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Optimized PLA-based EMAP systems for horticultural produce designed to regulate the targeted in-package atmosphere

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ABSTRACT

An innovative biodegradable bio-based film packaging system has been designed to achieve equilibrium modified atmosphere packaging (EMAP) of high value fresh horticultural produce through tuning the packaging barrier properties combining laser micro-perforation, breathable membrane technologies and materials. The tested commodities were cherry tomatoes and peaches. Laser micro-perforated 30 μm polylactic acid (PLA) film was used as the main bio-based packaging material. Key parameters of the novel bio-based EMAP system for the selected horticultural produce were optimized in terms of performance and cost reduction. Laboratory experiments were employed in order to validate the optimal design of the innovative EMA package. Results from lab experiments show improved efficiency of the optimized PLA based EMAP system in prolonging the shelf-life time of horticultural commodities as compared to non-packed commodities and commodities packed with conventional oriented polypropylene (OPP) film. The exposure of the PLA film to the EMA packed fresh produce conditions during the shelf-life period has negligible effect on the mechanical, physical and chemical properties of the film.

1. Introduction

Fruits and vegetables are perishable products with active metabolism during the post harvest period. Postharvest phases of fresh vegetables and fruits are directed to prolong their shelf-life, preserving food sensory and nutritional quality. The quality attributes for fresh fruits and vegetables must be maintained as effectively as possible through the transportation, storage and distribution systems. The produce should reach the retail stores in such a condition that ensures consumer acceptability and buyer appeal (Shewfelt, 1986; Zagory and Kader, 1989). Since fruits and vegetables contain large amounts of water and have high water activities, water is readily lost under low relative humidity (RH) conditions. Loss of water from fresh produce can lead to skin wrinkling, loss of crunchiness and crispiness, wilting and undesirable colour changes. Proper packaging of fresh commodities can restrict the rate of water loss (Wills et al., 1989) and has an important role to play in maximizing the extension of shelf life (Robertson, 2005).

A relatively new packaging technique – equilibrium modified atmosphere packaging (EMAP) is an effective method for prolonging the shelf-life of fresh produce by optimizing the in-package equilibrium atmosphere (Del-Valle et al., 2009), making it ideal for exports, long haul transportation and retail packaging. This is achieved by modifying the permeability of the packaging film, usually through perforation, in order to optimally regulate the equilibrium concentrations of O_2 and CO_2. When packaging vegetables and fruits in EMAP, the gas atmosphere of package reaches equilibrium, consisting usually of a lowered level of O_2 and an increased level of CO_2. This kind of package slows down the normal respiration of the product and so prolongs the shelf-life of the product. The effect of the EMAP gas atmosphere on slowing down respiration is attributed to low O_2 levels and possibly to increased CO_2 levels. The effect of the range of the gases levels on respiration depends however very much on the produce/cultivar and temperature (Fonseca et al., 2002; Mattos et al., 2012). For example, for tomatoes, the combination of both low O_2 levels and increased CO_2 levels results in slowing down the normal respiration. The in-package RH has also to be regulated, since it is responsible either for the excessive weight loss or for enhancing fungal spoilage of the fresh produce. Several research works can be found in literature regarding EMA packaging (e.g. Del-Valle et al., 2009; Gonzalez et al., 2008). The growing popularity of EMAP for vegetables and fruits can be explained with the behaviour of the modern consumer who demands fresh vegetables and fruits which have a long shelf-life without the use of preservatives. As EMAP enables processors to extend shelf-life without using chemicals it is also ideal for the packaging of organic produce.

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EMAP for the packaging of fresh fruit and vegetables differs markedly from the modified atmosphere packaging (MAP) designed for meat, fish, poultry and bakery goods in that produce is still “alive” and respiring. Traditional gas flushed, barrier MAP packs aiming at lowering the amount of oxygen (O_2) to slow down the oxidation reactions rate and the growth of various forms of aerobic life, used in the meat industry are unsuitable for the produce industry. The films typically used in the produce industry, possibly modified by appropriate perforations, offer controlled exchange for the relevant gases (CO_2, O_2, and water vapour). Moreover, they exhibit high clarity, good sealing, and anti-fog properties. The most commonly used films for equilibrium modified atmosphere packaging are made of low density polyethylene (LDPE) and of isotactic polypropylene (PP). Both plastics can be formulated into films of adequate strength. In addition, both LDPE and PP are rather inexpensive, but not biodegradable, materials (Farber and Dodds, 1995). The latter point is an enormous drawback, due to the continual environmental pollution caused by non-degradable synthetic polymer wastes.

Developing and using biodegradable bio-based polymers is considered as the most thorough method for resolving the serious plastic waste management problems and replacing fossil-oil based materials with materials from renewable resources. With this background, the development of biodegradable polymers has been a growing concern since the last decade of the 20th century. A variety of biodegradable polymer materials have been prepared and several of them have already been industrialized (Stridsberg et al., 2002; Lindblad et al., 2002; Okada, 2002; Kricheldorf, 2004; Albertsson and Varma, 2002). Although significant advances have been made with the biodegradable polymers development, they are far from becoming substitutes for traditional fossil oil based polymers. The major reasons lay in the higher price of bio-based polymers, the lack of international standardization and labelling and partially, in the properties of some of these materials (e.g. high hydrophilicity, poor processabilty).

A few studies reported in the literature show that the major limitation in the current formulations of biodegradable polymers for applications as packaging materials is their poor barrier properties (Shogren, 1997; Kantola and Helén, 2001). The water vapour transmission rates (WVTR) of biodegradable polymers at 25 °C is 20–300 g/m^2/d (depending on polymer type) is much higher than that of polyethylene, which is around 1 g/m^2/d (Shogren, 1997). The high permeability to water vapour, compared to traditional synthetic plastics inhibited so far their use for packaging of horticultural produce, when loss of water content is the major factor that reduces shelf-life. This holds also for perforated films, as biodegradable films used for packaging of tomatoes were found to induce a much larger weight loss in the produce due to release of water, compared to a polyethylene package with the same perforation characteristics (Kantola and Helén, 2001). In order to attain optimum conditions, the package must be specifically designed to match the handling conditions, ethylene sensitivity and respiration rate of the produce to be packed.

Several research efforts have been carried out and work is in progress aimed at developing biodegradable packaging materials for various applications, including food packaging. For example, poly(lactic acid) (PLA) is currently used as a food packaging polymer for short shelf life products with common applications such as containers, drinking cups, sundae and salad cups, overwrap and lamination films and blister packages. A limited portion of this research effort is dedicated to EMAP packaging systems. The development of biodegradable films that are based on renewable raw materials and are designed for EMAP systems for fresh produce, meeting the design criteria of water vapour and gas barrier properties, ensuring safety of the produce while maintaining the original quality, firmness and colour of the fresh produce is still at the very early stages of research and development.

Current applications of bio-based materials have not taken full advantage of the inherent properties of the biodegradable products that would revolutionize food packaging. An innovative biodegradable bio-based film packaging system has been developed recently to achieve EMAP of high value sensitive horticultural fresh produce by combining laser micro-perforation and breathable membrane technologies in the framework of *HortiBioPack* (EU Project ‘*HortiBioPack*’, 2008; Mistriotis and Briassoulis, 2012). The basic design concept and key design parameters of the novel bio-based EMAP system and their optimization in terms of performance and cost reduction are presented in the present work. The performance of the optimized PLA-based EMAP system was evaluated experimentally. The targeted in-package conditions have been achieved for specific cultivars of peach and cherry tomatoes under ambient shelf storage conditions. As a result the produce shelf life under the given conditions has been extended. The experimental results were also used to validate the analytical model developed for the PLA-based EMAP design (Mistriotis and Briassoulis, 2012) and were compared against the results of 3D numerical simulations used for modelling the effect the optimized design parameters on the behaviour of the EMAP system (Briassoulis et al., 2012). The overall performance of the PLA films used in these EMAP experiments was evaluated by measuring the evolution of some critical properties of the films at the end of the shelf-life time. The evaluation of the sensory quality characteristics and the microbiological spoilage of the horticultural produce packed with the PLA-based EMAP are beyond the scope of the present work as this topic has been investigated thoroughly with earlier full-scale experimental series (D’Aquino et al., 2011a,b, 2012a).

2. Innovative design of bio-based EMAP for horticultural produce

2.1. Design requirements for EMAP of tomatoes and peaches

Two specific sensitive high value horticultural fresh produce were considered in the framework of EU Project ‘*HortiBioPack*’ (2008): peach (fruits) and cherry tomato (vegetables). The research conducted allowed defining the design requirements of biodegradable EMAP to reduce microbiological spoilage in fresh cherry tomatoes and peaches as well as to preserve and prolong shelf-life through EMAP under simulated marketing conditions, i.e. 18–20 °C and 60–65% RH. Extensive laboratory experiments (D’Aquino et al., 2012a) have shown that for given storage conditions, specific in-package concentration values of CO_2, O_2 and water vapour (WV) could improve the shelf life and quality of cherry tomatoes and peaches.

Reduced levels of O_2 and increased levels of CO_2 (within certain limits) can conveniently prolong postharvest life and minimize ethylene-dependent responses of commodities prior the onset of ripening (possibly combined with hot water pre-treatment), but once the ripening process is initiated their physiological activity is drastically reduced (D’Aquino et al., 2011b). Decay was generally higher in packages with lower water vapour permeability, due to the higher levels of in-package humidity. On the other hand in-package humidity was found to be the most important factor affecting overall appearance, firmness, shrivelling, ageing. Only packed cherry tomatoes could maintain market quality for 28 days at 20 °C. In peaches kept in atmospheres containing below 10% O_2 and above 10% CO_2, the taste and odour were negatively affected (D’Aquino et al., 2011a). Large amounts of unwanted substances, such as ethyl acetate and a range of other alcohols and esters, were produced in peaches kept in those atmospheres, and only in fruit