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Packaging in the fresh fruit and vegetable supply chain: innovation and sustainability

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Il packaging nella filiera della frutta e verdura fresche: innovazione e sostenibilità

Riassunto. L'imballaggio è fondamentale per le materie prime fresche, come frutta e verdura, a causa della loro rapida deperibilità. È imperativo che i materiali utilizzati nella loro catena di fornitura rispondano alla loro varietà di esigenze. Lo scopo di questa recensione è di focalizzare l'attenzione sulle tipologie di packaging che vengono effettivamente utilizzate a diversi livelli della filiera di frutta e verdura fresca, inclusi i materiali considerati.

Parole chiave: packaging, supply chain, film, materiali plastici, innovazione.

Introduction

Considering the essential consumption of fresh fruit and vegetables (Rico *et al.*, 2007; Ramos *et al.*, 2013; Caleb *et al.*, 2013) in the current food system scenario, the subject of food packaging is viewed by several different points of view. It's the result of a long development process. The significance of the topic is realized in many national and international scientific publications. In fact, 3,407 publications related to different subject areas involving research on fruit packaging have been published in the past twenty years (fig. 1).

Agricoltural and biological sciences and engineering subjects area respectively cover 69% and 20% of the actually scientific litterature (Scopus). Logistic (García-Arca *et al.*; 2014; Orjuela-Castro *et al.*, 2017), innovation (Scetar *et al.*, 2010; Maijd *et al.*, 2016; Wyrwa and Anetta Barska, 2017; Matera *et al.*, 2017), sustainability (Albrecht *et al.*, 2007; Levi *et al.*, 2011; Singh *et al.*, 2012; Dominic *et al.*, 2015; Battini *et al.*, 2016), design (Zanderighi, 2001; Paul and Clarke, 2002; de Castro *et al.*, 2004; Del Nobile *et al.*, 2007; Mahajan *et al.*, 2007; Rodriguez-Aguilera and Oliveira, 2009; Biancolini *et al.*, 2010; Pankaj *et al.*, 2014), materials (Lange et al, 2000; Chonhenchob *et al.*, 2003; Kirwan and Strawbridge, 2003; Siracusa *et al.*, 2008; Defraeye *et al.*, 2013; Mangaraj *et al.*, 2009; Rojas-Grau *et al.*, 2009) cost (Ruiz and Ahern, 2004; Bortolini *et al.*, 2018), supply chain (Dominic , 2005; Sugiyono *et al.*, 2010; Albrecht *et al.*, 2013; Battini *et al.*, 2016), marketing (Ragaert *et al.*, 2004; van Herpen *et al.*, 2016; Wilfred and Onyeakusiobi, 2017), technique (Blanco *et al.*, 2005; Rojas-Grau *et al.*, 2009) and physiology (Song *et al.*, 2002; Fisk *et al.*, 2008; Khan *et al.*, 2016; Sortino *et al.*, 2017) best describe the framework within the litterature on the fruit packaging can be find. Considering the packaging process a good number of published reviews have focused advancements in the use of modified atmosphere packaging techno-

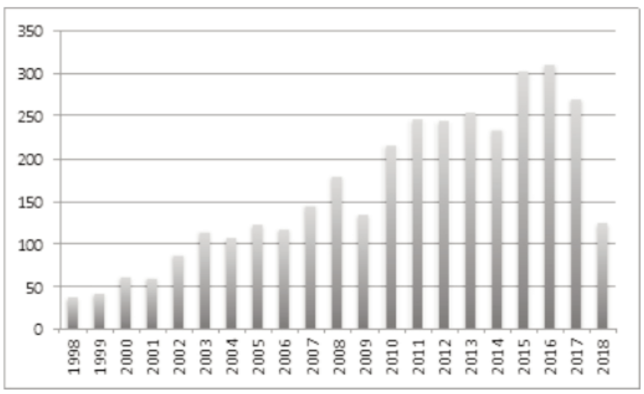

Fig. 1 - Number of articles on fruit packaging published during the past twenty years using Scopus databases with AND as a connector between the keywords on the topic (Scopus database – accessed 30 April 2018).
Fig. 1 - Numero di articoli sul confezionamento dei frutti pubblicati negli ultimi 20 anni reperiti sul database Scopus utilizzando AND quale legame fra le parole chiave (database Scopus visitato il 30 aprile 2018).

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logy (Edmond *et al.*, 1991; Lee and Renault,1998; Oliveira *et al.*, 1998; Fonseca *et al.*, 2000; Kader and Watkins, 2000; Fonseca *et al.*, 2002; Del-Valle *et al.*, 2004; Amoros *et al.*, 2008; Beaudry *et al.*, 2008; Rennie and Tavoularis, 2009; Li and Ban , 2010; Sandhya, 2010; Hussein *et al.*, 2015; Falagán and Terry, 2018) and its use to improve the quality and the shelf-life of different fresh products (Pesis *et al.*, 2002; Alique *et al.*, 2003; Farber *et al.*, 2003; Almenar *et al.*, 2007; Caner *et al.*, 2008; De Reuck *et al.*, 2009; Kim *et al.*, 2010; Caleb *et al.*, 2012; Caleb *et al.*, 2013) and fresh cut products (Farber *et al.*, 2003; Oms-Oliu *et al.*, 2007; Del-Valle *et al.*, 2009; Caleb *et al.*, 2013; Hussein *et al.*, 2015).

According to trends in manufacturing systems and technology many different sizes and shapes of materials are used in fresh fruit and vegetable products (Farber *et al.*, 2003; Mangaraj *et al.*, 2009; Hussein *et al.*, 2015). Furthermore, important changes are occurring today regarding economic and environmental considerations such as the need to adapt to new system handling requirements or mechanical procedures. As reported in the flow chart (fig. 2), many actors are involved in the food packaging system (Badalucco, 2011) that can be defined as an interdisciplinary process. According to Dominic (2005), many authors underscored the importance to have a holistic view of packaging in order to understand consumer demands and improve the efficiencies in pursuit of value creation (Vernuccio *et al.*, 2010).

Different products need different types of packages (Mangaraj *et al.*; 2009; Hussein *et al.*, 2015), depending on their physical, anatomical, and physiology nature and susceptibility to microbial decay. However, all types of packaging need to answer to essential requirements of post-harvest handling. The packaging requirements and functions for fresh produce can be summarized as:

- protection against bruising and physical injury
- protection against microbial contamination and deterioration
- provide ventilation for respiration and exchange of gases
- protect against moisture and weight loss
- slow down respiration rate, delay ripening and increase storage life
- control ethylene concentrations in the package (Sandyha, 2010; Verghese *et al.*, 2015)

Other important functions are related to the logistics (to facilitate the flow of products and, with them, the economic value that they represent) and communication (the packaging has been defined as the silent seller, seller quiet, to emphasize the communicative value). Overall, the packaging means a coordinated system to control products during transport, distribution, storage, sale and end use. The central operation in the cycle of preparation and marketing of food is that it is placed in a suitable container for storage and distribution. This significance is related to the moment when food packaging intervenes between production and consumption, but also to its importance in the business operations of production and distribution to consumers. Production, in fact, is interested in having adequate and cost-effective packaging, and packaging systems that help to streamline the production cycle; the distribution requires that the packaging prolongs the product life, assists in handling and commercial success. Consumers, on the other hand, are interested in obtaining a guarantee from the packaging about the quality of food, the convenience and the attention to environmental protection (Peano *et al.*, 2009). It is interesting to note that the packaging function has been amplified by the transformation of commercial distribution systems in a self-service form. In these cases, the information conveyed by the packaging is not only the selling information (label, decoration, discount or gadgets), but it is also useful to the consumer (nutrition information, recommendations for use, recipes), for regulatory conformity (trademarks, marks, dates) and to help with identification (bar codes or holograms). Additionally, in the fruit and vegetable business, the distribution channels influence the ability of the primary sector operators to remain competitive in a market where the competition is based on the system performance and product quality. One of the priorities of the horticultural weaving factory is a clear need for the production sector to be able to defer the offer maintaining qualitative and

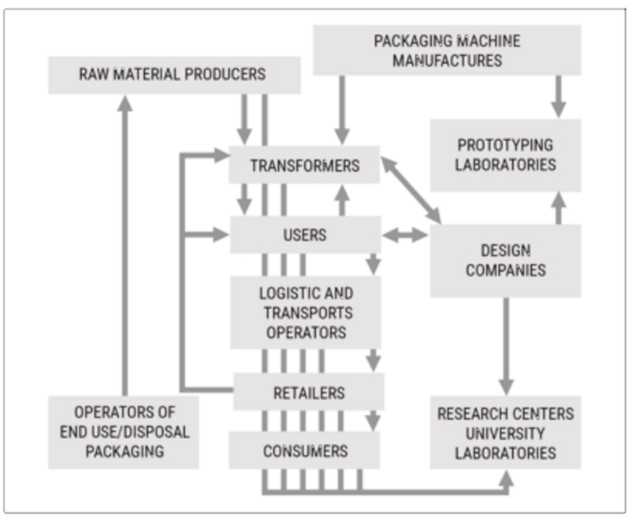

Fig. 2 - Supply chain of food packaging (Badalucco, 2011).
Fig. 2 - Catena del confezionamento (Badalucco, 2011).

organoleptic characteristics unchanged. This process needs to focus on process innovation rather than product innovation. The choices that concern new fruit cultivars or new production areas allow to extend the timetable for the commercial offering; they are not sufficient to compete if not supported by studies on the fruit physiology and techniques of storage. The fruit qualitative potential is produced in the field stage through the correct cultivation techniques and the choice of an appropriate harvest period but must be maintained and improved by the adoption of appropriate technologies during all stages of the weaving factory. This includes the immovable stage (warehouses, cold stores, pavilions) and during transport and transfer, which are both phases where the fruit are subjected to mechanical and physical stress. It is clear that innovation in the management of perishable/freshness is an essential theme of the future of fruit and vegetables, not only for the commercial and distribution systems, but also for the production system. Much success of sales of fresh fruit is determined by the ability to steer the consumer at the moment of choice and retain him or her for future purchases. To achieve this, the crucial step is the packaging product that cannot be carried out through “mass” systems. The current trend in the GDO is to pack more (on filmed or thermo-welded trays) to improve hygiene and reduce waste. The choice of packaging should not be random, but it is closely linked to the type of product, the function of use, the distribution channel and distinction between national and international markets. There is a wide variety of plastic films used for packaging, as there are many types of films produced to be metallized and then laminated in multilayer structures. The properties of these films are significantly influenced by production processes and by subsequent treatments, chemical or physical.

Use of packaging over time

1969-1979

The packaging helps to sell fresh fruit and vegetables in the GDO that began to appear as a form of sale.

1980-1989

This period is characterized by stagnation in the use of packaging. The emergence of electronic scales with the emission of a ticket, in the spaces dedicated to the free service, reduces the interest in the product pre-packed (except fresh cut products). Often the packaged product is linked to low price and quality.

1990-2000

This period witnessed a real revolution in the sale of packaged products. There was an considerable improvement of materials for packaging and the packaged products began to be associated with other functions.

2000 until now

The packaging plays a strong role in the marketing context (advertising, bases for promotion, tool to communicate a new brand). It is a driver for the consumer choices especially when it meets the sustainability requirements.

Fruit packaging and logistics

Flexible packaging is the most common format for fresh-cut produce MAP and is available in preformed bags, roll stock and standup pouches (Husein *et al.*, 2015). Rigid packaging formats consist of a rigid tray or container that may be designed as a clamshell, have a snap-on lid or a sealable, easy-peel lidding film (Toivonen *et al.*, 2009).

Considering the different levels in the entire fresh fruit supply chain, it’s possible to describe different types of packaging that address different logistical needs into three main steps.

From harvest to warehouse

The main function of the packaging in this step is to collect the product from the field and to transport it to the warehouse while preventing and avoiding losses due to mechanical climatic and biological hazards. Generally, returnable packaging such as wooden or plastic bulk bins and wooden boxes are used in this phase for fruit, such as kiwifruit, apples, pears, and nectarines. Bins are vented to improve the storability of product. When they are empty, they are palletized and transferred to the truck. They can be stocked directly into the refrigerated storage space (normal or controlled atmosphere) before fruits become processed. Most fresh perishable products such as soft berries (blueberries, raspberries, cranberries and strawberries) are currently directly hand-picked into baskets or consumer units (250,150 g) of polyethyleneterephthalate (PET). Also, most of the leafy vegetables are field packaged into cartons or crates and then transported to cooling facilities. These shipping containers are often wax covered (Cantwell and Kasmire, 2002). Some products (tomatoes and melons) are loaded into a fiber-reinforced plastic gondola attached to a highway trailer (Kader, 2002).

From warehouse to platform of distribution

After the product is received from the field, some operations occur in the warehouse before the packaging process occurs (fig. 3). In some cases, the product may be cooled before packaging (especially with apples, pears, kiwifruits, citrus, dry onions, cabbage, sweet potatoes, garlic, carrots and winter squashes); roots and tubers need to be cleaned and some fruits are waxed (Thompson *et al.*, 2002). During the storage cooling time, some packaging tools using modified active atmosphere (www.van-amerongen.com www.fruitsrougesandco.com) (Peano *et al.*, 2016, Peano *et al.*, 2017) can be used like pallet bags similar to systems used for shipment transports (www.transfresh.com). The packaging process can be mechanized or by hand. In the first case, systems work large volumes (fill or tight fill) of products at high speed. After filling, the packages pass through inspection, marking and closing operations and can receive special top padding. In the case of hand packaging operations, products receive visual inspection of quality and can be packed according to specific special presentation. Hand–packing operations can be associated also to mechanized operations. Packaging materials such as trays, cups, wraps, liners or pads are facilities for packaging operations used for undersized products in this phase. In the warehouse, specifying labelling operations are required. After packaging operations, products are palletized and transported to retail stores according to different transport methods. Pallets for sea transport may not exceed a total height of 2.05 m, to allow for transportation by truck and warehousing in intermediary depots. Standard sizes include: ISO pallet size of 1200x1000 mm, also called the sea pallet and European pallet size of 800x1200 mm, used in some parts of Europe.

At the seller or retailer point

Some packaging systems as designed for use in retail display. Packages used in retail display must fit the needs of the retailer, so package appearance becomes much more important than for other types of packaging (Thompson and Mitchell, 2002). The progressive growth of modern distribution and the rapidity of socio-economic changes affect the types of packaging that actually are at the retailer point. A common and economic practice for fresh products that are not pre-packed is to display them in the transport package received from the supplier and country of origin. This type of presentation is often used by “greengrocers” to show off exclusive and exotic produce. In these situations, it is crucial to use an attractively designed transport package displaying the produce at its best. The produce should also display a clean and tidy appearance. When fresh produce is presented unpacked and loose for self-service selection by the shopper or for sale by the piece, identification through a tag, sticker or package band is a better branding technique than relying on the branding on packaging where performance remains the main criterion (fig. 4).

Packaging requirements for fresh products

To develop the best type of packaging for a fresh product, it is necessary to know the characteristics of the commodity in terms of physiology (respiration

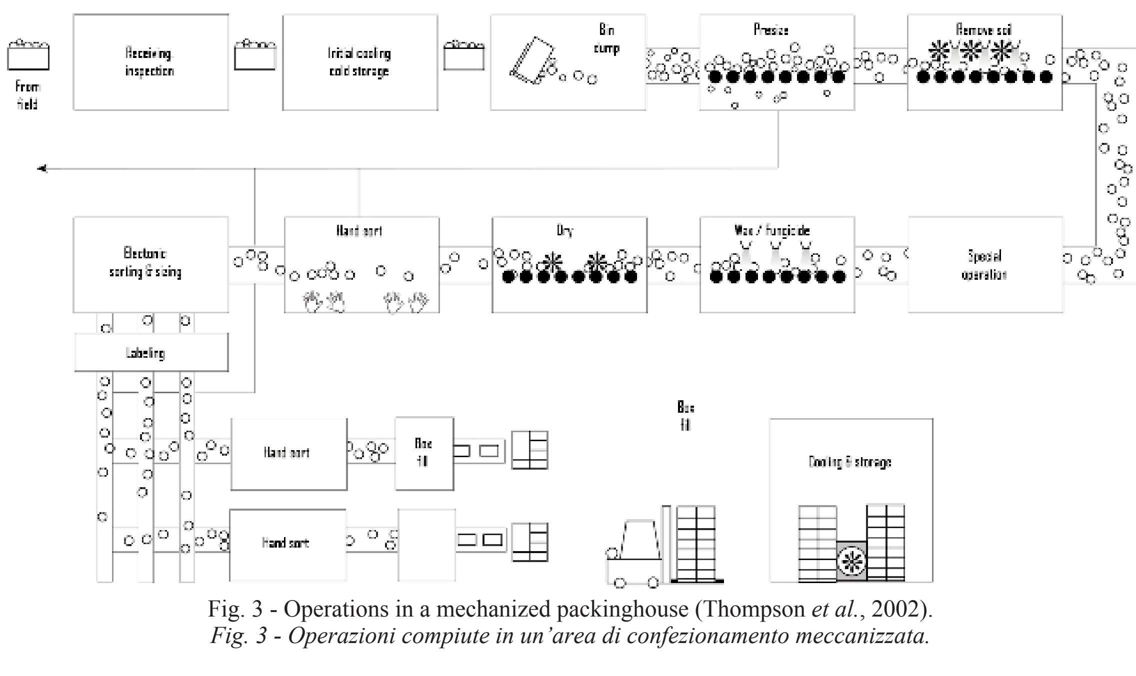

Fig. 3 - Operations in a mechanized packinghouse (Thompson *et al.*, 2002).
Fig. 3 - Operazioni compiute in un’area di confezionamento meccanizzata.

Fig. 4 - Identification of unpackaged fruits at the retailer point.
Fig. 4 - Frutti non confezionati.

behavior during the post-harvest chain, transpiration and ethylene production rate) (Beaudry *et al.*, 1992; Fonseca *et al.*, 2002; Song *et al.*, 2002), the storage environmental conditions during the market circuit (T, RH%, light intensity) and the type and nature of material. This especially relates to the thickness, surface area of material and permeation to water and gas O2 and CO2. Considering all of these aspects, a lot of mathematical models are reported to design and develop the most suitable packaging for different fresh fruits (Mahajan *et al.*, 2007; Sandya *et al.*, 2010; Defraeye *et al.*, 2013; Belay *et al.*, 2016). Some commodities need some special post-harvest treatments that must be considered in the packaging selection and design. For example, asparagus must be packed upright to avoid curvature caused by geotropism and needs a moist pad to limit water loss. Also, berries at some packing facilities need similar pads to avoid compression and abrasion damage during handling. Recently pads containing antimicrobial agents were investigated to evaluate the shelf life of strawberries (Chiabrando *et al.*, 2017; Hakymi *et al.*, 2017; Bovi *et al.*, 2018). Additionally, to control the decay of grapes, some sulfur dioxide fumigation are necessary after harvest, so well-vented packages are required to flow gaseous treatments (Thompson and Mitchell, 2002). For the fresh product, the maintaining of the optimal temperature during the storage time is fundamental for the design of the packaging to significantly affect the efficiency of the cooling rate and its uniformity around the product. Different studies were performed to model the efficiency of ventilated packaging (Shing *et al.*, 2008; Chourasia and Goswami, 2009; Vigneault *et al.*, 2009; Pathare *et al.*, 2012; Getahuna *et al.*, 2017) on different species but each approach needs to consider the product size (diameter or volume) and the location of the fruit and trays inside the package.

Materials

Petrochemical-based plastic

The definition of the plastic term is reported by the ASTM D833. Traditionally, petrochemical-based plastic materials were used only for primary or secondary packaging, but now they are considered at all levels in the supply chain. Different formats are available (flexible, semirigid, and rigid) and for the different types of polymers added with other chemical additives (fillers, anti-fog, antistatic agents, lubricants, stabilizers, plasticizers, colourants, processing aids) are used. Generally flexible materials (thickness ≤ 0.127 mm) are applied for wraps, lidding, pouches or bags; semirigid materials (> 0.127 mm) are used as sheets while rigid materials, including different applications such as containers, may be designed as a tray or clamshell (Toivonen *et al.*, 2009). Plastic materials are generally used as primary packaging but their use as secondary and transport is now increasing. In particular re-usable plastic boxes and trays are replacing single-use cardboard and wooden boxes. The most common raw materials used for fresh fruit and vegetable products are described in the following.

Polyethylene (PE) is the dominant plastic material used today with a 56% market share. PE is strong, stiff, ductile and tough while maintaining a glassy state (i.e., at temperatures below glass transition point where side motion is restrained) and can be oriented by stretching during molding and extrusion, which increases its strength and stiffness still further. Different types of polyethylene are available according to different density (high, medium, low), water and gas transmission (tab. 1). Applications of this material in combination with different type of post harvest treatments were used on different type of fresh fruits and vegetables such as peaches (Dhaliwal and Salunkhe, 1963; Santos *et al.*, 2008; Santana *et al.*, 2011), apricots (Ishaq *et al.*, 2009), plums (Singh

Tab. 1 - Basic properties of various PE films.
Tab. 1 - Proprietà di diversi films PE.

Type of polyethylene	Water vapour transmission	Gas transmission O_2 CO_2	
Low density (LPDE) 920 kgm^{-3}	1.4	500	1350
Medium density (MPDE) 940 kgm^{-3}	0.6	225	500
High density 960 kgm^{-3} (HDPE)	0.3	125	350

and Singh, 2012), citrus (Porat *et al.*, 2004), mandarins (Ladaniya and Sonkar, 1997; Randhawa *et al.*, 2009), oranges (Ben Yehoshua *et al.*, 2001; Palou *et al.*, 2003), tomatoes (Srinivasa *et al.*, 2006; Akbudak *et al.*, 2006), pears (Geeson *et al.*, 1991; Ning *et al.*, 1997; Li *et al.*, 2013), persimmon (Ben-Arie *et al.*, 1991; Nakano *et al.*, 2001), muskmelon (Yahia and Rivera, 1992), bel peppers (González and Tiznado, 1993; González-Aguilar *et al.*, 1999; Srinivasa *et al.*, 2006), strawberries (Picón *et al.*, 1993; Jiang *et al.*, 2013), apples (Li *et al.*, 2010; Wijewardane and Guleria, 2013; Jung *et al.*, 2015), avocados (Illeperuma and Nikapitiya, 2002; Baskaran *et al.*, 2002), cherries (Meheriuk *et al.*, 1995; Remón *et al.*, 2000; Petracek *et al.*, 2002; Miguel-Pintado *et al.*, 2017), grapes (Lichter *et al.*, 2008; Xu *et al.*, 2013), mangoes (Pesis *et al.*, 2000; Illeperuma and Jayasuriya, 2002), cantaloupes (Halloran *et al.*, 1999), raspberries (Toivonen *et al.*, 1999), banana (Chauhan *et al.*, 2006; Ahmad and Thompson, 2007; Bastiaanse *et al.*, 2010; Prill *et al.*, 2012; Sahay *et al.*, 2015).

Polyamide (PA) is a polymer developed by nylon. It is mainly used as fillers, plasticizers, antioxidants and stabilizers but it can be available for many films, pouches and bag-in-box structures. PA films are highly permeable to water vapor since the amide group is polar. PA competes with biaxially oriented PET but it shows a better gas barrier, softness and puncture resistance.

Poly (Ethylene Terephthalate) (PET) in function of its physical state crystalline (25-35% crystallinity, heat stable to 127°C, opaque) or oriented crystalline (35-45% crystallinity, heat stable to 140-160°C, clear) can be used respectively for trays or films (Robertson, 2003). PET films are most widely used in the biaxially oriented, heat stabilized form. It is the most commonly used packaging material world-wide for marketing berries. The use of post-consumer recycled PET (PCRPET) is gaining market acceptance for food use due to the sophisticated decontamination processes available (Welle, 2011). PET is also used to make "ovenable" trays for frozen food and prepared meals, where they are preferable to foil trays because of their ability to be microwaved without the necessity for an outer paperboard carton.

Polypropylene (PP), is one of the most versatile packaging materials due its low cost, heat resistance and chemical inertia (Kalaitzidou *et al.*, 2007). It is used mainly for flexible application (mainly films and bags) and it is also used as a barrier layer (Siracusa *et al.*, 2012; Sahoo *et al.*, 2015). It shows a lower density (900 kg m^{-3}) and a higher softening point (140-150°C) than the PEs, low water vapor transmission, medium gas permeability, good resistance to grease and chemicals, good abrasion resistance, high temperature stability, good gloss and high clarity. This polymer can be processed as unoriented film or biaxially oriented film (BOPP). The biaxial orientation is able to improve the moisture barrier properties of PP film and its low-temperature impact strength (Fortilene Polypropylene Properties, Processing, and Design Manual, 1981). Standards related to PP films are ASTM D2103-10 and ASTM D2673-09. Some returnable plastic containers are made in PP and represent the fruit supply chain in a virtuous way within a circular economy. An example of this is the CPR system (fig. 5). The CPR boxes agree with the European standards UNI-EN 13117 and thanks to their collapsible sides, this allows to save space and cost (4 closed boxes occupy the space of one open).

Ethylene vinyl alcohol (EVOH) is a copolymer of ethylene and vinyl alcohol. It is an excellent barrier to oil, fat, and oxygen. However, EVOH is moisture sensitive and is thus mostly used in multilayered co-extruded films (Sandhya, 2010; Dhawan *et al.*, 2014; Briassoulis *et al.*, 2017) in situations where it is not in direct contact with liquids (Marsh and Bugusu, 2007). Different research has been interested in this material to develop antioxidant active packaging (Lopez-de-Dicastillo *et al.*, 2010; Lopez-de-Dicastillo *et al.*, 2011; Muriel-Galet *et al.*, 2013).

Polystyrene (PS) belongs to the substituted olefins group and was marketable as the first moldable clear rigid plastics. It was considered as an antimicrobial support of lysozyme and synthetic peptides in some

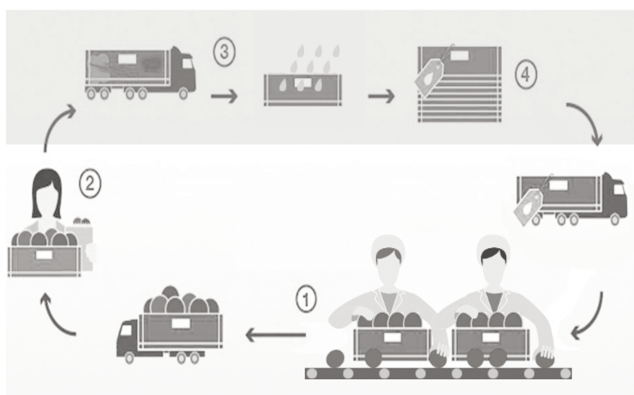

Fig. 5 - CPR system management (modified from www.cpr.system.it). 1. Use of CPR system in the packaging operation in the warehouse; 2. Use of CPR system at the retailer point; 3. Sanitization management of the used CPR box ; 4. New entry in the circuit.

Fig. 5 - Il sistema CPR (modificato da www.cprsystem.it). 1. Utilizzo del CPR system nelle operazioni di confezionamento in stabilimento; 2. Utilizzo presso il rivenditore finale; 3. Sanificazione delle confezioni CPR utilizzate; 4. Reimmissione nel circuito.

food antimicrobial packaging applications (Mermelstein 1998, Haynie *et al.*, 1995). Following the standard specification for rigid cellular polystyrene thermal insulation (ASTM C578), it shows good thermal and moisture resistance and it has good properties to be thermoformed. Additionally, PS can be used for foamed trays that need to be covered with a wrapping film or shipping box for fruit and fresh vegetables (Wu *et al.*, 2016; Kwanhong, 2017). Recently Capozzi *et al.*, 2018 used this material to develop active labels to promote the ripening of fruits.

The success of the plastic materials is thanks to their versatility to the different way of processability. Table 2 reports the most important use of flexible packaging for fresh products.

Paper and Paper-Based Packaging Materials

Paper packaging can be divided into three main groups: corrugated boxes, cartons and packaging papers. All these materials are from a pulping process that reduce the fibrous raw materials (cellulose, hemicelluloses, lignin) to a fibrous mass due to mechanical, thermal and chemical treatments (Kadla and Day, 2006). Because of their geometrical design, corrugated boxes are predominantly used to export a wide variety of commodities (Berry *et al.*, 2015; Pathare *et al.*, 2012), bulk handling and marketing (Opara and Pathare, 2014). The materials used on the inner and the outer layers are determined by the product it will hold. For example, the inner layer may be coated to resist moisture while the outer layer will usually be printed to identify the contents and for displaying inside retail outlets (FEFCO, 2011). The most common way to specify a corrugated board is by basic mass or grammage (mass per unit area) where higher basic mass results in stiffer and stronger board (Pankaj *et al.*, 2014). For produce transportation, double-faced corrugate is commonly used. The good stacking strength (when dry), the easy availability, the low cost (Twede and Harte, 2003), the low mass (saves money when transporting), the suitable printability, and recyclability (Allansson and Svard, 2001) have allowed them to be a prime choice for fresh produce packaging and most commonly used for consumer packaging (38%) (Pankaj *et al.*, 2014). Reduced mechanical damage has been reported using them on apples (Jarimopas, *et al.*, 2007) and mangosteen (Darmawati *et al.*, 2009, Sugiyono, *et al.*, 2010). The resistance to compressive forces, vibration and exposure to fluctuating storage temperature are functions of the presence of vents that are suggested to be less than 5% of the total box wall area (Kader, 2002, www.hortgro.co.za). The ventilation area is also fundamental to affect the cooling rate, the uniformity and its efficiency during the storage process. Different studies were performed to model the effect of ventilated packaging on different species (Defraeye *et al.*, 2013; Han *et al.*, 2015) but each approach needs to consider the product size (diameter or volume) and the location of the fruit and trays inside the package (Han *et al.*, 2017). Considering some negative aspects, paper-based materials are poor barriers to gases and water vapor, so generally the waxing process is necessary to improve these properties. Recycling the paperboard has proven to be challenging because the wax must be separated from the fibers so that they can be repulped. Because coating with paraffin wax or continuous film (LDPE, EVA) are associated with difficulties in the recycling process, different studies have been considered to apply bio-based material (starch and cellulose derivatives, chitosan, alginate, wheat gluten, whey proteins, polycaprolactone, PLA and polyhydroxyalkanoat) to simplify the recycling process.

Wood is largely used for transport packaging, in the form of crates, boxes and pallets (tertiary packaging). Good performance is related to its puncture

Tab. 2 - Most common uses of flexible films for fresh package products.
Tab. 2 - I più comuni film utilizzati per il confezionamento di prodotti freschi.

Nets	The nets allow the end user to see and feel the product being purchased. Nets are used for products such as potatoes, carrots, onions, garlic or citrus that are damage–resistant. The flexibility of sacks and bags means that they offer no support for the produce and do not protect it from top loads when stacked. Nets are in PP or PET and are also used to wrap baskets of fruits such as plums, apricots, table grape, kiwifruits.
Trays	They are from a termophored process, generally in PET. The cover film is also made from macrofored PE or PP, which makes sealing relatively straightforward. Fruits that are from organic production are wrapped with a monolayer extruded film to best isolate and protect products. The addition of salt into the polymer matrix of packaging trays represents a possible approach to control in-package humidity for fresh produce (Singh *et al.*, 2010; Rux *et al.*, 2015; Rux *et al.*, 2016; Mahajan *et al.*, 2017).
Baskets and clamshell	They represent the consumer units for different fruits, such as berries. Clamshell trays offer higher damage protection when stacked. Different studies reported good performances of bio-based PLA clamshell as an alternative to petroleum-based PET for storage fruits. (Almenar *et al*., 2010; Joo *et al*., 2011; Zhou *et al*., 2016)

resistance, tensile and compression strength, even if its use is influenced by the moisture content. Conifers species such as pine (*Pinus elliottii*) are the main raw material for manufacturing the pallets (Strutt *et al.*, 2013). Around 400 million wood pallets are produced in Europe every year and 3000 companies are employed (European Confederation of Woodworking Industries, 2011). If compared to plastic pallets, wood pallets are cheaper but they have some negative and unsustainable environmental factors due to forest depletion. Wood is also used to make bins and boxes to collect directly different fruit at the harvest time, but since it is adsorbent and porous material, it needs sanitary processing. Wooden crates may also have rough surfaces with sharp nails and staples. If containers are overpacked, compression damage will occur when they are stacked. Wooden packaging applications, including trays, punnets, and storage boxes for vegetables, are favorable for organic products.

Bio-based and Biodegradable packaging materials

The global market for bio-based and biodegradable packaging materials, generally associated with the terminology of biodegradable plastics, which started out as a niche product, has grown significantly in the last few years; a significant amount is represented by products coming partially or totally from renewable resources. According to their origin and method of production, these materials can be included into for main groups (Siracusa *et al.*, 2008; Robertson, 2013).

- Polymers directly extracted from biomass such as starch, cellulose and chitin (Muratore *et al.*, 2005; Durango *et al.*, 2006; Briano *et al.*, 2016; Giuggioli *et al.*, 2017; Vähä-Nissi *et al.*, 2017).
- "Classical" polymers synthesized from bioderived monomers such as polylactic acid (PLA) and bio-polyethylene (bioPE) (Almenar *et al.*, 2008; Briassoulis *et al.*, 2013; Qin *et al.*, 2016; Burgos *et al.*, 2017).
- Polymers produced directly by natural or genetically modified organisms such as polyhydroxyalkanoates (PHA) (Vandewijngaarden *et al.*, 2016; Burgos *et al.*, 2017).
- Polymers whose monomers are obtained from petrochemical-based monomers such as poly (caprolactone) (PCL), poly (butylene succinate-co-adipate) (PBSA) and PBAT (Makino and Hirata, 1997; Wang *et al.*, 2016;Yun *et al.*, 2017; Sogut and Seydim, 2018)

Commercially the most rapresentative developed materials are Mater-BiTM (www.materbi.com), NatureWorksTM Polylactide (http://www.cargill-dow. com), BioskaTM (www.plastiroll.fi), BioplastTM (www.biotec.de), SolanylTM (www.bio-polymer.net), PotatopacTM (www.potatoplates.com), GreenfilTM (www.greenlightint.co.uk) and Eco-FoamTM (www.eco-foam.com) (Davis and Song, 2006). Table 3 reports the properties of multilayered bio-based film.

Label and fresh product packaging

The label is an integral part of the packaging and is well-known to influence food choice (Grunert and Wills, 2007; Peters-Texeira and Badrie, 2005; Campos *et al.*, 2011; Mhurchu *et al.*, 2018). Labeling acts as a silent salesman through distinctive branding and facilitates identification in the supermarket during check-out through the Universal Product Code (UPC). The label can differentiate and market the product while underlining some quality attributes (Golan *et al.*, 2004). It is an instrument of traceability due to the incorporated unique codes that are available, such as printed barcodes or electronic radio frequency identi-

Tab. 3 - Main properties of multilayered bio-based film (modfied from Peelman *et al.*, 2013).
Tab. 3 - Principali caratteristiche del film bio-based *(modificato da Peelman* et al.*, 2013)*

Film	Shape	Permeability		Thickness (μm)
		O_2 (cc/m^{2}d) at 23°C-75% RH	H_2O (g/m^{2}d) at 38°C-90%RH	
NatureflexTM N913 (cellulose-based)	Flex.film (tr*)	9.9	10.1	55
NatureflexTM N931 (cellulose-based)	Flex.film (n-tr**)	3.4	5.0	44
Ecoflex+Ecovio/Ecovio/Ecoflex+Ecovio	Flex.film (n-tr)	815.0	216.4	55
Bioska504 (multilayer PLA)	Flex.film (tr)	617.6	275.1	34
NatureflexTM/PLA	Flex.film (tr)	11.01	11.3	60
PLA tray	Tray (tr)	46.8	3.8	200-300

* tr= transparent
** n-tr = non transparent

fication (RFID). In the specific case of fresh fruit and vegetables, it provides information to the consumer about the net weight, the product origin, the producer, the farming method (organic or traditional), the legal limits of eventual chemical residues, the brand identification and the pricing. The labelling varies in function of the presentation of the product at the point of sale (POS) (fig. 6). In fact, the labeling requirement covers both pre-packaged products and those sold without packaging. According to EU 1169/2011 legal requirements, a closed pre-packed consumer product will always have a label and to be scanned at the POS. Fresh fruit and vegetables delivered to the store to be picked by the consumer and weighed or counted at the POS, may carry a label in function of their size and nature. In this case, the decision to label is at the discretion of the retailer. Considering the organic farming products, a label is obligatory and differs depending on the certification body, the standards against which the production is certified and/or in which national market the product is sold. The labels are made in paper for easy printability and the layer separation is required for the final recyclability of the packaging. To improve the communication of green marketing initiatives along all the fruit supply chain process, labels can be an interesting tool, as reported by Tecco *et al.*, 2016.

New trends and future development

The future trends are related with industrial development, able to produce competitive products in performance and price. Different needs to be considered to develop innovative solutions in the fresh fruit and vegetable packaging sector. Considering the MAP technologies researches should focus on optimising of gas permeation behavior upon undesired environmental changes or reversible temperature changes by selection of appropriately permeable packaging materials, and on improving their interaction with active materials such as antimicrobials, antioxidants, O2 scavengers, CO2 emitters/absorbers, moisture regulators, flavor releasers, nanoparticles. According to legal issues novel materials (edible, biodegradable materials, plant extracts and nanomaterials) should be reasonable in price and suitable for packaging machines already in use for the actually sealing packaging procedures. Studies on consumer response to the use of packaging which replies to eco-sustainability requirements maintaining high qualitative standards of the products represent a good indicator to the concept of green logistic system acceptance. The most explored strategy for decreasing the environmental impact of packaging is by minimizing the packaging material impact through light-weighting of packaging materials and/or removal of excessive packaging (van Sluisveld and Worrell, 2013). Another approach is the selection of more renewable materials, and enhancing the efficiency and energy consumption associated with sourcing, producing and converting packaging materials (Wikstrom *et al.*, 2014). A perspective is in improving packaging attributes that influence behavior such as "easy to empty", easy to clean", "easy to separate into different fractions", "easy to fold" and "information on how to sort" (Wikstrom *et al.*, 2016). It is therefore possible to imagine that a future challenge can be integration of behavioral sciences into LCA to improve packaging and provide valuable insights to eco-design .

Abstract

Packaging is fundamental to fresh commodities, such as fruits and vegetables, due to their quick perishability. It is imperative that the materials used in their supply chain answer to their variety of needs. The aim of this review is to focus on the typologies of packaging that are effectively used at different levels

Fig. 6 - Labels on fruit at the sales point (PO).
Fig. 6 - Esempi di etichette al punto vendita.

of the fresh fruit and vegetable supply chain, including the materials considered.

Key words: packaging, supply chain, film, materials, innovation.

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