotion of food standards and strategies for supporting food integrity (high freshness and low additives) are most relevant. Nutrient-sensitive value chains focus on maintenance of vitamin contents and micronutrient availability in fresh food, mostly related to temperature management after harvest and storage duration. Improved trust and reliability in agri-food value chains and networks is considered as a key aspect for enhancing quality compliance (Fafchamps, 2004).

Processes / physical flow

Food security is critically dependent on dovetailing of supply chain process management and value chain network organization. Large improvements can be reached at relatively low costs by promoting better interaction between value chain agents and through the reduction of information failures that are responsible for long delays, excessive lead times and reduced shelf life. Improving simultaneously the physical, institutional and economic network architecture provides opportunities for reducing transaction costs and risks in supply chains and to enhance trust between value chain partners.

Agents / governance

Supply chain performance can be greatly enhanced when partners are better informed about expected physical flows and their quality characteristics. Food web approaches are useful to identify bottlenecks and to design focussed activities for better articulating food system governance (WRR, 2014). A first approach for reducing uncertainties and risks related to PHM refer to further engagement in contractual exchange (e.g. verbal or written mutual commitments regarding the delivery and purchase of specified commodities). Price uncertainties and spot exchange can be held responsible for a major share of post-harvest losses. A second strategy for improved PHM relies on grades and standards that provide incentives for producers and traders to engage in quality upgrading (Swinnen, 2007). Voluntary and private (B2B) standards enable an objective assessment of the 'fairness' and ''sustainability' of supply chain deliveries and offer prospects for enforcing quality upgrading (Ruben, 2017).

Information

ICT as intervention measure in the post-harvest chain will play a key role in creating food security in future scenarios. ICT has a particularly important role to play in improving communication (e.g. exchange of supply/demand information) between different parts of the supply chain. The use of big data obtained in the different stages of the supply chain, drones and other innovative digital technologies will improve the efficiencies of the overall food system – from production through to reduction of losses in supply chains and on the consumer's table (Berti & Mulligan, 2015). ICT systems are particularly used to reduce payment delays and non-payment uncertainties (e.g. through instant mobile phone payments) and can support the information on risks for quality degradation throughout the supply chain (e.g. through temperature and humidity sensor systems). Future digital compliance platforms (blockchain) will increasingly rely on the availability and quality of (scientifically) verified data.

Finance

Financial services, in particular harvest insurance, play a key role in reducing uncertainties for agents in the food supply chain. Weather index-based insurance services tend to enhance input use (improved seeds, fertilizers, pesticides) and provide incentives for careful crop management. In a similar vein, insurance against damages during transport and storage are helpful for reducing theft and handling losses. Useful systems for increasing value chain transparency and optimizing reliability make use of warehouse receipts and vouchers (invoice receipt financing) that satisfy short-term capital needs and contribute to more stable (and predictable) commodity flows.

3 Food safety

Value chain strategy

In the EU food is deemed to be unsafe if the food is injurious to the health of consumers or unfit for human consumption. Unfit foods include among others contaminated, deteriorated and decayed foods. To determine whether a food is injurious, not only acute, long term and cumulative adverse effects should be taken into account but also effects on offspring and more sensitive parts of the consumer populations. (General Food Law, Reg. (EC) 178/2002). In order to protect the health of consumers most countries have a system of legal requirements for the production of food. Part of this system are food safety standards, like maximum levels of contaminants and pathogenic micro-organisms in foods. Food business operators (FBOs) should comply with these legal requirements.

Product standardisation (1)

A result of the increased global sourcing and trade in food products is that the product quality specifications and requirements originating from the buyer-markets have set the conditions for producers that supply to these markets. Exporting Food Business Operators (FBOs) need to adjust their production process to comply with their trading partners' standards. Non-complying food is a source of food losses (out-grading). Not only food safety standards play a role here. As part of the harmonisation of the internal market EU regulation 1234/2007 describes general trade standards for a number of agricultural products, including fruit and vegetables. Apart from describing generic minimum quality requirements, also trade norms are set for specific products that apply to the products' size, shape and appearance (EU regulation 543/2011).

Suppliers of product for the European market are sometimes confronted with severe and strict quality standards. Non-EU countries that do export to the EU-market select top-quality produce only, leaving lower quality products for the domestic markets. The advantage of this is that in the medium or longer term domestic markets benefit from this as the overall quality of product ultimately will improve. The downside of this is that a product with a quality that does not meet the strict EU-standards, may also be the produce that is unfit for human consumption, because for example these will contain too high levels of residues from crop protection chemicals or contain mycotoxins.

Official control systems are in place in most countries to enforce compliance with legal requirements. Material checks are part of this control, with rules for sampling and analysis. For free trade in food products it is essential to harmonise legal food standards and official control systems. In the EU for instance the active substances allowed to be used and maximum residue levels (MRLs) for residues of plant protection products are set at the EU level, as are requirements for the sampling and analysis for detecting these MRLs. A system of EU and national reference laboratories ensures analyses being performed in a harmonised way.

Worldwide harmonisation of food safety standards is strived for within Codex. Implementation of Codex standards and guidelines for national law should ensure this. Food not complying with these food safety standards is not allowed to be marketed in most parts of the world.

Relation PHM and food safety

'Assuring food safety and quality is an indispensable element of food loss reduction. Food safety is the most critical dimension of food quality. If the quality has deteriorated to a level that the food is no longer safe for human health, the food needs to be removed from the FSC, resulting in quantitative food loss' (Bin Liu, 2016). For traded foods non-harmonised food safety standards are barriers for free trade. Each year for instance food products are rejected at the EU borders due to presence of residues of pesticides in concentrations higher than EU MRLs. Even prior to shipment to countries with stricter food standards than the exporting country, these differences can lead to losses, for example if these non-compliant foods are dumped on an already sufficiently provided local market.

The effectiveness of food safety control can vary from one geographical area to another and also depends on the selected value chain, infrastructure and national capacity, none of which should be overlooked when identifying the causes of food loss (Bin Liu, 2016).

Product standardisation (2)

In addition to public trade standards private sector companies in the food chain, like large retailers maintain their own quality standards (e.g. the BRC Global Standards, IFS). Some of these standards have the objective to improve food quality and food safety although other private standards, often referred to as cosmetic quality standards, apply only to the product's appearance, colour, shape and size. A recent study among fruit and vegetable growers in Belgium has shown that 66 percent of the investigated fruit and vegetable growers cannot sell part of their harvested crop due to non-compliance with the specified cosmetic standards. The volume of these rejected products varies per crop and per grower but was calculated at an average of over 10 percent (Gellynck et al., 2017). Standards that apply to sustainability in production and corporate social responsibility (license to produce) are becoming increasingly important for FBOs to adhere to as well.

Processes / physical flow

Quality and safety of food products immediately after harvest depend on inputs in the pre-harvest period like the quality of seed, soil, water, fertilizers, and plant protection products used. In order to prevent loss of food due to improper handling or storing, the use of Good Agricultural Practices and Good Manufacturing Practices are sometimes made mandatory by legislation.

As mentioned global sourcing and trade of fruit and vegetables has grown tremendously in the past decades. Globalization of food production and trade has increased the potential likelihood of international incidents involving contamination of food. The assurance of food safety in pre- and post-harvest management concerns:

- prevention of microbial contamination of fresh produce;
- use of good agricultural and management practices (incl. the use of crop chemicals);
- minimize microbial food safety hazards in fresh produce;
- assurance of the use of potable water in all fresh produce operations;
- proper management of the use of animal manure in order to minimize the potential for microbial contamination of fresh produce;
- worker hygiene and sanitation practices during production, harvesting, sorting, packaging and transportation; and

- research on how various post-harvest handling treatments influence the survival of human pathogens on fresh produce.

Shortening supply chains could also be a way to prevent PHL, processing products after harvest in the vicinity of production may reduce losses that otherwise occur due to improper storage and poor transport conditions.

Agents / governance

Business operators (producers, processors and retailers) that produce for the market are aiming at maximising profit; decisions made by the operators sometimes have as a consequence the generation of post-harvest losses, for example, when off-standard food products are not marketed but used for biorefinery or soil improvement. Legal and processor/retail quality standards also result in food not fulfilling these standards being wasted. The same is true for very strict legal safety standards. Furthermore legal labelling requirements like for best-before-dates sometimes result in processors and consumers throwing away food still perfectly edible and safe.

National policies that will address food losses in post-harvest chains will need to have local governance and institutions in place. These institutions will need to be adequately equipped to minimise food safety risk as a result of contaminated food products. Unfortunately many developing countries lack an adequately functioning food safety control mechanism. Exemplary are the local, informal markets (also referred to as street- or wet markets) in many developing countries. While a majority of the food consumed passes through these informal market channels (more than 80%), these markets are infamous for their poor hygiene and food safety standards. At the same time, these informal markets have a major role in food security (Roesel & Grace, 2015). Addressing food safety standards and applying proper regulation in these channels forms a particular, but necessary challenge to decrease food-borne illnesses.

Building a reliable and effective control system will therefore require investments at different levels and by different stakeholders (national control bodies, test laboratories, etc.). When investing in control bodies that will premise food safety, this may generate short term adverse effects as these re-adjustments may lead to an increase of PHL and declining prices. It is important to take these adverse effects into account as lead costs for investing in a healthy sector.

World wide differences in legal requirements for food safety may result in post-harvest losses. It is therefore imperative to strive even harder for international harmonisation.

Information

For exporting Food Business Operators (FBOs) it is not easy to fulfil all legal requirements of importing countries. Each country or group of countries has its own legislation, only in its own language sometimes, with its own idiosyncrasies. Information on legal requirements should be easy to find and understand. For instance what active substances are allowed on the EU market in plant protection products, and the MRLs for residues are easy to find in the EU pesticide database. For contaminants on the other hand, member states of the EU are still allowed to have national maximum levels (MLs) for contaminants with no EU MLs.

Finance

A level playing field for FBOs on the world market should include the same level and costs of official controls. In some countries FBOs pay a fee, in other countries control is paid out of public finances.

4 Economic revenue

Value chain strategy

Economic revenues of improved PHM refer to both *efficiency* (positive benefit-cost ratio) and to *effectiveness* (incentives for supply chain stakeholders to engage in PHM activities). For large-scale adoption of improved PHM practices, efficiency is a minimum and necessary condition, but not a sufficient condition; effectiveness is required to guarantee continuous engagement in PHM at market conditions.

Relation PHM and economic revenue

The economic appraisal of PHM strategies is based on net income effects for value chain partners due to reduced losses (= input cost reduction) and/or improved quality performance (= higher output price). Several financial optimization options are available: price differentiation along standard segments, premium pricing, etc.

The adoption of PHM practices critically depends on the type of market outlet(s). Sales of top and premium quality produce at the international markets is usually accompanied by sales of secondary class product at lower prices at the local market (e.g. tropical fruits). For several commodities, these market segments are closely interlinked and thus PHM incentives tend to decrease.

Effective PHM also will increase total market supply and thus eventually leads to lower farm-gate prices. This perverse effect for producers remains unless externalities are duly priced. On the other hand, effective PHM will safeguard product quality and increased availability of nutritious fruit and vegetables products may stimulate consumption of these products in local markets and so induce an upward shift in market demand.

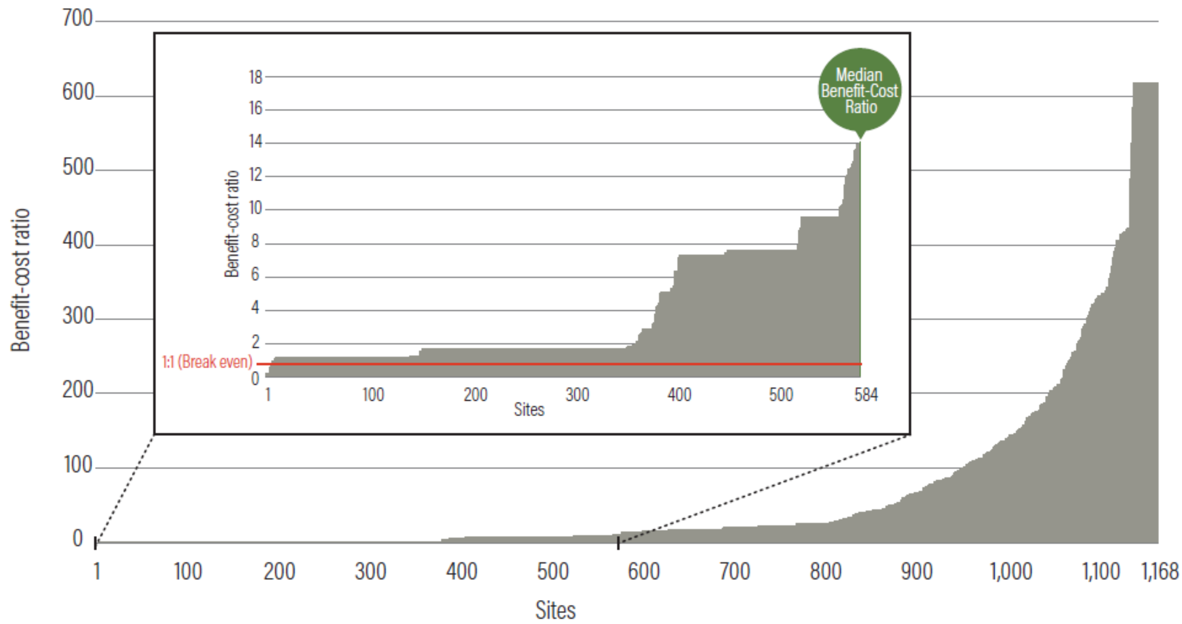
A recent report by a working group associated with the Champions 12.3 coalition addressed the issue that investment in interventions avoiding food loss and waste (FLW) may yield financial benefits, outweighing the costs (Hanson, 2017). The argument of this working group is that reducing FLW can generate ‘a triple win’: for the economy, for food security and for the environment. Benefits are the financial gains from reducing FLW, including optimising food or raw material purchases, lowering waste collection and management costs, reducing disposal fees, adding revenues from higher value food sales, etc. The study includes the results from a study of financial cost and benefit data for FLW reduction efforts of 700 companies in 17 countries (Australia, Belgium, China, France, Indonesia, Ireland, Italy, The Netherlands, Norway, Pakistan, Philippines, Poland, Singapore, Thailand, United Kingdom, United States, and Vietnam). More than 98 percent of the sites had a net positive financial return; that is, a benefit-cost ratio greater than 1:1. The median benefit-cost

Champions 12.3 Business Case for reducing FLW

The Champions 12.3 Coalition has recently compiled a case history of examples for successful actions to reduce food loss and waste (FLW). Through piling a compendium of successful cases from the UK the coalition strives after fuelling initiatives on different levels (country-, city-, company-) to make steps in taking action.

ratio—where half of the sites achieved a higher ratio while half achieved a lower ratio—was 14:1 (Figure 5). Thus, for every $1 invested in FLW reduction, the median company site realized a $14 return. Expressed in terms of return on investment (ROI) this is a 1,300 percent return on investment. Such a high return indicates that there can be a strong financial business case for companies to pursue efforts to reduce FLW. Whether these benefits will apply also as incentives for businesses in developing economies is yet to be substantiated. In developing economies costs of externalities such as waste and waste disposal are minimal or absent and thus create little benefits in terms of cost reduction.

Figure 5 Financial benefit-cost ratios of food loss and waste reduction efforts for company sites



Source : Hanson & Mitchel, 2017

Processes / physical flow

Most investments for improving PHM can yield positive net revenue streams and permit an average payback within 5-7 years. An average internal rate of return (IRR) of 16-18% is reported for PHM in vegetables systems in South-East Asia (Acedo & Weinberger, 2009). The post-harvest program impact assessment in Central America of maize farmers using metal silos indicated that farmers receive a higher price ($32.44/100 kg) while non-silo users received an average of $27.78/100. Generally, metal silo users gained 23 percent more than non-users, the benefit-cost-ratio (BCR) was 2.6 and the IRR 22 percent (Fisher et al., 2011).

Agents / governance

The most important mechanisms for enhancing effective governance of PHM are price transparency (certainty on expected forward prices) and insurance (harvest insurance against crop losses and storage/transport insurance for unexpected quality degradation). Insurance systems are still scarcely used for promoting PHM, but become promising once external procedures for grading and quality control are in place. Moreover, legal procedures for appeal procedures should count on trust, be accessible and reliability for all supply chain gains.

Information

Emerging possibilities for relying on E-governance and mobile phone applications make information on PHL readily available to other supply chain stakeholders, and enable early assessment of risks and responsibilities. Moreover, access to market information (prices, quality) enables producers and traders to better planning of production and trade volumes. Mobile access to phytosanitary information enables early implementation of prevention activities, thus reducing PHL incidence.

Finance

The financial 'flow of funds' related to different PHM strategies includes mainly downstream investments for reaching upstream revenues. This implies that due attention needs to be given to intra supply chain financial streams that enable co-funding of upstream investments (storage, processing) by downstream parties (wholesale, retail). Usually, these interlinkages are reinforced through long-term delivery contracts (including pre-finance facilities).

5 Employment

Value chain strategy

Engagement of farmers and other supply chain agents into loss-reducing activities might be either capital- or labour-intensive. The net employment effects finally depend both on the selected *technology* for PHM (i.e. drying, storage, cooling, transport, etc.) and on the *organization* of PHM activities (i.e. more or less harvesting rounds, reliance on grading, etc.). Integrated contractual procedures for better linking supply chain agents (through ICT, finance and insurance, contracts) provide interesting opportunities for enabling stakeholder engagement into PHL reduction activities. Key incentives for enforcing PHL reduction are reducing transaction costs and risk.

Relation PHM and employment

PHM may be quite demanding in terms of investments, labour use and management capacities. The simultaneous management of multiple side streams and the coordination of stakeholders throughout the supply chain are rather knowledge-intensive activities. They demand more qualified labour and investments in workforce training and upgrading. Whereas total employment might decrease, gross wage labour costs for PHM could increase.

Processes / physical flow

Much is known about the technical opportunities for reducing PHL through different farm- and supply chain-level (FAO, 2014). Whereas material flow models are widely available, information on labour intensity of different PHL strategies remains scarce. Core activities are usually performed better by labourers that are more committed to the firm.
PHL in tubers and horticulture crops can be reduced if crops are grown in mounds or raised beds, that also enables mechanical harvesting at lower labour costs. Labour requirements for cereals processing can be high and tend to be biased towards the use of (unpaid) female family workers. Packaging is considered a labour-intensive PHM strategy (and adequate packaging tends to reduce labour costs in transport), whereas heating, chilling or freezing are more capital-intensive approaches. In a similar vein, grading and selection can be done in a labour-intensive manner, although mechanization is relatively easy.

Agents / governance

Effective PHM requires supply chain governance based on transparency (with respect to quality and safety) and equitable rewards for stakeholders involved. The organization of (public/private) extension services, the forms of contracting (delivery contracts) and the payments regime (cash/kind, direct/delayed) strongly influence transaction costs. Standards and certification are increasingly used as incentives to support PHL managements.

Information

ICT applications for tracking and tracing of maturity and product quality are becoming more widely available, based on sensor-techniques and satellite linkages. This undoubtedly increases transparency and reduces labour use in PHM.

Finance

Different approaches can be applied for enhancing the adoption of appropriate PHL management strategies, based on a structure of incentives that is aligned with the objectives of farmers and supply chain partners. Advanced payments (pre-finance), insurance and well-defined delivery contracts are considered instrumental for effective loss reduction. Warehouse receipts and other post-harvest collaterised transactions tend to reduce risk and thus provide incentives for investment in quality management.

6 Climate footprint

Value chain strategy

The term 'climate footprint' refers to the extension of the concept 'carbon footprint' as a measure for calculating the emissions of greenhouse gases. Carbon footprint is defined here as a measure of the impact of our activities on the environment, in particular climate change (Wright et al., 2011). Climate footprint refers to a more comprehensive greenhouse gas indicator, that includes all gases with a greenhouse warming potential (i.e. GHGs that are not only based on carbon) (Wiedmann and Minx, 2008). In research on climate change the concept carbon footprint is more commonly used. Despite the differences in definition between 'carbon footprint' and 'climate footprint', the terms are alternately used in this paper as a reference to describe the effects of PHM on global warming and climate change in particular.

Besides GHGs contributed by the use of energy in the supply chain processes, other indicators of climate footprint that are to be considered are water usage, and the use of land and phosphate. Also the (re)use of residue streams that arise in the processes can be a factor of decreasing the climate footprint when opportunities for their reuse as resources in other products will be realised.

In order to understand the effects of PHM on the environment and climate change in particular, it is necessary to determine what the specific link between PHM and climate footprint is. In this paper the focus is on the contribution of PHM to the reduction of food losses in the postharvest chain, and as such to the establishing of a sustainable food system. According to a report by the HLPE (High level panel of Experts) of CFS (Committee on World Food Security) published in 2014, "food losses and waste (FLW) impact the sustainability of food systems in three dimensions: economic, social and environmental. They induce economic losses and reduce return on investments. They impede development and hinder social progress. They have an important impact on the environment both from the superfluous use of resources used to produce the food lost and wasted, and from the local and global environmental impacts of putting food waste at disposal in landfills, including the emissions of methane, a potent greenhouse gas" (HLPE, 2014). In other words, by investing in FLW reducing measures throughout the supply chain, resources can be used more efficiently and effectively, while GHG emissions from landfills will be decreased. According to the HLPE reduction of FLW should therefore be systematically considered and assessed as a potential means to improve agricultural and food systems efficiency and sustainability towards improved food security and nutrition. Direct and indirect causes of FLW in a given system should be analysed to identify hotspots where it would be most efficient to act (HLPE, 2014).

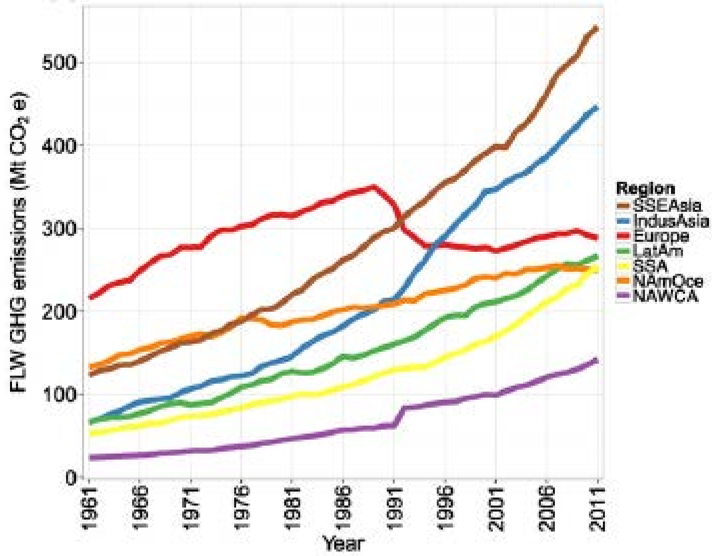
Relation PHM and climate footprint

Climate footprint: greenhouse gas emission

The magnitude of the GHG emissions from FLW was researched by the FAO in 2013 and enforced by the statement that "if food loss and waste were its own country, it would be the world's third largest emitter – surpassed only by China and the United States". Determining the effects of PHM on climate footprint involves on the one hand the anticipated positive effects from reduced food losses (and decreased GHG emissions) when PHM is effective and contributes to improved food availability and accessibility. On the other hand negative effects (i.e. increased GHG emissions) will be experienced from the increased use of energy, such as for the cooling of products. In addition refrigeration will also lead to an increased use (emitting) of refrigerants (BIO-IS, 2015).

In a study by Porter et al. (2016) based on FAO data, the GHG emissions from FLW in the global food supply chain over the period 1961-2011 were detailed for the relative contribution of FLW-related GHG emissions by commodity and by region. According to the study global annual production-phase GHG emissions associated with FLW more than tripled between 1961 and 2011 (from 680Mt to 2,2Gt CO_2-eq.). Figure 6 shows the development of these GHG emissions by region with a sharp increase for the regions in Asia. The relative importance of regions to FLW, and with that the related GHG emissions, has changed. Overall the largest increase in FLW-associated GHG emissions were from developing economies (75%), specifically China and Latin America – primarily from increasing losses in fruit and vegetables. In these countries more food was lost upstream than downstream in the supply chain.

Figure 6 Annual production-phase FLW-associated GHG emissions by region



Source: Porter et al., 2016

SSEAsia = South & South-East Asia; IndusAsia = Industrialised Asia; LatAm = Latin America; SSA = Sub-Saharan Africa; NAmOce = North America & Oceania; NAWCA = North Africa, West & Central Asia

The conclusion from the study by Porter et al. is that without interventions to reduce inefficiencies in the food supply chain the trend for developing countries to produce increasing proportions of global FLW and its associated GHG emissions is likely to continue. Given the fact that most food losses are incurred upstream in the supply chain (post-harvest), food loss reduction measures should be focussed on interventions that will have an effect in this part of the supply chain.

Climate footprint: use of land and water

Another climate footprint parameter is the blue water footprint. Globally, the blue water footprint of FLW – the consumption of surface and groundwater resources – is about 250 km^3, which is equivalent to the annual water withdrawal of 500 million people. Finally, produced but uneaten food occupies almost 1.4 billion hectares of land, representing close to 30 percent of the world's agricultural land area. While it is difficult to estimate its impact on biodiversity at global level, food wastage unduly compounds the negative impact that mono-cropping and agriculture expansion into wild areas have on loss of biodiversity, including mammals, birds, fish and amphibians. The direct economic cost of wastage of agricultural food products (excluding fish and seafood), based on producer prices only, is about USD 750 billion, equivalent to the GDP of Switzerland (FAO 2013).

Processes / physical flow

There are numerous post-harvest measures that have a positive impact on the reduction of food losses, and so on decreasing the climate footprint. They correlate with the causes of post-harvest losses as summarised in paragraph 1.4 of this paper. The proposed measures are seldom to be considered as single-solution interventions, but are rather to be implemented as a complex of post-harvest measures in a holistic approach.

In an FAO working paper (Puri, 2016) post-harvest interventions are advocated to be implemented at the early stages of the FSC (upstream) through adequate storage facilities to avoid degradation and spoilage of perishable foods. Ensuring the availability of cooled storages will also enable a more distributed supply of produce over a longer period of time, and so decrease the seasonal oversupply of markets (and hence lower prices). In general investing in the establishing of a cold chain in developing countries is often mentioned. This is partly explained from the fact that the use of refrigeration technologies has had a positive impact on performance of FSCs in developed countries (see also chapter 4). But also the fact that the majority of developing countries is located in the hottest regions of the planet would support the need for a cold chain in these regions. Some sources expect that around a quarter of total food wastage in developing countries could be eliminated if these countries adopted the same level of refrigeration as that in developed countries (IMechE, 2014). This would nevertheless require also a considerable investment in a sufficient, reliable and sustainable (renewable) energy infrastructure (Puri, 2016). A renewable source for this energy supply could be the electricity from biogas obtained through anaerobic digestion of organic residues (including FLW).

Remains the issue of the trade-off in terms of climate footprint effects between the increased consumption of energy from technological interventions in the supply chain, and the actual climate benefits from reduced food losses. The potential net sustainability benefits from investments in PHM is calculated from the potentially avoided GHG emissions from reduced food losses and the extra GHG emissions from the increased consumption of energy and refrigerant gasses that enable the food loss reducing technological intervention. The incremental effects from GHG emissions as a result of increased energy consumption will be lesser when renewable energy resources will be applied.

Bio Intelligence Service developed modelling scenarios for calculating such a trade-off from cold chain expansion vis-à-vis the reduction of food losses (BIO-IS, 2015). All scenarios showed that the decrease of FLW carbon footprint from cold chain expansion outbalances the newly created emissions, by a factor ten approximately. This factor will be higher when renewable energy will be applied as a resource for fuelling the cold chain.

Positive climate benefits are likely to be obtained when alternative modalities for international transport of fresh products other than airfreight come within grasp. Increased knowledge in product physiology and quality, product storage methods and energy monitoring technology enable the possibility to apply low carbon transport methods as alternative for current airfreight transportation methods with a high climate impact. The benefits from alternative transport modalities by lower CO_2 emissions are illustrated by WFBR studies such as 'Greenrail' and 'Green Corridor East Africa' (Van Gogh & Groot, 2012; Groot et al., 2013).

Agents / governance

The uptake of PHM technologies is essential for reducing PHLs and as such for mitigating GHG emissions from food supply chains. Facilitating impact on the climate footprint of food production through PHM will require concerted action between market-driven investments by private actors in these supply chains and the enabling of the public environment in which these investments will have the opportunity to pay off. This prerequisite does not apply to the topic of climate environment alone, but the fact that climate policy measures are pre-eminently part of the public domain does imply an important role of public policy in the successful implementation of PHM measures. Or as is phrased by a World Bank study on post-harvest food losses in Sub-Saharan Africa: "The private sector's efforts to develop improved postharvest systems need to be underpinned by an enabling environment that encourages private sector investment" (World Bank, 2011). The creation of market value in FSCs through reduced PHLs and improved product quality would then create a win-win situation in terms of supply chain performance and reduced climate impact.

Information

In order to truly understand how efficient a FSC is in terms of its climate footprint, a robust, complete and differentiated approach to data collection is required. This is one of the conclusions from a macro-study on food losses and climate impact by Porter et al. (2016). Efforts will have to be geared to acquiring data on losses and GHG emissions on the level of individual supply chains, in order to calculate the climate impact from PHM measures. This will become particularly relevant when incentives will be created for actors in the FSCs, either through public policy or through private sector standards (see also chapter 3), to acquire a 'license to produce' on the basis of their sustainable performance.

Finance

The financing of PHM is in the first place a process of calculating the costs of investments and of the anticipated revenues in order to assess the probability of a fair rate of return (ROI). In chapter 4 it was already addressed that this can be a complex process in food supply chains where investments in PHM required upstream in the supply chain may generate yields only downstream. An additional complicating factor is that these costs of production do not necessarily reflect the real costs, as the costs of the impact of the production activities on the climate footprint are not taken into account in this calculation. Acknowledging the fact that the absence of sufficient PHM measures will lead to post-harvest food losses, a waste of resources and ergo contribution to GHG-emissions, means that investment in PHM measures that are effective in reducing PHLs, will have beneficial effects in terms of a reduction of the climate footprint. Internalising the real costs of production, including the external costs, would therefore present a business case based on true costs and incorporating the long term true risks of the investment in PHM.

Only in recent years the shortcomings of current financial investment models on long term sustainability have gained attention from financial institutions, as most of these models do not take into account costs that arise from externalities on the environment, and on climate impact in particular. On national and international level alliances of financial institutions plead for the inclusion of natural capital-related risks in the costs of capital. A 'One Planet Thinking' for the financial sector in which risk management has to become more future oriented, also referred to as true risk (Leenders and Bor, 2016; NCFA, 2017).

The possibility of financing of PHM as a set of climate impact mitigating measures for reducing post-harvest losses and the related waste of resources and GHG-emissions, is therefore dependent on internalising the current external costs. These costs are incurred, amongst others, when food is lost in the FSC. (Future) investment models should therefore take into account the costs of externalities, as well as the allocation of the financial risks of investments in PHM measures in the FSC.

7 A value chain approach on post-harvest management: challenges for policies

The purpose of post-harvest management is to overcome the underperformance in post-harvest chains in terms of the loss of quantity and quality of the harvested product, and hence the loss of revenues and income in the value chain as well as the loss of resources. In the previous chapters the effects of post-harvest management were addressed in achieving food security and food safety, increasing economic revenues and employment, and in decreasing the external effects of food production on the environment and on global warming in particular. Post-harvest management (PHM) was defined as t**he whole of processes and measures that contribute to the flow throughout the supply chain of agricultural products (crops) which have been harvested, or are suitable for harvesting**. PHM includes the technological and non-technological infrastructure that enables the optimal processing, distribution and marketing of food products. As such PHM is a set of processes and measures that apply to the different links in the food supply chain.

For food supply chains (FSCs) in developing economies the majority of food losses is incurred in the stages between the harvesting of product until consumption: the post-harvest chain. The external effects of these post-harvest losses (PHLs) on food security and climate footprint are undisputable, although the contribution of specific post-harvest measures to the reduction of these PHLs is difficult to pinpoint. In the past years the strengthening of the post-harvest chain has gained renewed attention from policy makers, international governmental organisations (e.g. FAO, UNEP, World Bank), as well as from private NGOs and business platform organisations (e.g. World Economic Forum, Rockefeller Foundation). An important reason for this revival is the increased urgency for action to reduce FLW throughout the chain as a source of spoilage and unwanted waste of nutrition and of resources (land, water, energy). Although the general opinion is that the magnitude of FLW is considered a major obstacle in the effort to produce sufficient and safe food for a growing population, data on actually measured FLW are only limitedly available. **Increasing the performances and resilience of future food systems by solving the global problem of FLW is considered a necessity but will require improved data on post-harvest losses to measure the effects from investments in PHM measures**.

In this paper the topic of post-harvest management was reviewed from a value chain perspective. The intention of this approach is to stress the concept of **value creation as a condition for securing long-term sustainability of any investment in the post-harvest chain**. An important aspect of this creation of added value in the chain (e.g. by improved product quality, packaging or storability of product) is, that the costs of the product will include the actual costs of the resources (true cost) used to bring the product to its intended market. By valuing the true costs of the used resources potentially adverse effects (environmentally, economically or socially) that may be co-generated by the investment efforts (e.g. increase of energy consumption) will become transparent.

A second important aspect in the value chain approach is, that PHLs are not caused by one or two specific links in the chain, but are the result of an entire value chain. **Tackling PHLs therefore requires a value chain approach rather than actions from a single stakeholder or a single solution approach**. The value chain approach includes that the costs that are incurred in specific parts of the chain to create the added value, will be sufficiently compensated by the revenues from the entire value chain. Post-harvest management measures, in other words, will be stimulated when the prospect of obtaining the revenues in exchange for the costs and risk of investment is there.

From the reviews of PHM with regard to the specific societal themes food security, food safety, economic revenue, employment and climate footprint the key message was formulated that **post-harvest management contributes to the improvement of availability, quality and safety of perishable food products. Improved product quality may lead to higher incomes in the value chain, better consumer satisfaction, and lower environmental impact (as post-harvest losses will be reduced)**.

Intervening in the post-harvest chain on value chain level is foremost a matter for the private sector. Regarding the before mentioned issues there is, however**, a significant role to play for governmental policy on sectoral and national level in creating the desired incentives and infrastructure for investing in PHM (facilitate), in monitoring impact (measure), and in setting and maintaining concrete FLW targets for sector stakeholders to comply with (enforce).** Finally, **international harmonisation of legislation on food quality and food safety will avoid confusion and disturbances in international trade of food products and will create a level-playing field for food business operators**.

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