CHAPTER 11

INNOVATIVE POSTHARVEST TECHNOLOGIES FOR SUSTAINABLE VALUE CHAIN

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Nowadays, the distance that food travels from producer to consumer has increased as a result of food trade globalisation. Consequently, the up-keep of safety and quality along the food value chain is becoming a significant challenge. The twenty-two countries bordering the Mediterranean represent, in terms of value, almost 23% of the global trade in fresh vegetables and 25% of trade in fresh fruit. In the past fifteen years, exports have risen fivefold, including dramatic increases in fruit and vegetable shipments to the Middle East and North African (MENA) markets (FAO 2014a). For this reason, this chapter will focus on fruits and vegetables in order to question innovative postharvest technologies in green food value chain development in the Mediterranean.

Inefficiencies along the food production pipeline and the resulting waste have a strong negative impact on food availability, productivity and the environment. Greening food value chains plays a major role in improving food security (Godfray *et al.*, 2010). Food losses and waste (FLW) refer to the edible parts of plants and animals produced for human consumption that are not ultimately consumed by the population. They represent the decrease in the mass, nutritional value and/or quality attributes of edible food intended for human consumption (FAO, 2011). Food losses refer to the quantitative loss of food that occur during food value chain operations that does not reach intended consumers, while food waste refers to food that reaches intended consumers but is discarded and not consumed (FAO, 2011). Prevention and reduction of FLW is not only a goal in itself that is only tied to food security. It also relates to poverty alleviation, health and safety, employment generation, gender equality and preservation of the natural environment.

In the Mediterranean, particularly, in the MENA region quantitative FLW are estimated at over 250kg per year per capita (FAO, 2015) and at 594kcal per day in nutritional energy terms. Economic losses are estimated to exceed 50 billion dollars annually in terms of farm gate prices (FAO, 2014a) and the usage and consumption of natural environment assets (natural resources, ecosystem services, biodiversity, climate, etc.) that are lost and wasted are staggering. The horticulture secture is the most affected by FLW and is estimated at a staggering 45% (FAO, 2014a) and even 56% according to recent estimates (FAO, 2015). It is therefore clear that horticulture should be a priority area of intervention in the region. From a qualitative point of view, FLW are very high and exacerbated by a multitude of food distributional aspects ranging from lack of appropriate marketing infrastructures, to cold chains, logistics and pricing.

In the MENA region, food production is much lower than required. This is largely due to limited and depleting natural resources (arable land and water). Growing populations and growing rates of urbanisation have an increasing demand on already-stressed food systems in terms of quantity and of changing food preferences towards high-value, more perishable fruits, vegetables, meat and dairy. The region is a net importer of food and this leads to a wide range of economic, social, cultural and even political difficulties. Preventing and reducing FLW is the most efficient and feasible approach in economic as well as environmental terms in comparison to attempts at increasing food production. Inadequate data on FLW, lack of awareness on FLW, technical capacity to deal with FLW, lack of organised coordination by institutions in dealing with FLW, insufficient investment and lack of appropriate policies and regulations, all hinder the prevention and reduction of FLW in the MENA region (FAO, 2014a).

Thus, a holistic and comprehensive approach is required to address the evident inefficiencies found along the multitude of horticultural value chains that have a negative impact on food availability, poverty reduction, employment creation and the natural environment. Many of the FLW indicators found in the most diverse horticultural value chains are usually only symptoms of the root causes and do not provide information on the real root causes of such FLW. The green food value chain development approach for horticultural produce especially in postharvest management in terms of novel technologies and applied innovations is an efficient way of tackling FLW.

An overview of the green food value chain

Since the very high FLW in the Mediterranean countries can be attributed to the lack of appropriate infrastructure throughout the value chain, the development of a green food value chain should be considered. The latter focuses on the proactive prevention and reduction of the use of the natural environment (natural resources, ecosystem services and biodiversity) so as to diminish or mitigate adverse impacts or even have positive impacts on food value chain operations and activities. At the same time, the approach also considers disposal and recycling patterns of generated waste, to recapture value at every stage of the food value chain and thus further reduce environmental impact (Hilmi, 2015).

Thus, the main goals of greening food value chains are prevention, reduction and recapture primarily centred on products, processes and systems that influence environmental and economic performance. They can be classified into the following two categories: ensuring the efficient and sustainable use of the natural environment, while at the same time increasing the share of environmentally sound food products provided by renewable and recycled resources, maximising material and energy efficiency at each stage of the system; and preventing and reducing negative environmental impacts at all stages of the food value chain. The climatic conditions of the Mediterranean countries pose the major problems that need to be taken into consideration. The high temperatures especially during the summer period create a pressing need for environmentally friendly cooling technologies at each stage of the system. These technologies require energy, which has to be produced using environmentally friendly mechanisms.

Greening food value chains is a step-by-step process that begins with the identification of the occurrence of activities in food chains that have an environmental impact (which activities, where, why, how and when?) Such activities then need to be neutralised, or in other words, "*greened*". Once these environmental "*hotspots*" have been identified, the second step focuses on strategies that can *prevent* inappropriate use of the natural environment and the third step on strategies that *reduce* the inappropriate use of the natural environment. A fourth step looks at strategies that can *recapture* any value that can be found in waste from food chain operations and a fifth step considers all the efforts taking place in greening a food value chain (*stocktaking*). Step six provides a *checklist* to ascertain and evaluate if a food chain can be classified as *greener* and thus contribute to increasing food security and nutrition, and climate change mitigation. The process usually requires the public sector and economy sector to establish partnerships with all interested stakeholders in the private sector and among civil society. If the production and use of green energy is one of the main factors that will determine how green the food chain is, then every green technology approach, such as the installation of solar panels, wind energy devices placed in fruit and vegetable storage units, might be the answer for the greening of the system such as storage and transportation stages.

At the same time, the greening of value chains also considers disposal and recycling patterns of generated waste, to recapture value at every stage of the food value chain and thus further reduce environmental impact (Hilmi, 2015). In particular, a green pathway for developing food value chains requires innovative knowledge and technologies all along the agri-food chain. Wide access to state of the art knowledge and technology is therefore an important element in achieving greener food systems, thus enabling critical factors such as seasonality, globally-based growers, long transportation routes and storage delays to be converted into benefits (year-round availability of defined foods, waste reduction and reduced energy consumption).

Over the past few years, the emergence of greener food value chains and the renewed emphasis on efficiency and food safety has changed the way in which postharvest systems are conceived from a series of individual components to an integrated value chain linking producers and consumers through domestic and international trade.

A key and critical aspect of green food value chain development depends on improved postharvest management which, in turn, enables meeting consumer demand in a better and more efficient way, reducing costs and increasing benefits.

Eco-innovation in the agri-food chain: Barilla sustainable farming (BSF)

The BSF initiative of the Barilla group is an example of promoting more efficient cropping systems with the aim of obtaining safe and high quality agricultural products while protecting the environment and enhancing the social and economic condition of farmers. The first life cycle assessment of the environment was conducted on durum wheat pasta, including all chain phases (cultivation, milling, pasta production, packaging production or distribution and household cooking). The outcomes revealed that the phases with the highest negative impact on the environment were durum wheat cultivation and household cooking. The data have been used to update the "Barilla crop guidelines", and to publish a "Handbook for the sustainable cultivation of quality durum wheat in Italy", featuring a list of rules to help farmers make the production of durum wheat more efficient and sustainable, guide their long-term farm management strategy. A website (granoduro.net) also provides an online assistance system helping farmers to take operative decisions.

Between 2011-2013, an improvement in all performance indicators was observed by all farms that implemented the guidelines: a decrease in durum wheat direct production and inputs costs, yield increase resulting in an increase in gross income, a decrease in crop environmental impact (carbon, water, and ecological footprints) and an increase in nitrogen use efficiency. The adoption of appropriate cropping systems combined with suggestions from the group and the website led to an increase in yields of up to 20%, a decrease in farmers' direct costs of up to 31% and a reduction in CO_2 emissions of 36%, on average.

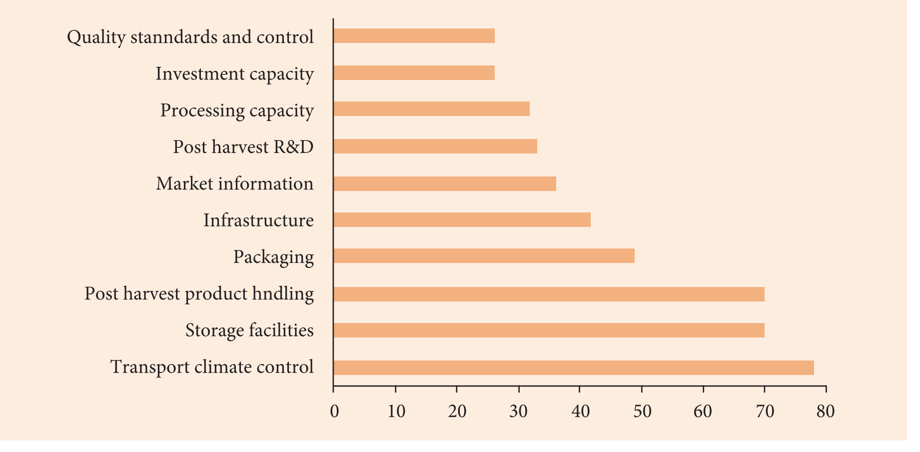
The BSF eco-innovation and its results are an interesting example showing that the sustainability goal provides opportunities for action that could lead to the application of environmentally advantageous and economically viable cropping systems in Italy in the near future. Although BSF is an innovation model only centred on durum wheat cultivation, it seems to have a value for several actors in the chain, including sourcing and supply chain operators, while at the same time, improving durum wheat environmental, social and economic sustainability. The involvement of sourcing and supply chain operators in the adoption of BSF might lead to a "win-win result'": research institutions (Horta) could use innovation outcomes for the implementation of web-based systems (like granoduro.net); universities (Cursa) could benefit in terms of research findings; farmers and elevators, from increased yields and revenues; processors, like Barilla, from the high quality of durum wheat received and obtained respecting sustainability parameters. By providing benefits to all actors involved, the BSF initiative has enabled discussions on the potential increase and distribution of value across the whole agri-food chain.

Source: Blasi et al. *(2015).*

Critical issues in postharvest management for the fruit and vegetable sectors

The causes of postharvest losses in the Mediterranean are mainly connected to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems. Postharvest losses also vary greatly among commodities and production areas and seasons (Figure 1).

Figure 1 - Main categories for causes of postharvest losses (in %)



Source: Aramyan and Van Gogh (2014).

Postharvest loss in Mediterranean countries is mainly caused by biological spoilage due to inappropriate postharvest management practices (inadequate transportation facilities and improper handling systems of storage or packaging as well as unfavourable climatic conditions of high temperatures and low relative humidity). Significant economic and environmental losses result from the inability to retard ripening and associated excessive softening of fruits between harvest and marketing, while loss of water from vegetables negatively affects their quality (El-Ramady *et al.*, 2015).

Two core challenges of greening food value chains are enhancing food security (as well as safety) and at the same time providing for environmental conservation. This involves improving productivity and efficiency at all levels of food supply (including its management), of which an integral part is increasing the efficiency of postharvest systems. Developing advanced postharvest technologies will allow wholesalers, warehouses, retailers, transportation companies throughout the fresh-produce value chain to guarantee optimum quality and extended shelf life. Current research and development (R&D) as well as technology transfer in postharvest technologies aims to combine knowledge of plant physiology and technology for the optimal maintenance of quality following harvest. Optimal postharvest treatments for fresh produce seek to slow down the physiological processes of senescence and maturation, reduce/inhibit the development of physiological disorders and minimise the risk of microbial growth and contamination. In addition to basic postharvest technologies of temperature management, a wide range of other technologies has been developed including various physical (heat, irradiation and edible coatings), chemical (antimicrobials, antioxidants and anti-browning) and gaseous treatments (Mahajan *et al.*, 2014). Ultimately, FLW are reduced mainly through capacity development, in the form of education, training and extension services, for all actors across the food value chain (Table 1).

Table 1 - Approaches to the FLW reduction

Production	Handling and storage	Processing and packaging	Distribution and market	Consumption
Donation of unmarketable crops	Improved access to low cost handling and storage technologies (evaporate coolers, storage bags, metal silos, crates)	Re-engineering the manufacturing process	Donation of unsold goods	Donation of unsold food
Improved availability of agricultural extension services	Improved ethylene and microbial management of food in storage	Improved supply chain management	Change food date labelling practices	Conduct consumer education campaigns
Improved market access	Introduction of low-carbon refrigeration	Improved packaging to keep food fresher for longer	Change in-store promotions	Reduce portion size
Improved harvesting techniques	Improved infrastructure (roads)		Guidance on food preparation and storage and inventory systems	Teaching home economics in schools

Source: Lipinski *et al.* (2013).

New postharvest technologies to prevent food losses

New cooling systems and temperature control

The major effect of low temperature applications between harvest and produce end use is a reduction in metabolism and implicitly a delay in quality loss and senescence. Beneficial effects of pre-cooling on produce shelf life are more pronounced in highly perishable products. In order to help maintain a higher product quality and longer shelf life starting at the harvesting site, the most advantageous systems are the mobile forced air-cooling tunnels and crates. These systems provide a shorter delivery time to market and decrease on-site production costs. Instead, a wide range of pre-cooling systems (radiant cooling, evaporative cooling units, solar chillers, Cool-Bots) and other suitable solutions can be implemented in Mediterranean countries including the "zeer" that is one of the simplest and yet most efficient evaporative coolers. Costing less than 2 dollars to produce, the zeer can contain up to 12kg of food and be reused for several years. For example, tomatoes and guavas that normally expire within two days without any storage, last up to twenty days in a zeer.

With regards to the greening of the cold chain systems, sustaining their capabilities becomes increasingly challenging as populations grow and new technologies emerge. New warehousing and transportation technologies can reduce greenhouse gas emissions, improve air quality, and replace environmentally-destructive refrigerants with benign alternatives. A recent technology using liquid nitrogen engines is being considered as a "quick-fix" solution to air pollution caused by refrigerated transport by allowing produce suppliers to create a zero-emissions fleet. As a by-product of the industrial gas sector, the infrastructure allowing to provide liquid nitrogen is already in place and it is described as cheaper than traditional fuel. Meanwhile, vehicle emission technologies are emerging to address transport refrigeration units (TRUs). Battery-electric TRUs are already available, as are eutectic plates that store cold in a salt solution (similar in principle to a beer cooler cold pack), both of which are quiet and, with fewer moving parts require lower maintenance. The Mediterranean countries stand at a crossroad: whether to build their cold chains using conventional technologies or the cleaner technologies of the future.

Reducing fresh produce waste through sustainable packaging

Major supermarket chains are already leading the way by encouraging their suppliers to use bio-based packaging materials and this trend is likely to grow: future bio-based food packaging materials are likely to be blends of polymers and bio-nanocomposites, in order to achieve the desired barrier and mechanical properties demanded by the food industry. Important research has already been undertaken in this area. If commercialisation is still carried out on a small-scale, the next decade will see significant production of bio-nanocomposites for food industry use (Robertson, 2008).

Although environmental pollution seems to be one of the most important issues that the consumer is worried about, the latter seems neither to realise nor to be aware of the importance of recycling and/or biodegradable packaging. This lack of awareness is mainly due to inadequate information. A more intensive campaign towards consumers' education regarding recycling and biodegradable packaging must be undertaken by consumer organisations worldwide in conjunction with incentives from governments. As an alternative to the current petroleum-based polymers, today, increasing attention is given to biopolymers derived from renewable sources. Biopolymers obtained directly from biomass (starch, chitosan, gelatine, collagen, gluten, zein. etc.), by chemical synthesis from monomers obtained from biomass (polylactic acid – PLA – and other polyesters), or produced by microorganisms (polyhydroxyalcanoates, bacterial cellulose, etc.) (Weber *et al.*, 2002) are already being used as packaging materials or coatings for food. These materials can be biodegradable and many of them are edible. They enable the control of physical, chemical and microbial processes in foods as well as, or better than conventional plastics. Producing biodegradable plastics using renewable biomass that ends up in biodegradation infrastructures like composting facilities is ecologically sound and promotes sustainability (Narayan, 2005). The improvement in polymer technologies and the use of smart additives (sensors, time temperature indicators. etc.) will confer the same performance to bio-based packaging as conventional packaging, with the added value of compostability. Bio-based packaging is compatible with new, innovative technologies such as the e+Remover Technology for ethylene adsorption.

Strategies for efficiently achieving a sustainable development

– Minimise the number of packaging layers through the optimal combination of primary, secondary and transport packaging.

– Eliminate unnecessary packaging, for example replace the plastic on blister packs with a simple tie.

– Reduce unnecessary void space.

– Use cut-out windows on corrugated shippers to reduce the weight of the pack; an added benefit is product visibility which clearly shows the pack's contents.

– Reduce the thickness of packaging.

– Increase the amount of product per package to reduce the packaging/product ratio.

– Use bulk packaging for distribution of industrial products.

– Concentrate the products that can be concentrated.

– Eliminate the use of glues in folded carton board by using tab closures.

Source: Lewis (2008).

One of the main goals in developing postharvest technologies is to advance innovative packaging equipment such as active and intelligent packaging with enhanced functions in response to the difficulties in maintaining adequate postharvest storage and distribution, aimed at improving quality and safety of the produce. While in active packaging the product, the package and the environment interact in a positive way to extend shelf life, intelligent packaging is an extension of the communication function of traditional food packaging, providing the user with reliable and correct information on the conditions of the food, the environment and/or the packaging integrity. As such, innovative packaging solutions also contribute towards a more sustainable world in which the harmful impact of packaging waste and food loss on the environment is reduced. Active, intelligent packaging will provide more than passive protection, making readily and practically available valuable information about the quality and safety status of the food products and will contribute to the better management of the food chain, the reduction of food waste and increased protection of the consumer. The most important factor for the preservation of perishable products is temperature. Therefore, the monitoring and controlling of this parameter under packaging conditions is of utmost importance for the food value chain particularly in the Mediterranean climatic conditions.

Time temperature indicator (TTI) Technology

The time temperature indicator (TTI) is among the most widespread intelligent packaging techniques. A TTI can be placed on shipping containers or individual packages as a small self adhesive label that experiences an irreversible change (in colour) when the TTI experiences abusive conditions. TTIs are also used as freshness indicators for the estimation of the shelf life of perishable products. However, most active or intelligent systems add cost to the package. Thus, innovations in packaging must have a final beneficial outcome that compensates for the extra expenses required for this technology.

Ethylene Controlling Technologies

In the Mediterranean countries where the climate resembles that of subtropical areas (high temperatures and dry conditions), the delay in the ripening and senescence of fruits and vegetables is of paramount importance for the preservation of quality characteristics. Several active packaging technologies based on absorbing or releasing compounds that interact with the product have been developed:

– The demand for discovering alternative technologies capable of scavenging ethylene has led to the development of a new material called e+® active Ethylene Remover, which has a significant adsorption capacity of this gas. It's Fresh! Technology has also demonstrated profound effects on non-climacteric fruit types such as strawberry. The technology is being further tested on fruit, flowers and vegetables around the world.

– The SmartFresh Quality System is a brand of a synthetic produce quality enhancer based on 1-methylcyclopropene (1-MCP). It is applied in storage facilities and transit containers to slow down the ripening process and the production of ethylene in fruit. SmartFresh applications have consistently improved the retention of firmness and reduced weight loss in store, provided greener, more acid fruit that were less susceptible to superficial scald and bitter pit.

– Some vegetables that are considered as non-climacteric are both sensitive to ethylene and also the ethylene binding inhibitor 1-MCP. Thus, root crops are often "cured" to prolong their storage life and minimise losses, while crops such as onions and potatoes may also be treated with sprout suppressants such as ethylene prior to long-term storage. In citrus and bananas, ethylene supplementation is used to induce fruit degreening as a natural process.

Antimicrobial active systems

Moreover, the Mediterranean climatic conditions enhance microbial growth that severely compromises the healthy aspects of perishable products. Therefore, solutions to diminish microbial activity are of great significance for producers of fruits and vegetables. Also, a fair amount of work has been done to develop antimicrobial active systems using various polysaccharide and protein-based biopolymers, which in some cases (chitosan, for example) possess antimicrobial activity. They constitute a good basis for the development of antimicrobial active packaging and coatings that slowly release fungicides and bactericides that migrate onto the packaged foods and combat contamination. In one system, known as "BioSwitch" (De Jong *et al.*, 2005), an antimicrobial is released on command when bacterial growth occurs: when there is a change in the environment (pH or temperature) takes place or when the packaging is exposed to UV light, the antimicrobial responds accordingly. Antimicrobials incorporated in packaging materials could extend shelf live by preventing bacterial growth and spoilage. Further development should be expected in future to provide possibilities that conventional polymers do not offer and also help to limit the problems of using non-renewable raw materials and polluting the environment (Kerbellec *et al.*, 2008).

Emerging smart packaging technologies

To date, there are three major technologies for the production of intelligent packaging: sensors (and by extension nose systems), indicators and radio frequency identification (RFID) systems (Kerry *et al.*, 2006). Besides, traditional sensors to measure temperature, humidity, pH-level and light exposure, and chemical sensors have received increasing attention in recent years to monitor food quality and package integrity. Small and flexible chemical sensors are particularly interesting to develop intelligent food packaging that is able to monitor volatile organic compounds and gas molecules related to food spoilage especially in modified atmosphere packaging (MAP). Today, manufacturers gradually start producing some conventional electronic devices (amorphous silicium photovoltaic cells, temperature sensors) via flexible printing, to reduce costs. Very recently, Thin Film Electronics ASA announced that it has successfully demonstrated a stand-alone, integrated printed electronic temperature-tracking sensor system powered solely by batteries, designed for monitoring perishable goods.

Carbon nanomaterials offer a high specific surface area and therefore present excellent detection sensitivity. In addition, their excellent electrical properties (high current density, high electrical conductivity) and mechanical characteristics (light weight, highly flexible, even under low temperature) make them suitable to be used as chemical sensors. Recently, an innovative method was demonstrated for the fabrication of selective chemical sensors from carbon nanotubes and graphite on the surface of paper. These sensors are capable of detecting and differentiating gases and vapours at a ppm (parts per million) concentration level (Mirica *et al.*, 2013). Besides, some promising technological properties such as silicon photonic-based sensors have two important assets: low production costs and the potential to produce on a large scale. Indeed, the same infrastructure and methodologies can be applied as those applied in the production processes of conventional silicon semiconductors for electronic devices. CheckPack will develop a silicon photonic-based chemical micro-sensor to measure VOCs and CO_2 concentrations in the headspace of food packaging.

Biosensors for pathogen identification could be one of the active and intelligent systems of the future: antibodies could be attached to a plastic packaging surface to detect pathogens or toxins (LaCoste *et al.*, 2005). It is also believed that tomorrow's food packages will certainly include radio frequency identification (RFID) tags. At present, RFID is being researched at laboratory level only to promote the understanding of the storage air and fruit pulp temperatures as well as of relative humidity in typical fruit supply chains (Gander, 2007). The cost is the biggest obstacle of the wide-scale adoption of monitoring technologies in the food chain. RFID technologies, enables wireless monitoring systems at a much lower cost (for example through the integration of ultrawide-band communication) though not yet completely developed.

Nanotechnologies

Applications of packaging nanotechnologies have been shown to increase the safety of food by reducing material toxicity, controlling the flow of gases and moisture, and increasing shelf life (Watson *et al.*, 2011). Currently, most nanotechnology applications in the agricultural supply chain are concentrated in packaging. Ultimately, the idea is to design intelligent packaging based on nano-sensors in view of promoting information and management across all elements of an agricultural supply chain. When incorporated into polymer matrices, nanomaterials interact with the food and/or its surrounding environment, thus providing active properties to packaging systems and resulting in improvements in food safety and stability (Monteiro Cordeiro de Azeredo *et al.*, 2011). Biodegradable and fully compostable bioplastics packaging have already been produced from organic cornflour using nanotechnology (Neethirajan and Jayas, 2011). In addition, nanotechnology can be used in antimicrobial packaging systems including an antimicrobial nanoparticle sachet that disperses bioactive agents in the packaging or coating bioactive agents on the surface of the packaging material (Coma, 2008).

Scientists have developed a portable nanosensor to detect chemicals, pathogens and toxins in food on real time basis enabling safety and quality verification at control points in the supply chain (Tiju and Mark, 2006). Current sensors using electrocatalysis and nanotechnology represent a new and promising technology for the affordable detection of ethylene production in fruits which will enable research in areas where ethylene could not be measured before, due to lack of portable, sensitive, and near real-time measurement equipment (Mahajan *et al.*, 2014). Several pesticide manufacturers are already developing pesticides encapsulated in nanoparticles. These pesticides may be time-released or released upon the occurrence of an environmental trigger such as increased temperature and humidity, or excessive light (Mahajan *et al.*, 2014).

Information technologies in postharvest management

Information technology is increasingly impacting agriculture from fundamental inputs, such as genomics and computer modelling that can help drive the next generation agricultural technologies: seed and planting technology as well as food distribution with smarter logistics that can help deliver food more quickly using less fuel and fewer machine resources and with less spoilage all along until consumption. Smart IT systems can have a positive and global impact thanks to track-and-trace technologies that support food safety and ultimately optimise food value chains; by increasing farm multifactor productivity thanks to improved water logistics and application, optimised machine/fleet maintenance, and improved farm operations/processes (Denesuk and Wilkinson, 2011).

In the agri-food value chain, Ruiz-Garcia *et al.* (2010) proposed a model and prototype implementation for the tracking and tracing of agricultural batch products along the food value chain. The proposed model suggests the use of web-based systems for data processing, storage and transfer that makes information access, networking and usability to achieve full traceability more flexible. José A. Alfaro and Luis A. Rábade (2009) presented the case study of a firm in the Spanish vegetable industry and found that the firm had significant qualitative and quantitative improvements in supply, warehousing, inventory and production processes after the implementation of a computerised traceability system.

One of the widest spread technology used for traceability is the barcode. GS1 is a non-profit organisation dedicated to the design and implementation of global barcode standards for identifying goods and services to improve the efficiency and visibility of supply chains. These GS1 standards could be implemented throughout the food supply chain to enable traceability. There are GS1 member organisations in 108 countries. Their well-known global trade item numbers (GTINs) including the UPC (Universal Product Code), the SSCC (Serial Shipping Container Code) and the EAN (European/International Article Number) have been used by retailers and suppliers of packaged goods for decades. The adoption of GS1 standards varies by country and sector but has significantly increased every year, and efforts are under way to increase their adoption by companies in the upstream supply chain. GS1 standards for product identification (product type and lot numbers) are the basis of a major initiative undertaken by the produce industry to enable traceability back to the farm. The initiative is called the "Produce Traceability Initiative" (PTI) and aims at achieving the adoption of electronic traceability throughout the supply chain for every case of produce (Denesuk and Wilkinson, 2011).

Implementing greener supply chains in developing countries such as those of the Mediterranean region, both in terms of logistics and the use of environmentally-friendly technologies, can substantially support the development of a sustainable agriculture. Thus, the expansion of the applications of IT in developing green value food chains will contribute to the promotion of food security for a growing global population, while meeting the energy and ecosystem requirements.

Implementing strategies and policy recommendations

Research & Development

According to many studies, between 30% and 40% of fruits and vegetables are lost before reaching the final consumer. These losses are observed at harvesting, during packing, transportation, in wholesale and retail markets, and during delays at different stages of handling. Physical and quality losses are mainly due to poor temperature management, use of poor quality packages, etc. Less than 5% of funding for horticultural research and extension (R&E) has been allocated to postharvest issues over the past twenty years. Research ranges from the fundamentals of storage and preservation of quality throughout the marketing chain, to food-science aspects of agro-processing and responses of consumers to new food products. While thousands of development projects have been launched in Mediterranean and developing countries between 1990 and the present time, very few have focused on horticulture (approximately 1%), and only a third of these very few horticultural projects included a postharvest component (Kitinoja *et al.*, 2011).

Many of the above-mentioned technologies and techniques are already being implemented by individual organisations and companies. While researchers have identified many potentially useful postharvest technologies to be implemented in developing countries, there is a lack of information regarding the costs and financial benefits of these technologies since costs are rarely documented during research studies. In general, postharvest loss reduction science is less expensive than production research, in the framework of which multiple studies must be conducted over years or seasons. Capacity-building efforts undertaken in postharvest technology in developing countries must be more comprehensive, and include technical knowledge on handling practices and research skills (Kitinoja *et al.*, 2011) as well as consider the natural environment aspects of such activities. There are several initiatives from government and development partnerships in Mediterranean countries aimed at improving the livelihoods of women farmers through value addition and marketing of perishables food crops such as fruits and vegetables (Lipinski *et al.*, 2013). These initiatives have two-pronged benefits: they contribute to the economic empowerment of rural women and to the reduction of postharvest losses of perishable commodities. However such initiatives also need to include considerations related to natural environment elements.

Doubling the share of investment in addressing postharvest losses (from 5% to 10%) would be a significant improvement and a step towards increasing adoption rates of technologies and approaches to reduce postharvest losses. National governments, development banks, philanthropic foundations and international organisations dedicated to food security all have a role to play in increasing this investment. Food loss prevention training and education programmes must be implemented throughout the world. In many cases, insufficient funds have prevented the implementation of such programmes.

Policy and training

Postharvest loss interventions should be integrated and due consideration must be taken of the socioeconomic, business, natural environment and political context of a country. Strategies for the consideration these contexts suggested by Lisa Kitinoja *et al.* (2011) include: the integration of postharvest loss science and education into the general agricultural curricula and government extension services; the establishment of "Postharvest Training and Services Centres" to test reduction innovations under local conditions, identify the most promising and cost-effective techniques and practices, provide demonstrations of innovations determined to be technically and financially feasible, and provide hands-on training and capacity building to farmers; and the establishment of country-level Postharvest Working Groups that connect researchers, extension agents, farmers, and other food value chain actors concerned about the reduction of postharvest losses. Such groups could facilitate exchange of information, training, shared learning and national and regional collaboration revolving around postharvest loss reduction. Reducing food loss and waste requires collaborative initiatives that provide a number of benefits such as building capacity within the entities that need to take ground action to reduce food loss and waste or facilitate sharing and transferring of best practices and common pitfalls. Researchers, civil society and intergovernmental organisations can identify and share best practices, provide technical assistance and convene stakeholders.

In order to minimise undesirable changes in quality parameters during the postharvest period, a series of techniques can be employed to extend the shelf life of fresh produce. Postharvest technology comprises different methods of harvesting, packaging, rapid cooling and storage under refrigeration as well as under a modified or controlled atmosphere and transportation under controlled conditions, among other essential strategies to maintain the shelf life of fresh produce. At each stage of the food value chain, general solutions can be implemented to address specific causes of losses and waste, and they involve improved practices, adoption of technical innovations, investments, or a combination of these. Storage conditions must be improved all along food value chains. The support and cooperation of the food industry and retailing is also required to improve the clarity of food date labelling, to provide advice on food storage, or to ensure that an appropriate range of pack or portion sizes is available to meet the needs of different households. Investment in food processing infrastructure, including packaging, can be considered as a huge opportunity to contribute to improved situations of food security, especially in sustainable ways to fulfil the growing demands of metropolitan areas (FAO 2014).

Investments and gender issue

The major challenge for the Mediterranean countries is the mobilisation of funds to establish green infrastructures throughout the food value chain in order to enhance sustainability and increase profits for farmers, wholesalers and retailers. This would enable high quality fruits and vegetables to reach the European markets. Moreover, funds should be invested in research and development to deal with applied aspects of greening the food value chain in subtropical areas such as the Mediterranean basin. Generally, there is a lack of continuation between laboratory findings and field application of the results. Increased investments in postharvest technology R&D can have a major impact on reducing losses, preventing and mitigating environmental impacts, and increasing the food supply, thus leading to improved incomes without an increase in production and the wasting of expenditures on required inputs (increased demand for land, water, seeds, fertilisers, pesticides, labour, etc.).

The gender issue is another important challenge in Mediterranean countries. Despite the key role they play from production to food processing, women experience barriers in the postharvest handling practices. Most of them lack knowledge of and access to good processing practices and efficient processing tools. Additionally, they are often excluded from training opportunities because most producer organisations, through which such capacity-building efforts are conducted, are dominated by men. As a result, women farmers end up with inferior processed products that cannot meet market standards and are therefore discarded or sold to alternative markets for lower prices.

Conclusion

There is a clear need for a more holistic and integrated approach when dealing with postharvest losses in the overall context of greening food value chains. Postharvest innovations, as described above, coupled with the context of greening food value chains, can have a very large impact on the prevention, reduction as well as possible recapture of value in food losses. Thus, it is clear that policy makers and decision makers must consider such an approach, especially as it contributes to improved food security (and health and safety), the mitigation of climate change, increased employment opportunities and the furthering of women equality. The achievement of the Sustainable Development Goals (SDGs) will require a significant improvement in the efficiency with which resources are used. We need to "do more with less". This is sometimes called eco-efficiency, a term that was coined by the World Business Council for Sustainable Development (WBCSD) in its 1992 publication (Schmidheiny, 1992). The critical issue is that we have exceeded the sustainable carrying capacity of the Earth, and we need to reduce our demands on its resources. A range of possible eco-design strategies to increase efficiency are provided in Box 2. They include "source reduction" or light weighting of packaging, as well as improvements in the efficiency of distribution (Lewis *et al.*, 2001).

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