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Evaluation of novel bitter cassava film for equilibrium modified atmosphere packaging of cherry tomatoes

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ABSTRACT

Equilibrium modified atmosphere packaging (EMAP) technology offers the possibility to maintain produce postharvest quality and extend its shelf-life. However, EMAP stability depends on well-tuned packaging design parameters to match environment conditions. This study defined design requirements of a biobased film EMAP that can preserve quality and prolong shelf-life of fresh cherry tomatoes under recommended and simulated abuse supply chain conditions. Optimum EMAP was evaluated based on headspace gas composition at 10–20 °C, 75–95% RH and verified by determining quality changes of packed cherry tomatoes in using a continuous or micro-perforated (0.27 µm) bio-based intact bitter cassava (IBC) film. This was compared with a non-bio-based polymer film (oriented polypropylene, OPP). The IBC film attained equilibrium O_2 (2–3%) after 180 h at 10 °C, with 0 and 1 perforation, for 75 and 95% RH while OPP film maintained a downward O_2 fall. Continuous and micro-perforated IBC film did not show any major differences in equilibrium headspace O_2, thus perforation can be neglected. Based on desirability optimisation results, biobased IBC film demonstrated better optimized EMAP system in attaining recommended gas and stretching cherry tomato shelf-life as compared to non-biobased (OPP) film. The application of bio-based IBC film offers new possibilities in packaging fresh produce under equilibrium modified atmosphere without compromising their quality.

1. Introduction

The increasing demand for natural, minimally-processed, nutritious fresh foods and convenience products, and the globalization of food trade have created major challenges for the food packaging industry. Moreover, the increased consciousness of healthy diet and the need for safety and quality maintenance in distribution chains have resulted into growth of innovative technologies in food processing (Caleb, Mahajan, Al-Said, & Opara, 2013; Siró, 2012). Thus, it is recognised that packaging is an indispensable food processing technology, particularly for safe handling and delivery of fresh products such as fruits and vegetables (Opara & Mditshwa, 2013; Ramos et al., 2013). Of these technologies, modified atmosphere packaging (MAP) and controlled atmosphere storage technologies offer the possibility to extend and preserve the quality and shelf-life of fresh fruits and vegetables (Solitani, Mobli, Alimardani, & Mohtasebi, 2015).

The MAP is a widely-demonstrated technique, which is increasingly used for the preservation of natural quality of fruits and vegetables in addition to extending the storage life (Horev et al., 2012). In particular, there is increased awareness of value chain actors on advantages of MAP due to stringent regulations on the use of chemical preservation methods (Gattorna, 2013). In MAP technique, the in-package air composition is modified so as to prolong the original fresh state of fruits and vegetables. This is usually achieved by lowering atmospheric oxygen (O_2) and raising carbon dioxide (CO_2) for the purposes of aerobic microorganism growth reduction and oxidation reaction prevention (Churc & Parsons, 1995; Robertson, 2013). The in-package gas balance is often realised using active means such as gas flushing and compensated vacuum or passive techniques such as equilibrium modified atmosphere packaging (EMAP) (Robertson, 2013). Among these, EMAP is the most commonly used technique for respiring products in which package permeability to O_2 and CO_2 is often accustomed to product's respiration level (Del-Valle, Hernandez-Munoz, Catala, & Gavara, 2009; Mattos, Moretti, & Ferreira, 2012; Sandhya, 2010; Siddiqui, Chakraborty, Ayala-Zavala, & Dhua, 2011). An EMAP is established inside the package when gas (O_2, CO_2) transmission rate of the package matches O_2, and CO_2 consumption rate of packed product (Jacxsens, Devlieghere, De Rudder, & Devebere, 2000; Jacxsens, Devlieghere, & Devebere, 2002).

Nowadays, efforts are focused on development of optimal EMAP

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systems (Briassoulis, Mistriotis, Giannoulis, & Giannopoulos, 2013; Caleb et al., 2013; Castellanos, Polanía, & Herrera, 2016; Mistriotis, Briassoulis, Giannoulis, & D'Aquino, 2016). However, the major challenge still remains in determining the most appropriate packaging material for provision of ultimate EMAP across a range of conditions of the distribution chain. Currently, conventional petrochemical low-density polyethylene, polyvinylchloride and oriented polypropylene (OPP) account for about 90% of fruit and vegetable MAP (D'Aquino et al., 2016; Mangaraj, Goswami, & Mahajan, 2009). This is due to their thermoplastic nature with heat sealing, heat resistance, excellent chemical and water resistance and transparency properties (Kirwan, Plant, & Strawbridge, 2011). While these plastic packets are versatile and present good mechanical properties (Siracusa, Rocculi, Romani, & Rosa, 2008), they are not sufficiently permeable for high-respiring fruits and vegetables (Cichello, 2015; Sandhya, 2010). Besides, they create anaerobic conditions resulting in fresh product with an undesirable taste, physiological change, and decay from fungi (Lee, Yun, Jeong, & Kim, 2005). Moreover, they adversely impact on the environment (neither totally recyclable nor biodegradable) causing risk to human health or ecosystems (Mahalik & Nambiar, 2010). According to Markets and Markets (2014) and Themelis, Castaldi, Bhatti, and Arsova (2011), global plastic film sheets market is predictable to reach 70.9 million tons by 2018, and only a small part of the plastic waste is finally recycled.

To mitigate non-renewable plastic challenges for EMAP of vegetables and fruits, research emphasis focused more on package perforations (Brockgreitens & Abbas, 2016; Castellanos et al., 2016; Ferreira, Alves, & Coelhoso, 2016). To date, macro- and micro-perforations have been reported to influence gas exchange inside the package system (Almenar, Samsudin, Auras, & Harte, 2010; Mistriotis et al., 2016; Rai, Tyagi, Jha, & Mohan, 2008) and prevent anaerobic conditions (Hirata et al., 1996; Lee et al., 1996). Very recently, D'Aquino et al. (2016) reported an increase of O_2 and decrease of CO_2 composition from 6% to 15% and 12% to 3% for cherry tomatoes stored in unperforated and perforated OPP films respectively for 21 days at 20 °C. In the same experiment with macro-perforated OPP, the gas values were reported to be those of atmospheric air. It is recommended that low levels (3–5%) O_2 and CO_2 are required for positive and effective packaging, proper respiration, anaerobic respiration prevention and fresh and natural colour preservation of fruits and vegetables (Day, 1996; Phillips, 1996; Robertson, 2013; Sandhya, 2010; Zagory & Kader, 1988). However, macro-perforation practice might raise food safety concern. Physical, chemical and biological impurities may transfer through the perforations and cause post processing contamination Siddiqui et al. (2011). While this is not yet approved scientifically, the concern can be true, in particular for tropics where conditions are suitable for possible contamination. Further, macro-perforations can cause high moisture loss from the product to create higher gradient in package; it has been reported to increase in-package O_2 greatly and possibly promote microbial growth (Fishman, Rodov, & Ben-Yehoshua, 1996).

Innovations in biobased materials such as polylactic acid (PLA) have led to the development of alternative EMAP systems (Briassoulis et al., 2013). The advantages of using bio-based materials, instead of petrochemical materials, are their low-cost, abundant, recyclability and eco-friendliness (Auras, Harte, & Selke, 2004; Tumwesigye, Oliveira, & Sousa-Gallagher, 2014). However, the challenge of EMAP design of biobased materials has been to obtain the right permeability to match the high respiration rates of fruits and vegetables. Further, while biobased design, including their perforated equivalents, has been positive, the higher production cost, property deficits such as high hydrophilicity, low strength and poor barrier properties limit their use in EMAP of fruits and vegetables (Kantola & Helén, 2001; Shogren, 1997). As result, perforation-enhanced permeability in biobased films such as PLA has been investigated as a solution to overcome the permeability problems (Mistriotis et al., 2016).

Recently, a flexible packaging film was developed from novel intact bitter cassava (IBC) using an improved simultaneous release recovery and cyanogenesis (SRRC) downstream processing, optimised and standardised (Tumwesigye, Oliveira, & Sousa-Gallagher, 2016a; Tumwesigye, Montañez, Oliveira, & Sousa-Gallagher, 2016; Tumwesigye, Peddapatla, Crean, Oliveira, & Sousa-Gallagher, 2016). This film was shown to have comparable properties with those of petrochemical and bio based film (Tumwesigye et al., 2016a). These include its: i) ability to allow visual appearance of packed product due to better transparent properties (high clarity); ii) relatively water-resistance; iii) smooth and flexible surfaces; iv) reasonable permeability to water vapour and gases; v) adequate mechanical properties; good seal strength; vi) thermoplastic/thermal stable properties; vii) printable material and bag manufacturing capability; and anti-fog attributes (Briassoulis et al., 2013; Tumwesigye et al., 2016a). In addition to biobased film properties, IBC has other advantages of being produced with low-cost biowastes, underexploited bitter cassava using SRRC, energy-efficient and developed with a holistic integrated approach for multiple uses (Tumwesigye, Morales-Oyervides, Oliveira, & Sousa-Gallagher, 2016; Tumwesigye, Oliveira, & Sousa-Gallagher, 2016b). Hence, IBC films can offer new possibilities in optimising EMAP system design for fruits and vegetables while providing zero environmental impact. Nonetheless, IBC film application to EMAP will hinge on its effective permeability to O_2, CO_2, and water vapour, direct interaction with product(s) and external environment supply chain conditions (temperature, relative humidity and mechanical stress). Therefore, it is important to understand fully the functional contribution of IBC film to EMAP of fruits and vegetables, in particular its suitability to package and extend shelf-life of cherry tomatoes.

Cherry tomatoes are most popular and widely consumed fresh products in the world today due to the economic and nutritional importance of the crop (Arah et al., 2016). As population increases and global cherry tomatoes consumption grow and expand in environments outside the traditional distribution chains, the need to have stricter controls on the packaging system becomes crucial. In this case, the influence of temperature and relative humidity (RH) are important. For example, large sums of water and high water activity of vegetables can be readily lost under low RH leading to skin wrinkling, crunchiness and crispiness losses, wilting and undesirable colour changes (Briassoulis et al., 2013). Besides, the high RH can lead to enhanced fungal spoilage (Briassoulis et al., 2013). Numerous writers have reported effects of temperature and RH on tomato quality (Caleb et al., 2013; Correia, Loro, Zanatta, Spoto, & Vieira, 2015; D'Aquino et al., 2016; Majidi, Minaei, Almassi, & Mostofi, 2014; Sandhya, 2010). Product respiration rate should also influence cherry tomato quality (Islam, Kim, & Kang, 2012; Duan et al., 2013; Tosati, de Oliveira, Lerin, Sarantópoulos, & Monteiro, 2015). For example, studies on MAP of cherry tomatoes in a targeted experiment using a PLA packaging film (area, 500–900 cm^2) and 5 micro-perforations (diameter, 200 μm) provided CO_2 and O_2 concentrations of 2–6% and 15–20% respectively (Briassoulis et al., 2013). Other studies reported MAP with 14–18% O_2 and 2–5% CO_2 beneficial for maintaining ripe cherry tomato quality of both cultivars stored at 20 °C (D'Aquino et al., 2016).

For an optimal EMAP design of IBC films, the product respiration, transpiration and permeation rates of the packaging system must be fully explored and understood. The optimization studies, employing desirability function (DF), have been successful in IBC films. Tumwesigye, Montañez et al. (2016), Tumwesigye, Peddapatla et al. (2016), Tumwesigye, Morales-Oyervides et al. (2016) demonstrated models predicting impact of processing conditions on film properties for food packaging, efficient material balance and low-cost and energy efficient film production. Other desired conditions and maximum responses, using DF, were obtained for widened applications (Andrade-Mahecha, Tapia-Blácido, & Menegalli, 2012; Candioti, De Zan, Cámara, & Goicoechea, 2014; Costa & Lourenço, 2016; John, 2013; Khor, bt Jaafar, & Ramakrishnan, 2016; Marcin, Jaroslaw, Monika, & Agnieszka, 2015; Wager, Hou, Verhoest, & Villalobos,

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