Trends in Food Science & Technology 46 (2015) 320–330

Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: http://www.journals.elsevier.com/trends-in-food-science-and-technology

Modified atmosphere packaging for shelf life extension of fresh-cut apples

Giovanna Cortellino*, Serena Gobbi, Giulia Bianchi, Anna Rizzolo

Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Unità di ricerca per i processi dell'Industria AgroAlimentare (CRA-IAA), Via Venezian 26, 20133 Milan, Italy

ARTICLE INFO

Article history:
Available online 16 June 2015

Processing steps, such as cutting and peeling, increase the respiration rate and ethylene production of apples, quickening senescence phenomena with effects on texture, color and flavor. Modified atmosphere packaging (MAP) and antioxidant pre-treatments are used to control the decay of fresh-cut apples during shelf life. MAP has become a widely used food preservation technique as it minimally affects fresh product characteristics. The purpose of this paper was to discuss the influence of conventional (O_2, N_2 and CO_2) and alternative (Ar and N_2O) MAPs as well as the interaction between anti-browning treatment and MAPs on ethylene production, firmness, browning, off-flavor and sensory characteristics, contextualizing the results obtained in a case study on 'Golden Delicious' apple slices developed within the Stayfresh project. The packaging under conventional modified atmospheres, characterized by low O_2 level (1 and 5%), and the alternative mix Ar + CO_2 successfully preserved the firmness of apple slices during all refrigerated storage limiting the ethylene production, even if the preserving efficacy of MAP resulted almost completely nullified by the dipping treatment, which caused a structural breakdown. MAPs were not able to control the enzymatic browning if not combined with an anti-browning dipping treatment. It was highlighted the key role of sensory analysis in finding the best combination between MAP, anti-browning treatment and shelf life time. The contrasting results among the various research groups could be reasonably also due to the different periods and temperatures of shelf life.

Introduction

Modified atmosphere packaging (MAP) is a technique used for prolonging the shelf life of fresh or minimally processed food (Sandhya, 2010). MAP has become a widely used food preservation technique as it minimally affects fresh product characteristics and it is perceived as a natural and additive-free technique by consumers (Day, 1996). This preservation technique consists of substituting the air surrounding the food in the package with an atmosphere with a different composition. So the shelf life of perishable products like meat, fish, fruit and vegetables could be prolonged with MAP delaying the physic-chemical changes related to quality loss of the product. The atmosphere composition in the package depends mainly on the type of product, but also on packaging materials and storage temperature. As fruit and vegetables are respiring products, the interaction between the product and the packaging material is particularly important. The permeability of the packaging film for O_2 and CO_2 has to be suitable for the specific product respiration rate in order to establish a balanced modified atmosphere in the package. This packaging technology is the most commonly used for fresh-cut products. For packaging vegetables and fruit, the modified atmosphere usually consists of a lower O_2 level and a higher CO_2 level than those of air, which slow down the normal respiration rate, prolonging the shelf life of the product. Current low oxygen MAP techniques may suffer from some inherent disadvantages. Novel high O_2 MAP is an innovative development that has been shown to be particularly effective in inhibiting enzymic discoloration, preventing anaerobic fermentation reactions and inhibiting both aerobic and anaerobic microbial growth (Day, 2001). It is hypothesized that active oxygen radical species damage vital cellular macromolecules and thereby inhibit microbial growth when oxidative stresses overwhelm cellular protection systems (Day, 2001). The microbiological aspect will not be in-depth analyzed in this review.

The three main conventional gases used in modified atmosphere packaging are CO_2, O_2 and N_2. They could be used singularly or in combination with the aim of safely extending product shelf life as well as preserving optimal sensory properties of the food.

* Corresponding author. Tel.: +39 02 239557209; fax: +39 02 2365377.
E-mail address: giovanna.cortellino@entecra.it (G. Cortellino).

http://dx.doi.org/10.1016/j.tifs.2015.06.002
0924-2244/

Recently, there has been a great interest in the potential benefits of using argon and other noble gases for MAP applications (Mostardini & Piergiovanni, 2002; Spencer, 1995). Argon is a tasteless and odorless gas, denser than nitrogen, which is included in the positive list of food additives (E-398) and can be used as balance gas in MAP (Spencer, 2005). Another "new" packaging gas, nitrous oxide (N_2O), has been allowed for food use in the EU (Day, 1996). Noble gases such as argon are in commercial use for products such as coffee and potato-based snack products. Day (2001) reported that a broad range of patents claim that argon, compared to N_2, can more effectively inhibit enzymic activities, microbial growth and degradative chemical reactions in selected perishable foods. More specifically, an Air Liquide patent for fresh produce applications claims that Ar and N_2O are capable of extending shelf life by inhibiting fungal growth, reducing ethylene emission and slowing down sensory quality deterioration (Fath & Soudain, 1992). However, literature data on their application and benefits for the shelf life of fresh-cut fruit is limited (Char *et al.*, 2012; Cocci, Rocculi, Romani, & Dalla Rosa, 2006; Rocculi, Romani, & Dalla Rosa, 2004; Rocculi, Romani, & Dalla Rosa, 2005). Recently, Wu, Zhang, and Wang (2012) have been coupling the use of argon with high pressure, finding that the inhibiting effect of argon was enhanced in such conditions because of the formation of a glass hydrate of the inert gas which, inhibiting the enzymatic reactions, reduced the metabolism of the product. This combination could be an effective method for improving quality of fresh-cut apples at cold storage conditions.

This review is dedicated to MAP technology, applied to extend the shelf life of fresh cut apples with special attention to fruit physiology, quality characteristics such as texture (firmness), color (browning) and aroma (off-flavor formation) and their relationship with sensory characteristics. The interaction between MAP and dipping treatment, applied to preserve color and texture, was also debated in depth.

Ethylene

Ethylene is a natural plant hormone and plays a central role in the initiation of ripening and it is physiologically active in trace amounts (0.1 $\mu L\ L^{-1}$). On the strength of the role of ethylene in the ripening process, fruit can be divided into two groups (Lelièvre, Latché, Jones, Bouzayen, & Pech, 1997):

1 fruit that could produce large amount of ethylene, which promotes their ripening, defined "climacteric", such as tomato, peach, apple, banana and kiwifruit;
2 fruit that produce only low basal amount of ethylene during ripening and are insensitive to exogenous ethylene, defined "non-climacteric", such as grape, strawberry, watermelon, pineapple and citrus.

For both fruit and vegetables the stress caused by technological steps, such as peeling and cutting, produces a physiological response with increased ethylene production and respiratory activity, with effects being observed very rapidly, often within minutes to a few hours (Toivonen & Brummel, 2008). The effect of wounding, caused by the several stages of producing fresh-cut products, can be more evident in climacteric fruit, for which wound-induced ethylene promotes ripening and softening. In climacteric fruit, wound-induced as well as exogenous ethylene may cause the same effect on tissue, causing a hastening of ripening and softening (Toivonen & Brummel, 2008). The general effects of ethylene are usually detrimental to fruit quality (Saltveit, 1999); therefore, its concentration or activity should be minimized to lengthen product shelf life. Being a climacteric-type fruit, apple results very sensitive to ethylene. It has been reported that low O_2 atmospheres and elevated CO_2 levels synergically act to reduce ethylene production and respiration rates, but could not completely stop senescence and tissue breakdown (Soliva-Fortuny & Martín-Belloso, 2003a). On the other hand, super-atmospheric levels of O_2 fail in extending the storability of fresh fruit and vegetables by enhancing the ethylene production (Kader & Ben Yehoshua, 2000).

The inhibition of ethylene production under anaerobic or low O_2 conditions has been observed by many authors, suggesting that oxygen participates in the conversion of 1-amino-cyclopropane-1-carboxylic acid (ACC) to ethylene (Yang, 1981). The action of CO_2 is complex. At low concentrations, carbon dioxide activates the biosynthesis of ethylene via the latter's role as co-factor for 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase (Smith & John, 1993). At high concentrations, carbon dioxide may stimulate the activity of ACC oxidase while inhibiting its synthesis (Cheverry, Sy, Pouliquen, & Marcellin, 1988). A complete inhibition of ethylene in fresh-cut 'Fuji' apples stored under oxygen-free conditions was found by Gil, Gorny, and Kader (1998), Anese, Manzano, and Nicoli (1997) reported that fresh-cut 'Golden Delicious' apples packed in air showed a maximum headspace ethylene concentration between 8 and 16 days of storage, while those packed in presence of N_2 as well as of CO_2/N_2 (80% CO_2 + 20% N_2) did not produced ethylene in detectable amounts. Soliva-Fortuny, Oms-Oliu, and Martín-Belloso (2002) confirmed that ethylene production of fresh-cut 'Golden Delicious' apple slices is almost completely inhibited in N_2-packaged samples. In contrast, if air was used as initial atmosphere, ethylene dramatically increased just after processing and packaging, reaching a maximum concentration, 100-fold higher than in N_2-packaged slices, at 10 days of storage. Successively ethylene concentration decreased in all bags, showing that its synthesis slowed down or even ceased after the first 10 days of storage. Furthermore, Soliva-Fortuny, Ricart-Coll, and Martín-Belloso (2005), evaluating the internal atmosphere of 'Golden Delicious' apple cubes packaged under 0 kPa O_2 and 2.5 kPa O_2/7 kPa CO_2, found that ethylene concentration increased dramatically from the first hours after processing in both cases. Infact the ethylene developed similarly in the apple tissue for all treatments as long as the O_2 was available for its biosynthesis. The maximum concentrations of ethylene, induced by wounding response, were reached between the first and the second week of storage. However, after the first week, internal ethylene concentrations resulted substantially lower in fresh-cut apples packaged under 0 kPa O_2 initial atmospheres, whereas the different oxygen permeability of the plastic material (15 and 30 $cm^3\ O_2\ m^{-2}\ bar^{-1}\ day^{-1}$) did not have a significant effect on ethylene evolution. The same authors confirmed that packaging under restrictive O_2 conditions limited ethylene response. Moreover they observed that ethylene response of the apple tissue, also after re-exposure to atmospheric conditions, was slightly lower for samples stored under initial conditions of anoxia. Rojas-Graü, Grasa-Guillem, and Martín-Belloso (2007) also confirmed that ethylene production was noticeably higher in 'Fuji' apple slices packaged under initial air atmosphere, achieving a maximum concentration of 60 $\mu L\ L^{-1}$ after one week of storage. In contrast, apple slices packaged under 2.5 kPa O_2 + 7 kPa CO_2 produced less ethylene and reached a maximum peak of 35 $\mu L\ L^{-1}$. Contrasting results have been obtained when the influence of the dipping step in antibrowning agents, applied to preserve color, on ethylene production was investigated. Soliva-Fortuny *et al.* (2002) demonstrated that dipping in ascorbic acid and calcium chloride did not entail noticeable changes in ethylene concentrations compared with samples where a dip was not carried out. Rojas-Graü *et al.* (2007) confirmed that ethylene production of fresh-cut apples was not affected by ascorbic acid but the ethylene evolution was significantly reduced by N-acetylcysteine. Previously, Gil