REVIEW

Trends in Fruit and Vegetable Packaging – a Review

Mario Ščetar*, Mia Kurek, Kata Galić

University of Zagreb, Faculty of food technology and biotechnology, Pierottijeva 6, 10000 Zagreb, Croatia

Summary

Processing and packaging are the two important phases of operations in the food industry. The final phase is the packaging stage. A great deal of automation strategies are constantly being utilized in every phase of processing and packaging.

The correct packaging enables processors to pack fresh and fresh-cut fruit and vegetables and extend their shelf life. The important parameters for this shelf life extension are temperature, moisture and a modified atmosphere (oxygen, carbon dioxide and ethylene). If both temperature and packaging are optimal, ageing of fruit and vegetables can be slowed down significantly.

This paper is concentrate on trends in fruits and vegetables packaging.

Keywords: fruit, vegetable, packaging, shelf-life

Sažetak

Tehnološki procesi prerade i pakiranja su dvije vrlo važne faze u prehrambenoj industriji. Završna faza je faza pakiranja. Uvelike prisutna strategija automatizacije stalno se koristi u svim fazama obrade i pakiranja.

Adekvatno pakiranje omogućava proizvođačima pakiranje svježeg i svježe rezanog voća i povrća i povećanje njihovog roka valjanosti. Važni čimbenici u povećanju roka valjanosti su temperatura, vlaga i sastav modificirane atmosfere (kisik, ugljikov dioksid i etilen). Ukoliko su temperatura i ambalaža optimalni sazrijevanje voća i povrća može se značajno usporiti.

Ovaj rad daje pregled novih spoznaja u pakiranju voća i povrća.

Ključne riječi: voće, povrće, pakiranje, rok valjanosti

Introduction

Fruit and vegetables play an important role in healthy nutrition and are high on the list of consumer priorities. However the major obstacle of purchasing ready-to-eat fresh-cut fruits and vegetables is their short shelf life, leading to quick degeneration and decomposition of the product and undesirable look and negative palatability. Fruit and vegetables are living products undergoing a ripening and at the end an ageing process, in which the plant tissue is broken down. The products undergo various biological processes, which also continue after the products have been harvested. For example there is wide variation in respiration rates (Table 1) and ethylene production (Table 2) between fruits and vegetables.

Conventional packs

It is essential to minimise physical damage to fresh produce in order to obtain optimal shelf-life. The use of suitable packaging is vital in this respect (Thompson, 1996). The most common form of packaging in this sector is the use of the fibreboard carton; however, for most produce, additional internal packaging, for example tissue paper wraps, trays, cups or pads, is required to reduce damage from abrasion. For very delicate fruits, smaller packs with relatively few layers of fruits are used to reduce compression damage. Moulded trays may be used which physically separate the individual piece of produce. Individual fruits may also be wrapped separately in tissue or waxed paper. This improves the physical protection and also reduces the spread of disease organisms within a pack.

Table 1. *Respiration rates of selected commodities (Rizvi, 1981)*

Commodities	**Respiration Rate at 5 °C ($mL\ CO_2\ kg^{-1}\ h^{-1}$)**
Dried fruits and vegetables, nuts	<5
Apple, grape, potato (mature), onion, garlic	5–10
Apricot, carrot, cabbage, cherry, lettuce, peach, plum, pepper, tomato	10–20
Blackberry, cauliflower, lima bean, raspberry, strawberry	20–40
Brussels sprouts, green onion, snap bean	40–60
Asparagus, broccoli, mushroom, pea, spinach, sweet corn	>60

Corresponding author: mscetar@pbf.hr

Table 2. *Clasification of fruits according to their maximum ethylene production rate (Kader, 2002)*

Commodities	**Ethylene production rate** (µL/ kg · hr at 20 °C)
Citrus fruits, strawberry, artichoke, cauliflower, cherry, asparagus, potato, grape, leafy vegetables, root vegetables	Very low: 0.01-0.1
Pineapple, blueberry, raspberry, blackberry,cranberry, aubergine, persimmon, cucumber, olive, sweet pepper, chili pepper, pumpkin, watermelon	Low: 0.1-1.0
Banana, fig , mango, honeydew melon, mango, tomato	Moderate: 1.0-10.0
Kiwifruit (ripe), apple, avocado, plum, peach, apricot, nektarine	High: 10.0-100.0
Exotic fruit, cherimoya	Very high: >100.0

Packaging can be a major item of expense in produce marketing, so the selection of suitable containers for commercial-scale marketing requires careful consideration.

Besides providing a uniform-size package to protect the produce, there are other requirements for a container:

- it should be easily transported when empty and occupy less space than when full, e.g. plastic boxes which nest in each other when empty, collapsible cardboard boxes, fibre or paper or plastic sacks;
- it must be easy to assemble, fill and close either by hand or by use of a simple machine;
- it must provide adequate ventilation for contents during transport and storage;
- its capacity should be suited to market demands;
- its dimensions and design must be suited to the available transport in order to load neatly and firmly;
- it must be cost-effective in relation to the market value of the commodity for which used;
- it must be readily available, preferably from more than one supplier.

Owing to perishability, the bulk of fresh fruit and vegetables are still sold unpacked at retail or wholesale level in perforated polyethylene (PE) bags or nets. Long term transport of these materials must remain minimal to avoid brushing and consequent decay of the loosely package product. When packaging is required at the source or when an extended storage life is desired, the packaging film should have a high gas permeability and anti-fog properties. The packaging of fresh vegetables and fruit provides the largest single use of printed PE bags. The prepackaging of potatoes, carrots, onions, parsnips, beets, radishes etc. for market sales has become an important aspect of food distribution. Because of low water vapour permeability of PE and polypropylene (PP), both films and bags are sometimes perforated to allow the product to ‘breathe’. Permeation is the key to extending fresh produce shelf life.

For most commodities light is not an important influence in their post-harvest handling. However green vegetables, in the presence of sufficient light, could consume substantial amounts of CO_2 and produce O_2 through photosynthesis. Shock and vibration leads to damage to produce cells which causes an increase in respiration and may lead to enzymes being released that will cause browning reactions to begin.

Modified atmosphere packaging (MAP)

Polymeric films have been used to package fresh products for over 35 years, with a number of benefits, including control of water loss, protection from skin abrasion and reduced contamination of the produce during handling. They also provide a barrier to the spread of decay from one unit to another (Kader, 1980). These films will also affect the movement of respiratory gases depending on the relative permeability of the film. This can lead to the development of lowered O_2 and raised CO_2 levels within the package and, as with control atmosphere (CA) storage, this can reduce the respiration of the produce and potentially extend shelf-life.

A modified atmosphere (MA) can be created within the pack in two ways. Active modification involves the pulling of a slight vacuum within the pack and then replacing the atmosphere with the desired gas mixture. Absorbers (active packaging) of CO_2, O_2 or ethylene may be included within the pack to control the concentration of these gases. In passive modification systems, the atmosphere is attained through the respiration of the commodity within the pack. The final equilibrium atmosphere will depend on the characteristics of the commodity and the packaging film (Kader, 1980). Temperature control is extremely important with MAP, as this will influence the gas permeability properties of the film as well as the respiration rate of the product. One of the main drawbacks to MAP is the potential for O_2 levels to fall too low and cause the production of undesirable off-odours caused by fermentation of the tissues.

The MA packaging technique consists of the enclosure of respiring produce in polymeric films in which the gaseous environment is actively or passively altered to slow respiration, reduce moisture loss and decay and/or extend the shelf life of the products. Many of the films used in MAP, singly do not offer all the properties required for a modified atmosphere pack.

To provide packaging films with a wide range of physical properties, many of these individual films are combined through processes like lamination and co-extrusion. There are several groupings in MAP films. Polyethylene is most commonly used to provide a hermetic seal and also as a medium of control for characteristics like anti-fogging abilities, peelability and ability to seal through a degree of contamination. The degree to which atmospheric modification takes place in packages is dependent upon several variables such as film permeability to O_2 and CO_2, product respiration and the influence of temperature on both of these processes (Beaudry et. al., 1992; Beaudry, 1999; Cameron et. al., 1994).

Accordingly, there has been a lot of commercial interest to develop films with high gas transmission rates (Lange, 2000). High gas transmission films are obtained by modifying the film manufacturing process so that gases such as O_2, CO_2 and water vapour exit or enter the package in a controlled manner such that aerobic respiration needs are met and desirable CO_2 and moisture levels are maintained.

For most plastic films, CO_2 permeability is 2-6 times greater than that of O_2, which provides a range of CO_2/O_2 permeability ratios. This allows the selection of films of suitable rations for some products.

Thus, packaging film of the correct permeability must be chosen to realise the full benefits of MAP of fresh produce (Day, 1998). Typically, the key to successful MAP of fresh produce is to maintain an equilibrium MA (EMA) containing 2–10 % O_2/CO_2 within the package. For highly respiring produce such as mushrooms, beansprouts, leeks, peas and broccoli, traditional films like low-density polythene (PE-LD), poly(vinyl chloride) (PVC), ethylene/vinyl acetate (EVAC), oriented polypropylene (OPP) and cellulose acetate are not sufficiently permeable. Such highly respiring produce is most suitably packed in highly permeable microperforated films.

The permeabilities of two commercial ceramic-filled PE-LD films were measured and compared with those of a plain PE-LD film. The ceramic films have higher oxygen (O_2), carbon dioxide (CO_2) and ethylene (C_2H_4) permeabilities, higher

Table 3. *Gas permeability and water transmission rate (WTR) of polymeric film available for packaging of MAP produce (Chung and Yam, 1999; Day, 1993; Greengrass, 1993; Guilbert et al., 1996; Han, 2000; Park, 1999; Phillips, 1996).*

Film	**Permeability** (cm^3/m^2 d atm) for 25 µm film at 25 °C			**WTR** (g/m^2/day/atm) at 38 °C, 90% RH
	O_2	**N_2**	**CO_2**	
Ethylene- vinyl alcohol (EVAL)	3–5	–	–	16–18
PVdC–PVC copolymer (Saran)	9–15	–	20–30	–
Low-density polythene (PE- LD)	7800	2800	42.000	18
High-density polyethylene (PE-HD)	2600	650	7600	7–10
Polypropylene cast (PPcast)	3700	680	10,000	10–12
Polypropylene, oriented (OPP)	2000	400	8000	6–7
Polypropylene, oriented, PVdC coated (OPP/PVdC)	10–20	8–13	35–50	4–5
Rigid poly(vinyl chloride) PVC	150–350	60–150	450–1000	30–40
Plasticized poly(vinyl chloride) (PVC-P)	500–30.000	300–10.000	1500–46.000	15–40
Ethylene - vinyl acetate (EVAC)	12.500	4900	50,000	40–60
Polystyrene, oriented (OPS)	5000	800	18,000	100–125
Polyurethane (PUR)	800–1500	600–1200	7000–25,000	400–600
PVdC–PVC copolymer (Saran)	8–25	2–2.6	50–150	1.5–5.0
Polyamide (Nylon-6), (PA)	40	14	150–190	84–3100

CO_2 to O_2 permeability ratio, and higher C_2H_4 to O_2 permeability ratio (Lee et. al., 2006). Table 3 gives the details of film types and permeability availability. Films that have improved rates of gas transmission by virtue of their polymeric nature are usually blends of two or three different polymers, where each polymer of a blend performs a specific function such as strength, transparency and improved gas transmission to meet certain product descriptions. Furthermore, films can be laminated to achieve needed properties. Among this class are high (6–18 %) EVAC content, PE-LD, oriented polypropylene laminates, styrene butadiene block copolymer films and ultra low-density ethylene octene copolymer films and polyolefin plastomer octene copolymer films. A lot of work has been reported on MAP using different types of films (Barth and Zhuang, 1996; Geeson et. al., 1994; Hong and Kim, 2004; Jacobsson et. al., 2004; Lee et. al, 2002; Porat et. al., 2004; Schick and Toivonen, 2002; Srinivasa et. al., 2002). Commercially available MAP systems for small and large quantities of produce are given in Table 4. Films using micro perforations can attain very high rates of gas transmission (Alique et. al., 2003). The diameter of micro perforation generally ranges from 40 to 200 µm and by altering the size and thickness of micro perforations; gas permeability through a package can be altered to meet well defined product requirements. Based on the rates of respiration and gas transmission through the micro perforations and the base film, packages have been developed that maintain desired levels of O_2 and moisture for high respiring mushrooms (Gosh et. al., 2000). Micro perforated films have also been used to extend the storability of strawberries and nectarines (Meyers, 1985), leeks, asparagus, parsnips, cherry tomatoes, sweet corn (Geeson, 1988) and apple (Watkins et. al., 1998). A procedure permitting the simple determination of O_2 and CO_2 permeance of micro perforated films used to pack respiring foods under real conditions has been evaluated (Ozdemir et. al., 2005). Macro perforated films has also been used to improve the keeping quality of strawberries and raspberries by combining high O_2 atmospheres with low oxygen MAP (Van der Steen et. al., 2002).

However, microperforated films are relatively expensive, permit moisture and odour loss, and may allow for the ingress of microorganisms into sealed packs during wet handling situations (Day, 1998).

A very interesting development for the packing of fresh prepared produce involves the use of high O_2 (70–100 %) MAP, which has been recently shown to overcome the many disadvantages of current air packing and low O_2 MAP. High O_2 MAP has been demonstrated to inhibit enzymic discolorations, prevent anaerobic fermentation reactions and inhibit microbial growth with the result of extending prepared produce shelf-life (Day, 1998; Day 1999).

Different commodities have different amounts of internal air space (potatoes 1–2 %, tomatoes 15–20 %, apples 25–30 %). A limited amount of air space leads to increase in resistance to gas diffusion. One of the primary effects of MAP is a

Table 4. *Recommended gas mixtures for MAP (Day, 1993; Exama et al., 1993; Moleyar and Narasimham, 1994; Powrie and Skura, 1991; Smith and Ramaswamy, 1996).*

Fruits	**O_2 (%)**	**CO_2 (%)**	**N_2 (%)**	**Vegetables**	**O_2 (%)**	**CO_2 (%)**	**N_2 (%)**
Apple	1–2	1–3	95–98	Artichoke	2–3	2–3	94–96
Apricot	2–3	2–3	94–96	Beans, snap	2–3	5–10	87–93
Avocado	2–5	3–10	85–95	Broccoli	1–2	5–10	88–94
Banana	2–5	2–5	90–96	Brussels sprouts	1–2	5–7	91–94
Grape	2–5	1–3	92–97	Cabbage	2–3	3–6	81–95
Grapefruit	3–10	5–10	80–92	Carrot	5	3–4	91–95
Kiwifruit	1–2	3–5	93–96	Cauliflower	2–5	2–5	90–96
Lemon	5–10	0–10	80–95	Chili peppers	3	5	92
Mango	3–7	5–8	85–92	Corn, sweet	2–4	10–20	76–88
Orange	5–10	0–5	85–95	Cucumber	3–5	0	95–97
Papaya	2–5	5–8	87–93	Lettuce (leaf)	1–3	0	97–99
Peach	1–2	3–5	93–96	Mushrooms	3–21	5–15	65–92
Pear	2–3	0–1	96–98	Spinach	Air	10–20	–
Pineapple	2–5	5–10	85–93	Tomatoes	3–5	0	95–97
Strawberry	5–10	15–20	70–80	Onion	1–2	0	98–99

lower rate of respiration, which reduces the rate of substrate depletion. Ethylene (C_2H_4) is a natural plant hormone and plays a central role in the initiation of ripening, and is physiologically active in trace amounts (0.1 ppm). C_2H_4 production is reduced by about half at O_2 levels of around 2.5 %. This low O_2 retards produce ripening by inhibiting both the production and action of C_2H_4.

Also metabolic processes such as respiration and ripening rates are sensitive to temperature. Biological reactions generally increase two to three-fold for every 10 °C rise in temperature. Therefore temperature control is vitally important in order for a MAP system to work effectively. Film permeability also increases as temperature increases, with CO_2 permeability responding more than O_2 permeability. Low RH can increase transpiration damage and lead to desiccation, increased respiration, and ultimately an unmarketable product. One serious problem associated with high in-package humidity is condensation on the film that is driven by temperature fluctuations. A mathematical model was developed for estimating the changes in the atmosphere and humidity within perforated packages of fresh produce (Lee et. al., 2000; Montanez et al., 2010a; Montanez et al., 2010b). The model was based on the mass balances of O_2, CO_2, N_2 and H_2O vapours in the package. Also a procedure to maintain desired levels of O_2 and CO_2 inside packages that are exposed to different surrounding temperatures was designed and tested (Silva et. al., 1999).

The concentrations of O_2 and CO_2 within a package can be modeled. Useful models have been developed that would allow fresh produce processors to choose packaging materials most suited to the enclosed product. A common mathematical model involves the use of what is known as a Michaelis–Menten type respiratory model to describe the influence of temperature, O_2 (and potentially CO_2) on respiration. This approach has been used for blueberries (Cameron et al., 1994), strawberries (Joles, 1993), raspberries (Joles et. al., 1994) and apple slices (Lakakul et al., 1999). Respiratory models are then coupled with an equation describing the temperature sensitivity of film permeability to gases (known as the Arrhenius equation) to predict package O_2 partial pressure as a function of temperature, product mass, surface area and film thickness (Cameron et al., 1994; Lakakul et al., 1999). Using polymeric films, MA packaging systems for products with low to medium respiration rates have to some extent been successfully developed. Products such as broccoli, mushrooms, leeks, etc exhibit very high rates of respiration such that conventional films can potentially over modify the pack atmosphere and thus result in fermentation.

Qualitative changes in the broccoli (*Brassica oleracea italica*) under MAP in perforated polymeric film had also been studied (Rai et. al., 2008). It has been found that perforated PP film packages (2 holes, each of 0.3 mm in diameter) and having a film area of 0.1 m^2 could be used to store broccoli for 4 days under MAP with maintenance of chlorophyll and ascorbic acid. Comparative evaluation of the effect of storage temperature fluctuation on MAP of selected fruits and vegetables like mushrooms (*Agaricus bisporus*), broccoli (*Brassica oleracea L. cv. Acadi*) and mature-green tomatoes (*Lycopersicon esculentum cv. Trust*) had also been done by Tano et al. (2007). The quality of the products stored under the temperature fluctuating regime was severely affected as indicated by extensive browning, loss of firmness, weight loss increase, the level of ethanol in the plant tissue, and infection due to physiological damage and excessive condensation, compared to products stored at constant temperature. It was clear that temperature fluctuation, even if it should occur only once, can seriously compromise the benefits of MAP and safety of the packaged produce. The effect of storage conditions and physical tissue damage on membrane peroxidation in minimally processed cucumber tissue was investigated (Karakas and Yildiz, 2007). Tissue hardness of MAP sealed samples increased for the first 3 days for all tissues but chilled tissues started to soften on the sixth day. Cucumbers packaged in perforated 31.75 µm PE-LD bags were found to have less severe chilling injury than non-wrapped fruit in storage at 5 °C and 90–95 % RH (Wang and Qi, 1997). The influence of MAP on the sensory characteristics and shelf life of shiitake mushrooms (*Lentinula edodes*) was also studied using PE-LD, PP and macro perforated film (Ares et al., 2006). Sensory analysis showed that mushrooms stored under MA (active and passive) had a higher deterioration rate than those stored in PP macro perforated films, and lower sensory quality values during the entire storage time. These results suggest that mushroom deterioration was probably due to shiitake mushrooms' sensitivity to high CO_2 concentrations. Mushrooms have been packed under micro porous and hydrophilic films and stored at 10 °C and 20 °C under high relative humidity (>92 %) to study the unique gas barrier properties of hydrophilic films (wheat gluten based material and synthetic polymer). Unique steady state atmospheres, poor in both oxygen and carbon dioxide, were observed, regardless of the temperature and the hydrophilic film used, owing to their high selectivity to gas diffusion (Barron et al., 2002). The effect of super-atmospheric O_2 and MAP on plant metabolism, organoleptic quality and microbial growth of minimally processed baby spinach was also studied (Allende et al., 2004). Packaging film O_2 transmission rate and initial levels of super-atmospheric O_2 in the packages significantly affected the changes of in-package atmospheres during storage and consequently quality of baby spinach leaves. Microbial proliferation and sensory quality aspects of sliced onions were tested at different temperatures (-2, 4 and 10 °C) and atmospheric conditions (with or without 40 % CO_2 / 59 % N_2 / 1 % O_2) by Liu and Li (2006). The microbial shelf lives of the tested onions in 40 % CO_2 / 59 % N_2 / 1 % O_2, or at -2, 4 and 10 °C, were 12.5, 9.5, 7, 12, 9 and 6 days, respectively, and their sensory shelf lives were 12, 8, 5, 10.5, 7 and 5 days, respectively.

Work on other vegetables has also been reported like sweet corn (Rodov et al., 2000) and snow pea pods (Pariasca et al., 2001). The shelf life of shelled peas packed in PE-LD (25 µm thickness) was 45, 17, 7 and 4 days when stored at the temperatures of -11, 5, 15 °C and room temperature respectively, considering the quality indices like total soluble solids, total water soluble sugars, protein, physiological weight loss and decay (Sandhya and Singh, 2004a). The shelf life of shelled peas packaged in PE-HD was found as 4, 7, 17 and 45 days when stored at the temperatures of ambient, 15, 5 and -11 °C, respectively (Sandhya and Singh, 2004b). The influence of different storage conditions on the storability of packaged shredded cabbage had also been studied (Plestenjak et al., 2008). A higher variation in CO_2 and O_2 concentrations, and consequent accumulation of anaerobic metabolites had a negative influence on the sensorial properties of the cut cabbage.

Nitrogen (N_2) gas packaging for fresh-cut vegetables (lettuce and cabbage) has been examined as a means of MAP for extending the shelf life of cut vegetables (Koseki and Itoh, 2002). Degradation of cut vegetables in terms of appearance was delayed by N_2 gas packaging. Because of this effect, the appearance of fresh-cut vegetables packaged with N_2 gas remained acceptable at temperatures below 5 °C after 5 days.

The MAP combined with ozone and edible coating films were used for improving the effect of preservation of strawberry (Zhang et al., 2005). The optimum gas composition of MAP test for strawberry was 2.5 % O_2 / 16 % CO_2. Also the

Table 5. *Effect of packaging materials and methods on the shelf life of fruits and vegetables*

Food/Treatment	Packaging materials/methods	Shelf life	Reference
Peach, **Cauliflower,** **Truffle**	Tray: PP; Cover: PE-LD/PET(40 μm), 0-14 microperforated package, all wrapped in PE	4 days at 4 °C	González-Buesa et al., 2009
Strawberry	stretch PVC	8 days at 1 °C	Nunes et al., 1995
Minimally processed fruits (kiwi, banana and prickly pear)	1) PE/Al/PET	4-12 days at 5 °C	Del Nobile et al., 2007
	2) Coex.polyolefinic high permeable film		
Sweet cherry	5 % O_2 + 10 % CO_2	80 days at 1 °C	Ai-Li et al. 2002
	PE: 13-18 % O_2 + 2-4 % CO_2	40 days at 1 °C	
	70 % O_2 + 0 % CO_2	20 days at 1 °C	
	Air	30 days at 1 °C	
Cactus pear fruits	Cryovac MY 15 Plastic box	9 days at 4 °C	Piga et al., 2003
Carrots, minimally processed	PP+cPP/OPP in:		Ayhan et al. 2008
	5 % O_2 / 10% CO_2 / 85 % N_2	2 days at 4 °C	
	80 % O_2 / 10 % CO_2 / 10 % N_2	7 days at 4 °C	
Cabbage, shredded	OPP (30 μm)	9-10 days at 3 °C	Pirovani et al., 1997
Cabbage, shredded	Glass jar; PE (30 μm); PP (30 μm) in:	7 days at 0 and 10 °C	Plestenjak et al., 2008
	Air		
	100 % N_2,		
	MAP 1: 100 % N_2,		
	MAP 2: 5 % O_2 / 95 % N_2,		
	MAP 3:10 % O_2 / 90 %		
	MAP 4: 70 % O_2 / 30 % N_2 and 100 % O_2		

Lettuce (shredded)	OPP (30 μm)	8 days at 4 °C	Pirovani et al., 1998
Spinach Fresh-cut	PE-LD	8 days at 4 ºC and 90 % HR	Piagentini and Güemes, 2002
	OPP	6 days at 4 ºC and 90 % HR	
Lettuce	PE	10 days in the dark at 7 °C.	Zhang et al., 2007
Broccoli	PE-non-perforated	13 days at 4 °C; 3 days at 20 °C	Jia et al., 2009
	PE-2 holes (750 μm in dia.)	23 days at 4 °C; 5 days at 20 °C	
	PE-4 holes (8.8 mm in dia.)		
	unwrapped broccoli	10 days at 4 °C, 2.5 days at 20 °C	
Fresh-cut vegetables, fennels cut lettuce salads and shredded carrots	PA/PE (102 μm)		Corbo et al., 2006
	Air	less than 5 days at 4 °C	
	Vacuum	13.5 at 4 °C	
	MAP: 70 % N_2 / 30 % CO_2	5.8 at 4 °C	
Cherry tomatoes ozone treatment (5–30 mg/l ozone gas for 0–20 min)	CA 1: 5 % CO_2 / 17 % O_2 (7°C)	20 days at 7 °C	Daş et al., 2006
	CA 2: 5 % CO_2 / 15 % O_2 (22°C)	10 days at 22 °C	
	PE-LD (50 μm); MAP		
	glass jars		
Melon, minimally fresh processed	MAP passive in:	10 days at 5 °C	Aguayo et al., 2003
	PP mikroperforated		
	BOPP		
	OPP		
	PP-makroperforated (control)		
Blueberry nectar Aseptically Filled (93–97°C for 30 s)	PET 1: standard	9-12 months at 4-20 °C	Trošt et al., 2009
	PET 2: O_2-absorber		
	PET 3: 5-layers		
	PET 4: 3-layers		
Tomato	PE-LD (50 mm) MAP + O_2-absorber	8 days at 20 °C	Charles et al., 2003

integrated model approach was used to study the effect of MA conditions on the keeping quality of ‘Elsanta’ strawberries as limited by spoilage (Hertog et al., 1999). It was observed that the quality of SO_2-free ‘Superior seedless’ table grapes was preserved in MAP (Artes-Hernandez et al., 2006). The improvement of the overall quality of table grapes stored under MAP in combination with natural antimicrobial compounds had also been studied (Guillen et al., 2007). The effect of MA on the quality of many fresh-cut products has been studied. Successful applications include mushroom (Simon et al., 2005), apples (Soliva-Fortuny et al., 2005), tomato (Aguayo et al., 2004; Artes et al., 1999; Gil et al., 2002), pineapple (Marrero and Kader, 2006), butterhead lettuce (Escalona et al., 2006), potato (Beltran et al 2005; Tudela et al., 2002), kiwifruit (Rocculi et al., 2005), salad savoy (Kim et al., 2004), honeydew (Bai et al., 2003), mangoes (Beaulieu and Lea, 2003), carrot (Barry-Ryan and O’Beirne, 2000; Kakiomenou et al., 1996).

Fresh-cut cantaloupe cubes were placed in film sealed containers in which the internal gas mixture was attained naturally (nMAP), was flushed with 4 kPa O_2 / 10 kPa CO_2 (fMAP), or was maintained near atmospheric levels by perforating the film (PFP). While both nMAP and fMAP maintained the saleable quality of melon cubes at 5 °C, fMAP maintained quality better than MAP (Bai et al., 2001). Also quality of fresh-cut tomato slices was compared during cold storage under various MAP conditions (Hong and Gross, 2001). MAP provided good quality tomato slices with a shelf life of 2 weeks or more at 5 °C. Effects of packaging materials and methods on the shelf life of some fruits and vegetables are given in Table 5.

Edible coatings and films

The application of edible coatings appears to be one of the most innovative approaches to extend the commercial shelf life of fruits and vegetables by, among other mechanisms, acting as a barrier against gas transport (Table 6) and showing similar effects to storage under controlled atmospheres (Park, 1999). Indeed, over the last two decades the development and use of bio-based packaging materials to prolong the shelf-life and improve the quality of fresh products has been receiving increased attention (Galić, 2009). The reasons for such an interest are mainly related to environmental issues due to disposal of conventional synthetic food-packaging materials. However, in order such edible films and coatings to be used at a commercial level in food products they must fulfill some basic require-

Table 6. *Oxygen and carbon dioxide permeabilities of edible films*

Film	**Thickness** (mm)	**Permeability at 0% RH** (10^{-15} l /m^2 s Pa)		**Permeability ratio** (CO_2/O_2)	**Reference**
		O_2	CO_2		
Corn-zein	0.12-0.31	0.36 30 °C	2.67 21 °C	7.5	Park and Cginnan, 1995
Wheat gluten	0.23-0.42	0.20 30 °C	2.13 21 °C	9.5	
Methyl cellulose Low level (MC (L))	0.04-0.07	2.17 30 °C	69.00 21 °C	31.6	
Hydroxypropylcellulose Low level (HPC (L))	0.05	3.57 30 °C	143.99 21 °C	40.6	
HPC/Lipids	0.15	3.44 30 °C	81.75 21 °C	23.7	
Cozeen	0.09	0.89 37,8 °C	5.25 22,8 °C	5.9	Aydt et al., 1991
Wheat gluten	0.14	0.09 37,8 °C	0.03 22,8 °C	0.3	
Corn-zein	0.08	0.16 25 °C	-	-	Gennadios et al., 1993
Wheat gluten	0.15	0.08 25 °C	-	-	

ments: acceptable sensorial characteristics, appropriate barrier properties (Table 6), good mechanical strength, reasonable microbial, biochemical and physicochemical stability, safety, low cost and simple technology for their production (Diab et al., 2001). The effectiveness of edible coatings for protection of fruits and vegetables also depends on controlling the wettability of the coating solutions, which affects the coating thickness (Park, 1999). Thus, edible coating formulations must wet and spread uniformly on the vegetable's surface and, after drying, a coating that has adequate adhesion, cohesion and durability to function properly must be formed (Ribeiro et al., 2007).

Edible films and coatings are generally based on biological materials such as proteins, lipids and polysaccharides. The main polysaccharides that can be included in edible coating formulations are starch and starch derivatives, cellulose derivatives, chitosan, pectin, alginate and other gums. Carboxymethyl-cellulose is a cellulose derivative that has received considerable attention with several examples of applications in many fruits and vegetables. Some polysaccharides have been used as edible coatings to improve the quality of different fresh-cut fruit (Tapia et al., 2007; Rojas-Grau et al., 2007; Rojas-Grau et al., 2008).

A commercial edible coating formulation based on carboxymethylcellulose and sucrose fatty acid esters, has been applied to pears (Zhou et al., 2008), cherries (Yaman and Bayoindirli, 2002) and asparagus (Tzoumaki et al., 2009). Pullulan, an extracellular polysaccharide produced by *Aureobasidium pullulans,* also is capable of forming edible films but has not been largely exploited as a coating material in fruits and vegetables, presumably because of its high water solubility. One example of pullulan used as a coating hydrocolloid was for strawberries and kiwifruit (Diab et al., 2001). Proteins that can also be used in formulations of edible coatings for fruits and vegetables include those derived from animal sources, such as casein and whey proteins, or obtained from plant sources, like corn zein, wheat gluten and soy protein (Vargas et al., 2008). Whey protein based coatings have been extensively used to extend the shelf life of fruits and vegetables (Cisneros-Zevallos and Krochta, 2003; Lerdthanangkul and Krochta, 1996).

Antimicrobial packaging

The use of edible coatings as carriers of antimicrobial compounds is another potential alternative to enhance the safety of fresh-cut produce. Antimicrobial edible coatings may provide increased inhibitory effects against spoilage and pathogenic bacteria by maintaining effective concentrations of the active compounds on the food surfaces. There are several categories of antimicrobials that can be potentially incorporated into edible coatings, including organic acids (acetic, benzoic, lactic, propionic, sorbic), fatty acid esters (glyceryl monolaurate), polypeptides (lysozyme, peroxidase, lactoferrin, nisin), plant essential oils (cinnamon, oregano, lemongrass), nitrites and sulphites, among others (Franssen and Krochta, 2003). Although several types of antimicrobials incorporated into edible coatings have been used for extending shelf-life of fresh commodities, their use in fresh-cut fruits is yet limited. Currently, organic acids and plant essential oils are the main antimicrobial agents incorporated into edible coatings for fresh-cut fruits. Despite the good results achieved so far with the incorporation of essential oils into edible coatings, the major drawback is their strong flavour which could change the original taste of foods.

Comprehensive reviews on antimicrobial food packaging have been published by Appendini and Hotchkiss (2002) and Suppakul et al. (2003). To confer antimicrobial activity, antimicrobial agents may be coated, incorporated, immobilised, or surface modified onto package materials (Suppakul et al., 2003). A comprehensive list of antimicrobial agents for use in antimicrobial films, containers and utensils is presented in a review by Suppakul et al. (2003). The classes of antimicrobials listed range from acid anhydride, alcohol, bacteriocins, chelators, enzymes, organic acids and polysaccharides. Examples of commercial antimicrobial materials in the form of concentrates (e.g. AgIONe, AgION Technologies LLC, USA) extracts (Nisaplin® (Nisin), Integrated Ingredients, USA) and films (Microgarde Rhone-Poulenc, USA) were also presented. Antimicrobial packages have had relatively few commercial successes except in Japan where Ag-substituted zeolite is the most common antimicrobial agent incorporated into plastics. Ag-ions inhibit a range of metabolic enzymes and have strong antimicrobial activity (Vermeiren et al., 1999). Antimicrobial films can be classified into two types: those that contain an antimicrobial agent which migrates to the surface of the food and, those which are effective against surface growth of microorganisms without migration. Coating of films with antimicrobial agents can result in effective antimicrobial activity. Natrajan and Sheldon (2000) carried out a study to evaluate the potential use of packaging materials as delivery vehicles for carrying and transferring nisin-containing formulations onto the surfaces of fresh poultry products. The antimicrobial activity of the fabricated multilayer films was also evaluated using an agar plate diffusion method. It was reported that coating the PE film with grapefruit seed extract (GFSE) with the aid of a polyamide binder resulted in greater antimicrobial activity compared to GFSE incorporation by co-extrusion. Using the agar diffusion test, the co-extruded film with 1% w/w GFSE showed antimicrobial activity against *Metaphycus flavus* only, whereas a film coated with 1% GFSE showed activity against several microorganisms such as *Escherichia coli, Staphylococcus aureus* and *Bacillus subtilis*. There is a growing interest in edible coatings due to factors such as environmental concerns, the need for new storage techniques and opportunities for creating new markets for under utilised agricultural commodities with film forming properties (Quintavalla and Vicini, 2002). Edible coatings and films prepared from polysaccharides, proteins and lipids have a variety of advantages such as biodegradability, edibility, biocompatibility, aesthetic appearance and barrier properties against oxygen and physical stress.

Antimicrobial packaging can play an important role in reducing the risk of pathogen contamination, as well as extending the shelf-life of foods; it should never substitute for good quality raw materials, properly processed foods and good manufacturing practices. It should be considered as a hurdle technology that in addition with other non-thermal processes such as pulsed light, high pressure and irradiation could reduce the risk of pathogen contamination and extend the shelf-life of perishable food products. Participation and collaboration of research institutions, industry and government regulatory agencies will be a key on the success of antimicrobial packaging technologies for food applications (Appendini and Hotchkiss, 2002).

Active packaging

Active packaging is an emerging and exciting area of food technology that is developing owing to advances in packaging technology, material science, biotechnology and new consumer demands. This technology can confer many preservation benefits on a wide range of ambient-stable and chilled food products. The intention is to extend the shelf-life of foods, whilst at the same time maintaining nutritional quality and assuring microbial safety (Labuza and Breene, 1989). The use of active packaging is becoming increasingly popular and many new opportunities will open up for utilising this technology in the future (Day, 1999; Miltz, 1995; Randell et al., 1995; Ahvenainen and Hurme, 1997; Ishitani, 1995).

Active packaging employs a packaging material that interacts with the internal gas environment to extend the shelf-life of a food. Such new technologies continuously modify the gas environment (and may interact with the surface of the food) by removing gases from or adding gases to the headspace inside a package.

- **Ethylene scavenging**

A chemical reagent, incorporated into the packaging film, traps the ethylene produced by ripening fruit or vegetables. The reaction is irreversible and only small quantities of the scavenger are required to remove ethylene at the concentrations at which it is produced.

- **Oxygen scavenging**

The presence of oxygen in food packages accelerates the spoilage of many foods. Oxygen can cause off-flavour development, colour change, nutrient loss and microbial attack. One of the most promising applications of oxygen scavenging systems in food packages (Table 7) is to control mould growth.

Table 7. *Properties of major types of Ageless oxygen scavengers (Pocas, 2001)*

Type	**Function**	**a_w**	**Aborption speed**	**Capacities**
Z	Decreases O_2	< 0.65	1 – 4 days	20 – 2 000 cc
S	Decreases O_2	> 0.65	0.5 – 2 days	500 – 2000 cc
FX	Decreases O_2	> 0.85	0.5 – 1 days	20 – 300 cc
E	Decreases O_2 Decreases CO_2	> 0.30	3 – 8 days	O_2: 25–200 cc CO_2: 250 – 2000 cc
G	Decreases O_2 Increases CO_2	0.3 - 0.5	1 – 4 days	NA

- **Humidity control**

Condensation or ‘sweating’ is a problem in many kinds of packaged fruit and vegetables. When one part of the package becomes cooler than another water is likely to condense in the cooler areas.

- **Carbon dioxide release**

High *carbon dioxide* levels are desirable in some food packages because they inhibit surface growth of microorganisms. Fresh meat, poultry, fish, cheeses and strawberries are foods which can benefit from packaging in a high carbon dioxide atmosphere. However with the introduction of modified atmosphere packaging there is a need to generate varying concentrations of carbon dioxide to suit specific food requirements. Since carbon dioxide is more permeable through plastic films than is oxygen, carbon dioxide will need to be actively produced in some applications to maintain the desired atmosphere in the package.

- **Sulphur dioxide**

Serious loss of table grapes can occur unless precautions are taken against mould growth. It is necessary to refrigerate grapes in combination with fumigation using low levels of sulphur dioxide. Fumigation can be conducted in the fruit cool stores as well as in the cartons. Carton fumigation consists of a combination of quick release and slow release systems which emit small amounts of sulphur dioxide. When the temperature of the cartoned grapes rises due to inadequate temperature control, the slow release system fails releasing all its sulphur dioxide quickly. This can lead to illegal residues in the grapes and unsightly bleaching of the fruit.

A review of the history of active packaging shows that most of the advances in research in this field have occurred during the last decade (Rooney, 1995).

Flexible packaging materials such as PE-LD and linear low density polyethylene (PE-LLD) when impregnated with potassium permanganate and cinnamic acid, respectively become ethylene scavengers. Fresh fruits and vegetables, such as mango, tomato, banana, and papaya exhibit more shelf-life of two to three weeks when packed in such ethylene scavenging films. The incorporation of ethylene scavengers improves the physico-mechanical properties of the packaging materials considerably.

Design of active modified atmosphere packaging for vegetables was studied by developing a mathematical model predicting gas changes and based on the following independently evaluated parameters: vegetable respiration rate, film permeability, and oxygen absorption kinetic of the absorber. A step-by-step model validation was performed on a tomatoes/low-density polyethylene pouch/commercial iron-based scavenger (Table 5) system at 20 °C (Charles et al., 2003).

Smart or intelligent packaging

Smart packaging uses features of high added value that enhance the functionality of the product, notably mechanical, electronic and responsive ink features, for example electronic and mechanical dispensers in which drugs are supplied and the prepared meal that automatically tells the microwave how it should be cooked. Smart packaging can be categorised into two types, those which incorporate integrated circuits (IC's) and does which do not incorporate IC's otherwise known as chipless smart packaging. Packaging that incorporate diagnostic indicators are also included in smart packaging. These can be used for such functions as monitoring vibration, acidity, tilt, shock, humidity, light, heat, time chemicals, virus or bacteria as they develop or as they are contacted.

Fresh-cut produce continues to be one of the fastest growing segments of food retailing and while conventional film packaging is suitable for lettuce and prepared salads, it cannot cope with the high respiration rates of pre-cut vegetables and fruit, leading to early product deterioration. Novel breatheable polymer films are already in commercial use for fresh-cut vegetables and fruit. Packaging films that are acrylic side-chain crystallisable polymers tailored to change phase reversibly at various temperatures from 0-68°C are available. As the side-chain components melt, gas permeation increases dramatically, and by further tailoring the package and materials of construction, it is possible to fine tune the carbon dioxide to oxygen permeation ratios for particular products. The final package is 'smart' because it automatically regulates oxygen ingress and carbon dioxide egress by transpiration according to the prevailing temperature. In this way, an optimum atmosphere is maintained around the product during storage and distribution, extending freshness and allowing shipping of higher quality products to the consumer.

Intelligent packaging can change colour to let the customer know how fresh the food is and show if the food has been spoiled because of a change in temperature during storage or a leak in the packaging.

Time temperature integrators (TTI's) are devices that show an irreversible change in a physical characteristic, usually color or shape, in response to temperature history. The TTI's are expected to mimic the change of a certain quality parameter of the food product undergoing the same exposure to temperature. The TTI's presently on the market have working mechanisms based on different principles: biological, chemical and physical. For the first type, the change in biological activity, such as microorganisms, spores or enzymes is the basic working principle. The others are based on a purely chemical or physical response towards time and temperature, such as an acid-base reaction, melting, polymerization, etc.

Fresh-Check®LifeLines integrator is supplied as self-adhesive labels, which may be applied to packages of perishable products to assure consumers at point-of-purchase and at home that the product is still fresh. It is commonly referred to as having a bull's eye configuration. It is a full history indicator whose working mechanism is based on the color change of a polymer formulated from diacetylene monomers. It consists of a small circle of polymer surrounded by a printed ring for color reference. The polymer, which starts lightly colored, gradually deepens in color to reflect the cumulative exposure to temperature. The polymer changes color at a rate proportional to the rate of food quality loss: the higher the temperature, the more rapidly the polymer changes in color.

Vitsab® Indicator is a full history integrator based on an enzymatic reaction. The device consists of a bubble-like dot containing two compartments: one for the enzyme solution, lipase plus a pH indicating dye compound and the other for the substrate, consisting primarily of triglycerides. The dot is activated at the beginning of the monitoring period by application of pressure on the plastic bubble, which breaks the seal between compartments. The ingredients are mixed and as the reaction proceeds a pH change results in a color change. The dot, initially green in color, becomes progressively yellow as product approaches the end of shelf-life. The reaction is irreversible and will proceed faster as temperature is increased and slower as temperature is reduced. The integrator, in the format of adhesive labels, is available in two basic configurations: single or triple-dot. Single-dot tags are used for transit temperature monitoring of cartons and pallets of product and for consumer packages as well.

ripeSense™ is the world's first intelligent ripeness indicator label. *ripeSense*™ evolved from the simple idea of making a fruit label that is capable of more than just branding product and this has lead to the next revolution in fresh produce marketing.

The *3M Monitor Mark* uses a coloured ester and phthalate mix with the desired melting point that is coloured with a blue dye. Above its melting point it diffuses along a wick, and the progress along this wick gives an indication of how long the indicator has been liquid. A polyester strip keeps the liquid away from the wick, until it is pulled by the operator to start the device.

It is believed that tomorrows food packages will certainly include radio frequency identification (RFID) tags (Gander, 2007). RFID tags are an advanced form of data information carrier that can identify and trace a product.

Biodegradable packaging

Currently, there are several types of bio-based polymers on the market: same coming from petrochemical monomer, like certain types of polyester, polyester amides and polyvinyl alcohol, produced by different manufacturer, used principally as films or moulding. Four other bio-based polymers are starch materials, cellulose materials, polylactic acid (Polyester, PLA), polyhydroxy acid (polyester, PHA). Until now, the PHA polymer is a very expensive polymer because it is commercially available in very limited quantities. PLA is becoming a growing alternative as a green food packaging materials because it was found that in many situations it performs better than synthetic ones, like oriented polystyrene (OPS) and PET materials (Auras et al., 2005).

There is an increasing demand for identifying biodegradable packaging materials and finding innovative methods to make plastic degradable. Biodegradation is the process by which carbon-containing chemical compounds are decomposed in the presence of enzymes secreted by living organisms. The use of bioplastic is to replicate the life cycle of biomass by conserving the fossil fuels, carbon dioxide and water production. There are three requirements for the fast degradation process *viz.* temperature, humidity and type of microbes.

In the short term, biobased materials will most likely be applied to foods requiring short-term chill storage, such as fruits and vegetables, since biobased materials present opportunities for producing films with variable CO_2/O_2 selectivity and moisture permeability (Table 8). However, to succeed, biobased packaging of foods must be in compliance with the quality and safety requirements of the food product and meet legal standards. Additionally, the biobased materials should preferably preserve the quality of the product better and longer to justify any extra material cost.

Application of nanocomposites

Nanocomposite materials are composed of nanoscale structure that enhances the macroscopic properties of food products. The common nanocomposites used in the food packaging industry are (i) Polymer clay nanoclay (ii) Silica nanocomposites of nanosilver. The effects of nanoclay in polymers are increased stiffness, strength, nucleating agent in foams, smaller cell size, higher cell density, and flame retardant. Nanosilver is composed of de-ionized water with silver in suspension which has excellent antibacterial properties. Silver nanoparticles interact well with other particles as they have large surface area relative to volume which increases their antibacterial efficiency as a result of which they are extensively used in the food packaging industry (Tonnie, 2007).

Table 8. *Properties of some biodegradable plastics (Berkesch, 2005)*

Material	**Film preparation**	**Moisture barrier**	**Oxygen barrier**	**Mecanical properties**
Starch/ Polyvinyl alcohol (PVAL)	Extrusion	-	+	+
Polyhydroxybutyrate/valerate (PHB/V)	Extrusion	+	+	+/-
Polylactic acid (PLA)	Extrusion	+/-	-	+

Although application of nanotechnology in the food industry started later than other industries, the great potential of food nanotechnology, especially in the area of improving food quality and securing food safety, has been recognised by many nanoscientists and technologists (Tarver, 2006). Nanotechnology is already applied to the food and food packaging industries (Nachay, 2007; Brody, 2007).

One of the potential applications of nanotechnology in food packaging is polymer/clay nanocomposites; they have recently emerged due to their potential for improving properties of packaging materials such as increased mechanical, barrier and chemical properties with a small amount (less than 5% by weight) of nanoclays reinforcement (Brody, 2007). However, most work done on polymer/clay nanocomposites has focused mainly on synthetic polymers (Rhim and Ng 2007).

The functional properties of biopolymer-based edible films or coatings have been shown to act as barrier to solute and gas and enhance food quality and shelf life (Krochta et al., 1994; Gennadios, 2002). However, these films do not display good mechanical and water vapor barrier properties due to their hydrophilic characteristics. To overcome these issues, a new approach has been developed, which use hybrid materials consisting of polymers and layered silicates (Giannelis, 1996). Layered silicates, such as montmorillonite (MMT) clay mineral, result from the stacked arrangement of negatively charged silicate layers and contain a platelet thickness of about 1 nm with a high aspect ratio (ratio of length to thickness) (Sorrentino et al., 2007). The layered silicate filled polymer composites exhibit extraordinary enhancement of mechanical, thermal and physicochemical properties at a low level of filler concentration in comparison to pure polymer and conventional microcomposites (Uyama et al., 2003). In particular, these nanocomposites have excellent barrier properties because the presence of clay layers delays the diffusing molecule pathway due to tortuosity (Bharadwaj, 2001; Sorrentino et al., 2006). Some of the works done with biopolymer-based nanocomposites were based on starch or polysaccharides, such as wheat and maize starch (McGlashan and Halley, 2003), thermoplastic starch (Park et al., 2003), and chitosan (Lin et al., 2005; Xu et al., 2006; Rhim et al., 2006; Gunister et al., 2007). A few studies on protein-based nanocomposites have been published, including soy protein (Dean and Yu, 2005; Rhim et al., 2005), whey protein (Hedenqvist et al., 2006), and wheat gluten (Olabarrieta et al., 2006). Most of the biopolymer-based nanocomposites have shown appreciable improvements in mechanical and barrier properties compared to the counterpart biopolymer films. Whey protein has received much attention for its potential use as an edible film and coating because it has been shown to make transparent films and coatings that can act as excellent oxygen barriers and provide certain mechanical properties (Sothornvit and Krochta, 2000; Sothornvit and Krochta 2005). Unlike chitosan film, whey protein films have not shown any antimicrobial activity; therefore, incorporation of antimicrobial agents, such as sorbic acid, p-aminobenzoic acid (Cagri et al., 2001), and lysozyme (Min et al., 2008), is needed to impart this property. Recently, Rhim et al. (2006) found that chitosan-based nanocomposite films blended with some organically modified MMT, such as Cloisite 30B, exhibited antimicrobial activity against Gram-positive bacteria. They postulated that the antimicrobial action came from the quaternary ammonium salt of the organically modified nano-clay.

Conclusion

The vision of the future of packaging is one in which the package will increasingly operate as a smart system incorporating both smart and conventional materials, adding value and benefits across the packaging supply chain. For smart materials to be adopted in packaging, they need to be inexpensive relative to the value of the product, reliable, accurate, reproducible in their range of operation, and environmentally benign and food contact safe.

References:

Aguayo E., Allende A., Artes F. (2003) Keeping quality and safety of minimally fresh processed melon, *European Food Research and Technology,* 216, pp. 494–499.

Aguayo E., Escalona V., Artes F. (2004) Quality of fresh-cut tomato as affected by type of cut, packaging, temperature and storage time, *European Food Research and Technology,* 219(5), pp. 492–499.

Ahvenainen R., Hurme E. (1997) Active and Smart Packaging for Meeting Consumer Demands for Quality and Safety, *Food Additives and Contaminants,* 14, pp. 753-763.

Ai-Li J., Sjhi-Ping T., Yong X. (2002) Effects of Controlled atmosphere with high-O_2 or high-CO_2 concentrations on postharvest physiology and storability of „Napoleon“ sweet cherry, *Acta Botanica Sinica,* 44(8), pp. 925—930.

Alique R., Martinez M. A., Alonso J. (2003) Influence of the modified atmosphere packaging on shelf life and quality of Navalinda sweet cherry, *European Food Research and Technology,* 217(5), pp. 416–420.

Allende A., Luo Y., McEvoy J. L., Artes F., Wang C. Y. (2004) Microbial and quality changes in minimally processed baby spinach leaves stored under super atmospheric oxygen and modified atmosphere conditions, *Postharvest Biology and Technology,* 33(1), pp. 51–59.

Appendini P., Hotchkiss J.H. (2002) Review of antimicrobial food packaging, *Innovative Food Science and Emerging Technologies,* 3, pp. 113–126.

Ares G., Parentelli C., Gambaro A., Lareo C., Lema P. (2006) Sensory shelf life of shiitake mushrooms stored under passive modified atmosphere, *Postharvest Biology and Technology,* 41(2), pp. 191–197.

Artes F., Conesa M. A., Hernandez S., Gil, M. I. (1999) Keeping quality of fresh-cut tomato, *Postharvest Biology and Technology,* 17(3), pp. 153–162.

Artes-Hernandez F., Tomas-Barberan F. A., Artes F. (2006) Modified atmosphere packaging preserves quality of SO2-free 'Superior seedless' table grapes, *Postharvest Biology and Technology,* 39(2), pp. 146–154.

Auras R., Singh S.P., Singh J.J. (2005) Evaluation of oriented poly(lactide) polymers vs. existing PET and oriented PS for fresh food service containers, *Packaging Technology and Science,* 18, pp. 207–216.

Aydt T. P., Weller C. L., Testin R. F. (1991) Methanical and barrier properties of edible corn and wheat protein films, *Trans. ASAE,* 34 pp. 207-211.

Ayhan Z., Eştürk O., Taş E. (2008) Effect of modified atmosphere packaging on the quality and shelf life of minimally processed carrots, *Turkish Journal of Agriculture and Forestry,* 32, pp. 57–64.

Bai J. H., Saftner R. A., Watada A. E., Lee Y. S. (2001) Modified atmosphere maintains quality of fresh-cut cantaloupe, *Journal of Food Science,* 66(8), pp. 1207–1211.

Bai J., Saftner R. A., Watada A. E. (2003) Characteristics of fresh-cut honeydew (Cucumis xmelo L.) available to processors in winter and summer and its quality maintenance by modified atmosphere packaging, *Postharvest Biology and Technology,* 28(3), pp. 349–359.

Barron C., Varoquaux P., Guilbert S., Gontard N., Gouble B. (2002) Modified atmosphere packaging of cultivated mushroom with hydrophilic films, *Journal Food Science,* 67(1), pp. 251–255.

Barry-Ryan C., O'Beirne D. (2000) Effects of peeling methods on the quality of ready-to-use carrot slices, *International Journal of Food Science & Technology,* 35(2), 243.

Barth M.M., Zhuang H. (1996) Packaging design affects antioxidant vitamin retention and quality of broccoli florets during postharvest storage, *Postharvest Biology and Technology,* 9, pp. 141–150.

Beaudry, R. M. (1999) Effect of O2 and CO2 partial pressure on selected phenomena affecting fruit and vegetable quality, *Postharvest Biology and Technology,* 15, pp. 293–303.

Beaudry R.M., Cameron A.C., Shirazi A., Dostal Lange D.L. (1992) Modified atmosphere packaging of blueberry fruit: effect of temperature on package O_2 and CO_2, *Journal of the American Society for Horticultural Science,* Alexandria, Va., The Society, 117(3), p. 436- 441.

Berkesch, S. (2005) Biodegradable Polymers. A Rebirth of Plastic.
Available at: http://www.iopp.org/files/public/BerkeschShellieMSUBiodegradablePlastic.pdf, pp. 1-14,Accessed: 12.04.2010.

Beaulieu J. C., Lea J. M. (2003) Volatile and quality changes in fresh-cut mangoes prepared from firm-ripe and soft-ripe fruit, stored in clamshell containers and passive MAP, *Postharvest Biology and Technology,* 30(1), pp. 15–28.

Beltran D., Selma M. V., Tudela J. A., Gil M. I. (2005) Effect of different sanitizers on microbial and sensory quality of fresh-cut potato strips stored under modified atmosphere or vacuum packaging, *Postharvest Biology and Technology,* 37(1), pp. 37–46.

Bharadwaj R.K., (2001) Modeling the barrier properties of polymer-layered silicate nanocomposites, *Macromolecules,* 34, pp. 9189–9192.

Brody A.L. (2007) Nanocomposite technology in food packaging, *Food Technology,* 61(10), pp. 80-83.

Brody A. L. (1996): Integrating aseptic and modified atmosphere packaging to fulfil a vision of tomorrow, *Food Technology,* 50(4), pp. 56–66.

Cagri A., Ustunol Z., Ryser E.T. (2001) Antimicrobial, mechanical, and moisture barrier properties of low pH whey protein based edible films containing *p*-aminobenzoic or sorbic acids, *Journal of Food Science,* 66, pp. 865–870.

Cameron A.C., Beaudry R.M., Banks N.H., Yelanich M.V. (1994) Modified atmosphere packaging of blueberry fruit: modelling respiration and package oxygen partial pressures as a function of temperature, *Journal of the American Society for Horticultural Science,* 119, pp. 534–539.

Charles F., Sanchez J., Gontard N. (2003) Active modified atmosphere packaging of fresh fruits and vegetables: modeling with tomatoes and oxygen absorber, *Journal of Food Science,* 68(5), pp. 1736–1742.

Chung D., Yam, K. L. (1999) Antimicrobial packaging material containing propyl Paraben, IFT annual meeting technical program: Book of abstracts. (pp. 21). Chicago: Institute of Food Technologists.

Cisneros-Zevallos L., Krochta J. M. (2003). Whey protein coatings for fresh fruits and relative humidity effects, *Journal of Food Science,* 68(1), pp. 176-181.

Corbo M.R., Del Nobile A., Sinigaglia M. (2006) A novel approach for calculating shelf life of minimally processed vegetables, *International Journal of Food Microbiology,* 106, pp. 69–73.

Das E., Candan G. G., Bayındırlı A. (2006) Effect of controlled atmosphere storage, modified atmosphere packaging and gaseous ozone treatment on the survival of *Salmonella* Enteritidis on cherry tomatoes, *Food Microbiology.* 23(5), pp. 430-438.

Day B. P. F. (1999) Recent developments in active packaging, *South African,Food & Beverage Manufacturing Review,* 26 (8), pp. 21–7.

Day B.P.F. (1998) Novel MAP. A brand new approach, *Food Manufacture,* **73,** pp. 22–24.

Day B.P.F. (1993), Fruit and vegetables. In: R.T. Parry, Editor, Principles and applications of MAP of foods, Blackie Academic and Professional. New York, USA, pp. 114–133.

Dean K., Yu L. (2005) Biodegradable protein-nanocomposites. In: R. Smith, Editor, Biodegradable Polymers for Industrial Application, CRC Press, Boca Raton, FL, pp. 289–309.

Del Nobile M.A., Licciardello F., Scrocco C., Muratore G., Zappa M. (2007) Design of plastic packages for minimally processed fruits, *Journal of Food Engineering,* 79, pp. 217–224.

Diab T., Biliaderis C., Gerasopoulos D., Sfakiotakis E. (2001) Physicochemical properties and application of pullulan edible films and coatings in fruit preservation, *Journal of the Science of Food and Agriculture,* 81, pp. 988–1000.

Escalona V. H., Verlinden B. E., Geysen S., Nicolai B. M. (2006) Changes in respiration of fresh-cut butter head lettuce under controlled atmospheres using low and super atmospheric oxygen conditions with different carbon dioxide levels, *Postharvest Biology and Technology,* 39(1), pp. 48–55.

Exama A., Arul J., Lencki R.W., Lee L.Z., Toupin C. (1993) Suitability of plastic films for modified atmosphere packaging of fruits and vegetables, *Journal of Food Science,* 58, pp. 1365–1370.

Franssen L.R., Krochta J.M. (2003) Edible coatings containing natural antimicrobials for processed foods. In: S. Roller, Editor, Natural antimicrobials for the minimal processing of foods, CRC Press, Boca Raton, Florida.

Galić K. (2009) Jestiva ambalaža u prehrambenoj industriji, *Hrvatski časopis za prehrambenu tehnologiju, biotehnologiju i nutricionizam,* 4 (1-2), pp. 23-31.

Gander P. (2007) The smart money is on intelligent design, Food Manufacture Feb: xv-xvi.

Geeson J. D. (1988) Modified atmosphere packaging of fruits and vegetables, In International symposium on post harvest handling of fruits and vegetables, Leuven, Belgium, pp. 143–147.

Geeson J. D., Genge P. M., Sharples R. O. (1994) The application of polymeric film lining systems for modified atmosphere box packaging of English apples. *Postharvest Biology and Technology,* 4(1–2), pp. 35–48.

Gennadios A., Weller C.L., Testin R.F. (1993) Temperature effect on oxygen permeability of edible protein-based films, *Journal of Food Science,* 58, pp. 212–214, 219.

Gennadios A. (2002) Protein based films and coatings. CRC, New York, pp. 66–115

Giannelis E.P. (1996) Polymer layered silicate nanocomposites, *Advanced Materials,* pp. 29–35.

Gil M. I., Conesa M. A., Artes F. (2002) Quality changes in fresh cut tomato as affected by modified atmosphere packaging. *Postharvest Biology and Technology,* 25(2), pp. 199–207.

Gonzalez-Buesa J., Ferrer-Mairal A., Oria R., L. Salvador M. (2009) A mathematical model for packaging with microperforated films of fresh-cut fruits and vegetables, *Journal of Food Engineering,* 95 (1), pp. 158-165.

Gosh V., Xiong L., Anantheswaran R. C. (2000) Designing a modified atmosphere package for mushrooms using micro perforated film. In Presented at IFT annual meeting, Houston, TX, USA.

Greengrass, J. (1993) Films for MAP of foods. In R. T. Parry (Ed.), Principles and applications of modified atmosphere packaging of food. New York: Blackie Academic and Professional, pp. 63–100

Guilbert S., Gontard N., Gorris L. G. M. (1996) Prolongation of the shelf life of perishable food products using biodegradable films and coatings, *Food Science and Technology,* 29, pp. 10–17.

Guillen F., Zapata P. J., Martinez-Romero D., Castillo S., Serrano M., Valero, D. (2007) Improvement of the overall quality of table grapes stored under modified atmosphere packaging in combination with natural antimicrobial compounds. *Journal of Food Science,* 72(3), pp. 185–190.

Gunister E., Pestreli D., Unlu C.H., Atici O., Gungor N. (2007) Synthesis and characterization of chitosan-MMT biocomposite systems, *Carbohydrate Polymers,* 67, pp. 358–365.

Han, J. H. (2000) Antimicrobial food packaging, *Food Technology,* 54(3), pp. 56–65.

Hedenqvist M.S., Backman A., Gallstedt M., Boyd R.H., Gedde U.W. (2006) Morphology and diffusion properties of whey/montmorillonite nanocomposites, *Composites Science and Technology,* 66, pp. 2350–2359.

Hertog M. L. A. T. M., Boerrigter H. A. M., van den Boogaard G. J. P. M., Tijskens L. M. M., van Schaik, C. R. (1999) Predicting keeping quality of strawberries (cv. ‘Elsanta’) packed under modified atmospheres: an integrated model approach, *Postharvest Biology and Technology,* 15(1), pp. 1–8.

Hong J. H., Gross K. C. (2001) Maintaining quality of fresh-cut tomato slices through modified atmosphere packaging and low temperature storage, *Journal of Food Science,* 66(7), pp. 960–965.

Hong S., Kim D. (2004) The effect of packaging treatment on the storage quality of minimally processed bunched onions, *International Journal of Food Science & Technology,* 39(10), 1033.

Ishitani, T. (1995) Active packaging for food quality preservation in Japan. In Foods and Packaging Materials - Chernical Interactions, (eds. P. Ackermann, M. Jagerstad & T. Ohlsson). Cambridge, UK: Royal Society of Chemistry. pp. 177- 188.

Jacobsson A., Nielsen T., Sjoholm I. (2004) Influence of temperature, modified atmosphere packaging and heat treatment on aroma compounds in broccoli, *Journal of Agriculture and Food Chemistry,* 52, pp. 1607–1614.

Jia C.G., Xu C.J., Wei J., Yuan J., Yuan G.F., Wang B.L. et al., (2009) Effect of modified atmosphere packaging on visual quality and glucosinolates of broccoli florets, *Food Chemistry,* 114, pp. 28–37.

Joles D. W., Cameron A. C., Shirazi A., Petracek P. D., Beaudry, R. M. (1994) Modified atmosphere packaging of 'heritage' red raspberry fruit: respiratory response to reduced oxygen, enhanced carbon dioxide and temperature, *Journal of the American Society for Horticultural Science,* 119(3), pp. 540–545.

Joles D. W. (1993) Modified atmosphere packaging of raspberry and strawberry fruit: Characterizing the respiratory response to reduced O_2, elevated CO_2 and changes in Temperature. MS thesis, Michigan State Univ., East Lansing, MI 48824.

Kader A.A. (2002) Postharvest technology of horticultural crops. 3rd ed., Oacland, California, Publication no. 3311.

Kader A.A. (1980) Prevention of ripening in fruits by use of controlled atmospheres, *Food Technology,* 34 (3), pp. 45.

Kakiomenou K., Tassou C., Nychas G. (1996) Microbiological, physicochemical and organoleptic changes of shredded carrots stored under modified storage, *International Journal of Food Science & Technology,* 31(4), 359.

Karakas B., Yildiz F. (2007) Peroxidation of membrane lipids in minimally processed cucumbers packaged under modified atmospheres, *Food Chemistry,* 100(3), pp. 1011–1018.

Kim J. G., Luo Y., Gross K. C. (2004) Effect of package film on the quality of freshcut salad savoy, *Postharvest Biology and Technology,* 32(1), pp. 99–107.

Koseki S., Itoh K. (2002) Effect of nitrogen gas packaging on the quality and microbial growth of fresh-cut vegetables under low temperatures, *Journal of Food Protection,* 65(2), pp. 326–332.

Krochta J.M., Baldwin E.A., Nisperos-Carrido M. (1994) Edible Coatings and Films to Improve Food Quality, Technomic Publishing Co., Lancaster, PA.

Labuza T.P., Breene W.M. (1989) Applications of 'active packaging' for improvement of helf-life and nutritional quality of fresh and extended shelf-life foods, *Journal of Food Processing and Preservation,* 13, pp. 1-69.

Lakakul R., Beaudry R. M., Hernandez R. J. (1999) Modeling respiration of apple slices in modified atmosphere packages, *Journal of Food Science,* 64, pp. 105–110.

Lange D. L. (2000). New film technologies for horticultural products, *Horticultural Technology,* 10, pp. 487–490.

Lee D.S., Jang J.D., Hwang Y.I. (2002) The effects of using packaging films with different permeabilities on the quality of Korean fermented red pepper paste, *International Journal of Food Science and Technology,* 37, pp. 255–261.

Lee D.S., Haggar P.E., Lee J., Yam K.L. (2006) Model for Fresh Produce Respiration in Modified Atmospheres Based on Principles of Enzyme Kinetics, *Journal of Food Science,* 56(6), pp. 1580 - 1585.

Lee D.S., Kang J.S., Renault P. (2000) Dynamics of internal atmosphere and humidity in perforated packages of peeled garlic cloves, *International Journal of Food Science and Technology,* 35, pp. 455–464.

Lerdthanangkul S., Krochta J.M. (1996) Edible coating effects on post harvest quality of green bell peppers, *Journal of Food Science,* 61(1), pp. 176–179.

Lin K.F., Hsu C.Y., Huang T.S., Chiu W.Y.M., Lee Y.H.,. Young T.H. (2005) A novel method to prepare chitosan/montmorillonite nanocomposites, *Journal of Applied Polymer Science,* 98, pp. 2042–2047.

Liu, F., & Li, Y. (2006). Storage characteristics and relationships between microbial growth parameters and shelf life of MAP sliced onions, *Postharvest Biology and Technology,* 40(3),

Marrero A., Kader A. A. (2006) Optimal temperature and modified atmosphere for keeping quality of fresh-cut pineapples, *Postharvest Biology and Technology,* 39(2), pp. 163–168.

McGlashan S.A., Halley P.J. (2003) Preparation and characterization of biodegradable starch-based nanocomposite materials, *Polymer International,* 52, pp. 1767–1773.

Meyers R. A. (1985) Modified atmosphere packaging and process. US patent Nr.4515266.

Miltz J., Passy N., Manneheim C.H. (1995) Trends and applications of active packaging systems. In: P. Ackermann, M. Jagerstad and T. Ohlsson, Editors, Foods and packaging materials-chemical interactions, The Royal Society of Chemistry, Cambridge, UK, pp. 201–210.

Min S., Rumsey T.R., Krochta J.M. (2008) Diffusion of the antimicrobial lysozyme from a whey protein coating on smoked salmon, *Journal of Food Engineering,* 84, pp. 39–47.

Moleyar V., Narasimham P. (1994) Modified atmosphere packaging of vegetables: an appraisal, *Journal of Food Science & Technology,* 31(4), pp. 267–278.

Montanez J. C., Rodriguez F. A.S., Mahajan P. V., Frias J. M. (2010a) Modelling the gas exchange rate in perforation-mediated modified atmosphere packaging: Effect of the external air movement and tube dimensions, *Journal of Food Engineering,* 97(1), pp. 79-86.

Montanez J. C., Rodriguez F. A.S., Mahajan P. V., Frias J. M. (2010b) Modelling the effect of gas composition on the gas exchange rate in Perforation-Mediated Modified Atmosphere Packaging, *Journal of Food Engineering,* 96(3), pp. 348-355.

Nachay K. (2007) Analyzing nanotechnology. *Food Technology,* 61(1), pp. 34-36.

Natrajan N., Sheldon B. (2000) Efficacy of nisin-coated polymer films to inactive *Salmonella typhimurium* of fresh broiler skin, *Journal of Food Protection,* 63, pp. 1189–1196.

Nunes M.C.N., Brecht J.K., Morais A.M.M.B., Sargent S.A. (1995) Physical and chemical quality characteristics of strawberries after storage are reduced by a short delay to cooling, *Postharvest Biology and Technology,* 6, pp. 17-28.

Olabarrieta I., Gallistedl M., Ispizua I., Sarasua J.-R., Hedenqvist M.S. (2006) Properties of aged montmorillonite-wheat gluten composite films, *Journal of Agricultural and Food Chemistry,* 54, pp. 1283–1288.

Ozdemir I., Monnet F., Gouble B. (2005) Simple determination of the O_2 and CO_2 permeances of micro perforated pouches for modified atmosphere packaging of respiring foods, *Postharvest Biology and Technology,* 36(2), pp. 209–213.

Pariasca J. A. T., Miyazaki T., Hisaka H., Nakagawa H., Sato T. (2001) Effect of modified atmosphere packaging (MAP) and controlled atmosphere (CA) storage on the quality of snow pea pods (Pisum sativum L. var. saccharatum), *Postharvest Biology and Technology,* 21(2), pp. 213–223.

Park H. J., Chinnan M. S. (1995) Gas and water vapor barrier properties of edible films from protein and cellulosic materials, *Journal of Food Engineering,* 25(4), pp. 497-507.

Park H.M., Lee W.K., Park C.Y., Cho W.J., Ha C.S. (2003) Environmentally friendly polymer hybrids. Part I Mechanical, thermal, and barrier properties of thermoplastic starch/clay nanocomposites, *Journal of Materials Science,* 38, pp. 909–915.

Park, H. J. (1999) Development of advanced edible coatings for fruits, *Trends in Food Science & Technology,* 10, pp. 254–260.

Phillips C. A. (1996) Review: modified atmosphere packaging and its effects on the microbiological quality and safety of produce, *International Journal of Food Science & Technology,* 31, pp. 463–479.

Piagentini A.M., Güemes D.R. (2002) Shelf life of fresh-cut spinach as affected by chemical treatment and type of packaging film, *Brazilian Journal of Chemical Engineering,* 19, pp. 383–389.

Piga A., Del Caro A., Pinna I., Agabbio M. (2003) Changes in ascorbic acid, polyphenol content and antioxidant activity in minimally processed cactus pear fruits, *Lebensmittel-Wissenschaft und-Technologie,* 36, pp. 257-262.

Pirovani M.E., Piagentini A.M., Güemes D.R., Di Pentima J.H. (1998) Quality of minimally processed lettuce as influenced by packaging and chemical treatment, *Journal of Food Quality,* 21, pp. 475–484.

Pirovani M.E., Güemes D.R., Piagentini A.M., Di Pentima, J.H. (1997) Storage quality of minimally processed cabbage packaged in plastic films, *Journal of Food Quality,* 20(5), pp. 381-389.

Plestenjak A., Pozrl T., Hribar J., Unuk T., Vidrih R. (2008) Regulation of metabolic changes in shredded cabbage by modified atmosphere packaging, *Food Technology and Biotechnology,* 46(4), pp. 427–433.

Pocas M. F. (2001) Innovations in Intelligent Packaging Technologies for Perishable Foods. In: Novel processes and control technologies in the food industry (eds.T. F. Bozoglu, T. Deak, B. Ray), IOS Press, pp. 197-211.

Porat R., Weiss B., Cohen L., Daus A., Aharoni N. (2004) Reduction of post harvest rind disorders in citrus fruit by modified atmosphere packaging, *Postharvest Biology and Technology,* 33(1), pp. 35–43.

Powrie W. D., Skura, B. J. (1991) Modified atmosphere packaging of fruits and vegetables. In B. Ooraikul, M. E. Stiles, & E. Horwood (Eds.), Modified atmosphere packaging of food. New York, USA, pp. 169–245.

Quintavalla S., Vicini L. (2002) Antimicrobial food packaging in meat industry, *Meat Science,* 62, pp. 373–380.

Rai D. R., Tyagi S. K., Jha S. N., Mohan S. (2008) Qualitative changes in the broccoli under modified atmosphere packaging in perforated polymeric film, *Journal of Food Science and Technology-Mysore,* 45(3), pp. 247–250.

Randell, K., Ahvenainen, R., Latva-Kala, K., Hurme, E., Mattila-Sandholm, T. and Hyvonen, L. (1995) Modified atmosphere-packed marinated chicken breast and rainbow trout quality as affected by package leakage, *Journal of Food Science,* 60: 667-684.

Rhim J.W., Ng P.K.W. (2007) Natural biopolymer-based nanocomposite films for packaging applications. *Critical Reviews in Food Science and Nutrition,* 47, pp. 411-433.

Rhim J.W., Hong S.I., Park H.M., Ng P.K.W. (2006) Preparation and characterization of chitosan-based nanocomposite films with antimicrobial activity, *Journal of Agricultural and Food Chemistry,* 54, pp. 5814–5822.

Rhim J.W., Lee J.H., Kwak H.S. (2005) Mechanical and barrier properties of soy protein and clay mineral composite films, *Food Science and Biotechnology,* 14, pp. 112–116.

Ribeiro C., Vicente A., Teixeira J.A., Miranda C., (2007) Optimization of edible coating composition to retard strawberry fruit senescence, *Postharvest Biology and Technology,* 44, pp. 63–70.

Rizvi S.S.H. (1981) Requirements for Foods Packaged in Polymeric Films. *Critical Reviews in Food Science and Nutrition,* 14, pp. 111-134.

Rocculi P., Romani S., Rosa M. D. (2005) Effect of MAP with argon and nitrous oxide on quality maintenance of minimally processed kiwifruit, *Postharvest Biology and Technology,* 35(3), pp. 319–328.

Rodov V., Copel A., Aharoni N., Aharoni Y., Wiseblum A., Horev B., et al. (2000) Nested modified-atmosphere packages maintain quality of trimmed sweet corn during cold storage and the shelf life period, *Postharvest Biology and Technology,* 18(3), pp. 259–266.

Rojas-Grau M.A., Tapia M.S., Martin-Belloso O. (2008) Using polysaccharide-based edible coatings to maintain quality of fresh-cut Fuji apples, *LWT- Food Science and Technology,* 41, pp. 139-147.

Rojas-Grau M.A., Grasa-Guillem R., Martin-Belloso O. (2007) Quality changes in fresh-cut Fuji apple as affected by ripeness stage, antibrowning agents, and storage atmosphere, *Journal of Food Science,* 72, pp. 36–43.

Rooney M. L. (1995). Active Food Packaging. London: Blackie, pp. 1–37

Sandhya, Singh A. K. (2004a) Modified atmosphere storage of shelled peas in low-density polyethylene bags, *Journal of the Institution of Engineers* (India), *Agricultural Engineering,* 85, pp. 44–49.

Sandhya, Singh, A. K. (2004b) Packaging of shelled peas in high-density polyethylene, *Journal of Research Punjab Agricultural University,* 41(1), pp. 110–118.

Schick J. L., Toivonen P. M. A. (2002) Reflective tarps at harvest reduce stem browning and improve fruit quality of cherries during subsequent storage, *Postharvest Biology and Technology,* 25(1), pp. 117–121.

Silva F. M., Chau K. V., Brecht J. K., Sargent S. A. (1999) Modified atmosphere packaging for mixed loads of horticultural commodities exposed to two postharvest temperatures, *Postharvest Biology and Technology,* 17(1), pp.1–9.

Simon A., Gonzalez-Fandos E., Tobar V. (2005) The sensory and microbiological quality of fresh sliced mushroom (Agaricus bisporus L.) packaged in modified atmospheres, *International Journal of Food Science & Technology,* 40(9), 943.

Smith J. P., Ramaswamy H. S. (1996) Packaging of fruits and vegetables. In L. Somogyi, H. S. Ramaswamy, & Y. H. Hui (Eds.), Processing fruits: Science and Technology. Lancaster, PA: Technomic Publishing Co., pp. 379–427.

Soliva-Fortuny R. C., Ricart-Coll M., Martin-Belloso O. (2005) Sensory quality and internal atmosphere of fresh-cut Golden Delicious apples, *International Journal of Food Science & Technology,* 40(4), 369.

Sorrentino A., Gorrasi G., Vittoria V. (2007) Potential perspectives of bio-nanocomposites for food packaging applications, *Trends in Food Science and Technology,* 18, pp. 84–95.

Sorrentino A., Gorrasi G., Tortora M., Vittoria V., (2006) Barrier properties of polymer/clay nanocomposites. In: Y.-W. Mai and Z.-Z. Yu, Editors, Polymer Nanocomposites, Woodhead Publishing Ltd., Cambridge, UK, pp. 273–292.

Sothornvit R., Krochta J.M. (2005) Plasticizers in edible films and coatings. In: J.H. Han, Editor, Innovations in Food Packaging, Elsevier Academic Press, London, UK, pp. 403–433.

Sothornvit R., Krochta J.M. (2000) Oxygen permeability and mechanical properties of films from hydrolyzed whey protein, *Journal of Agricultural and Food Chemistry,* 48, pp. 3913–3916.

Srinivasa P., Baskaran R., Ramesh M., Prashanth K. H., Tharanathan R. (2002) Storage studies of mango packed using biodegradable chitosan film, *European Food Research and Technology,* 215(6), pp. 504–508.

Suppakul P., Miltz J., Sonneveld K., Bigger S.W. (2003) Active packaging technologies with an emphasis on antimicrobial packaging and its applications, *Journal of Food Science,* 68, pp. 408-420.

Tano K., Oule M. K., Doyon G., Lencki R. W., Arul, J. (2007) Comparative evaluation of the effect of storage temperature fluctuation on modified atmosphere packages of selected fruits and vegetables. *Postharvest Biology and Technology,* 46(3), pp. 212–221.

Tapia M.S., Rojas-Grau M.A., Rodriguez F.J., Ramírez J., Carmona A., Martin-Belloso O. (2007) Alginate- and gellan-based edible films for probiotic coatings on fresh-cut fruits. *Journal of Food Science,* 72, pp. 190-196.

Tarver T. (2006) Food nanotechnology. *Food Technoogy,* 60(11), pp. 22-26.

Thompson A.K. (1996) Postharvest technology of fruit and vegetables. Blackwell, Oxford.

Tonnie, A.O. (2007) A reference searching related to nanomaterials. *Food Packaging and Sustainability.*

Trošt K., Golc-Wondra A., Prošek M. (2009) Degradation of Polyphenolic Antioxidants in Blueberry Nectar Aseptically Filled in PET, *Acta Chimica Slovenica,* 56,pp. 494–502.

Tudela J. A., Espin J. C., Gil M. I. (2002) Vitamin C retention in fresh-cut potatoes. *Postharvest Biology and Technology,* 26(1), pp. 75–84.

Tzoumaki M.V., Biliaderis C.G., Vasilakakis M. (2009) Impact of edible coatings and packaging on quality of white asparagus (*Asparagus officinalis,* L.) during cold storage, *Food Chemistry,* 117 (1), pp. 55-63.

Uyama H., Kuwabara M., Tsujimoto T., Nakano M., Usuki A., Kobayashi S. (2003) Green nanocomposite from renewable resources: plant oil-clay hybrid materials, *Chemistry of Materials,* 15, pp. 2492–2494.

Van der Steen C., Jacxsens L., Devlieghere F., Debevere J. (2002) Combining high oxygen atmospheres with low oxygen modified atmosphere packaging to improve the keeping quality of strawberries and raspberries, *Postharvest Biology and Technology,* 26(1), pp. 49–58.

Vargas M., Pastor C., Chiralt A., McClements D. J., Gonzalez-Martinez C. (2008) Recent Advances in Edible Coatings for Fresh and Minimally Processed Fruits, *Critical Reviews in Food Science and Nutrition,* 48 (6), pp. 496-511(16)

Vermeiren L., Devleghere F., Van Beest M., De Krujif N., Debevere, J. (1999) Developments in the active packaging of foods, *Trends in Food Science & Technology,* 10(3), pp. 77-86.

Wang C. Y., Qi L. (1997) Modified atmosphere packaging alleviates chilling injury in cucumbers, *Postharvest Biology and Technology,* 10(3), pp. 195–200.

Watkins C. B., Brookfield P. L., Elgar H. J., McLeod S. P. (1998) Development of a modified atmosphere package for export of apple fruit. In S. Ben-Yehoshua (Ed.), Recycling of plastic waste from protected agriculture into novel multilayered greenhouse covers. Jerusalem, Israel: Laser Pages Pub. Ltd.. pp. 586–592

Xu Y., Ren X., Hanna M.A. (2006) Chitosan/clay nanocomposite film preparation and characterization, *Journal of Applied Polymer Science,* 99, pp. 1684–1691.

Yaman O. and Bayoindirli L. (2002) Effects of an edible coating and cold storage on shelf-life and quality of cherries, *Lebensmittel-Wissenschaft und-Technologie,* 35: pp. 146-150.

Zhang M., Xiao G., Peng J., Salokhe V. M. (2005) Effects of single and combined atmosphere packages on preservation of strawberries, *International Journal of Food Engineering,* 1(4), pp. 141-148.

Zhang FZ, Wagstaff C, Rae AM, et al. (2007) QTL for shelf life in lettuce co-locate with those for leaf biophysical properties but not for leaf developmental traits, *Journal of Experimental Botany,* 58, pp. 1433–1449.

Zhou R., Mo Y., Li Y.F., Zhao Y.Y., Zhang G.X., Hu Y.S. (2008) Quality and internal characteristics of Huanghua pears *(Pyrus pyrifolia Nakai,* cv. *Huanghua*) treated with different kinds of coatings during storage, *Postharvest Biology and Technology,* 49 (1), pp. 171–179.

Authors

Mario Ščetar, MSc
Faculty Of Food Technology And Biotechnology
Pierottijeva 6
10000 Zagreb

Mia Kurek, MSc
Faculty Of Food Technology And Biotechnology
Pierottijeva 6
10000 Zagreb

Ph. D. Kata Galić, Full professor
Faculty Of Food Technology And Biotechnology
Pierottijeva 6
10000 Zagreb