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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, 2016). While the DF provided good results in broad application areas, its strength has not been explored for EMAP. Thus, it was crucial to evaluate the impact of temperature, RH and microperforations on headspace O_2 and CO_2, and establish an EMAP process robustness incorporating low-cost base materials and formulations.

The general objective of this study was to define the design requirements of IBC film EMAP which can preserve the quality of fresh cherry tomatoes as well as prolonging their shelf-life under recommended and simulated abuse supply chain (10–20 °C, 75–95% RH) conditions (Suslow & Cantwell, 2009). To satisfy the above purpose, the study: i) analysed the effect of design packaging parameters (microperforation, temperature, RH) on gas composition (O_2, CO_2) of cherry tomatoes; ii) determined the optimal design parameters and gas composition in order to achieve desirable dynamic conditions for EMAP of cherry tomatoes; and iii) evaluated the performance of optimised EMAP system using quality-determining shelf-life factors (weight loss, colour, pH and total soluble solids) of cherry tomatoes in order to verify EMAP system robustness. If natural breathable continuous IBC film regulated targeted in-package atmosphere in simulated market conditions, then the need for perforation system can be avoidable, with recommendation of low-cost novel IBC film as additional clean and green fresh packaging system.

2. Materials and methods

2.1. Bitter cassava bio-based film preparation

The biobased film used in the evaluation of EMAP of cherry tomato was produced from intact bitter cassava (IBC) derivatives. The IBC is composed of whole root of cassava (*Manihot esculenta* Crantz), with its wastes (peel, cambium, phloem, central xylem fiber) and edible parenchyma. It is one of the renewable resources, with less competition with food supply and a cost-effective option compared to the commonly used sweet cassava (Tumwesigye et al., 2016a). The films were manufactured using the casting method, with IBC derivatives (3% w/v), glycerol (30% w/w), according to the procedure described by Tumwesigye et al. (2016a). Films were produced to uniform thickness 30 ± 5 μm by pouring film-forming solution (30 ml) onto a previously lubricant sprayed 54 cm diameter flat glass plate and verified using an absolute digital calliper (Digmatic, Mitutoyo UK Ltd). The films were reported in Tumwesigye et al. (2016a) to possess the following attributes: waste content, 16%; total cyanogens, 0.4–2.5 ppm (recommended codex 2013 safe levels, ≤10 ppm); transparency (T), 3.64% more transparent films are obtained when T tends to 0%; water vapour [438.6 g/(m^2 day)], O_2 [812.9 cm^3/(m^2 day)], and CO_2 822.3 cm^3(m^2 day)] transmission rates; and seal strength, 323.0 (g(f)/25 mm). Prior to in-package O_2 and CO_2 evaluations, the films were conditioned (54 % RH, 23 ± 2 °C, for 48 h), and equilibrated (75 or 95 % RH, 10 or 20 °C, for 48 h). The equilibrated films were used for EMAP evaluations.

2.2. Experimental design, product preparation and packaging experimental set-up

2.2.1. Design

The design requirements of IBC film EMAP were defined based on four different factors viz, nature of the packaging material, number of perforations in the film, temperature and relative humidity conditions. The factors were previously reported to influence atmosphere packaging of respiring products (Briassoulis et al., 2013; Caleb et al., 2013; Castellanos et al., 2016; D'Aquino et al., 2016; Islam et al., 2012; Mangaraj, Goswami, Giri, & Joshy, 2014; Sandhya, 2010; Siddiqui et al., 2011). A full factorial experimental design was used with four factors at two levels, performing eight runs in total (Table 1).

The environment conditions were chosen based on the average recommended temperature (10 °C), for handling of tomatoes, and abuse conditions (20 °C) encountered in the supply chain (Briassoulis et al., 2013; Suslow & Cantwell, 2009). It is widely accepted that package behaviour and performance of any packaging material are by far influenced by the environmental conditions (temperature and relative humidity) and the in-packaged product characteristics Ahmed, Parmar, & Amin, 2014; Mo, Yuan, Lei, & Shijiu, 2014; Siracusa, 2012).

Table 1
Factors and levels used for the evaluation of equilibrium modified atmosphere packaging (EMAP) design of cherry tomatoes, using intact bitter cassava (IBC) and oriented polypropylene (OPP) packaging films.

Factors	Levels	
Nature of the packaging material	OPP	IBC
Number of perforations (270-micron diameter)	0	1
Temperature (°C)	10	20
Relative Humidity (%)	75	95

2.2.2. Product preparation

Cherry tomatoes (*Solanum lycopersicum*) were purchased from a local supermarket (Tesco, Cork, Ireland) on product arrival day. The choice to use cherry tomatoes in EMAP evaluations was based on its physiological nature to rapidly deteriorate when mishandled, its sale at premium prices and known respiration rate (Sousa, Oliveira, & Sousa-Gallagher, 2017). Samples were washed serially in running and distilled deionised water and dried with a clean tissue paper to remove excess water. To ensure that the qualitative analysis yielded convincing results, tomatoes with smooth, shiny and reasonably hard skin, with no visible mould were sampled for the study.

2.2.3. Packaging experimental set-up

The procedure for storing cherry tomatoes in-package and measuring O_2 and CO_2 evolution considered the respiration rate using the closed system described by Iqbal, Rodrigues, Mahajan, and Kerry (2009) and Sousa et al. (2017) with modifications. Cherry tomatoes (150 g) were placed into polypropylene trays (11.1 cm × 15.5 cm × 3.4 cm) and sealed with flexible transparent IBC film of a breathable area of 130 cm^2 (Illustration 1). A manual table top tray lidding sealer (VS300, UK) with adjustable temperature control was used for optimal seal quality. Further, an air-tight adhesive tape was used reinforce any possible leakage between the film and the tray. The sealed trays were stored in temperature-controlled incubators at 10 and 20 °C for 19 and 15 days, respectively. Relative humidity was controlled by placing the trays in boxes with standard saturated sodium chloride (for 75% RH) and anhdrous glycerol (for 95% RH) solutions (Forney & Brandl, 1992).

In initial EMAP evaluations, changes in-package O_2 was measured. This was achieved placing directly the optical fibre cable on the headspace side (containing the sensor) of a chromatic non-invasive system (PreSense Sensing GmBH). Two replicates were used in each sample.

In desirability optimisation of EMAP, O_2 and CO_2 were monitored by a gas analyser (PBI Dansensor, CheckMate 9900, Denmark) using the method described by Sousa et al. (2017) with slight changes in measurement time (on 6 h basis). Where abnormal values in the evolution pattern of O_2 and CO_2 were observed, a check would be instituted to compare O_2 values using non-invasive system (PreSense Sensing GmBH). In the event that the deviation was significant, the tray sample would be repeated.

For comparison with a non-biobased film, the experiment was repeated with oriented polypropylene (Infania Group GmbH, Germany). The OPP is commonly used in EMAP of cherry tomatoes when perforated due to its low permeability, acting as a barrier to water vapour, CO_2, and O_2 (Briassoulis et al., 2013; Mistriotis & Briassoulis, 2012; Sousa et al., 2017).

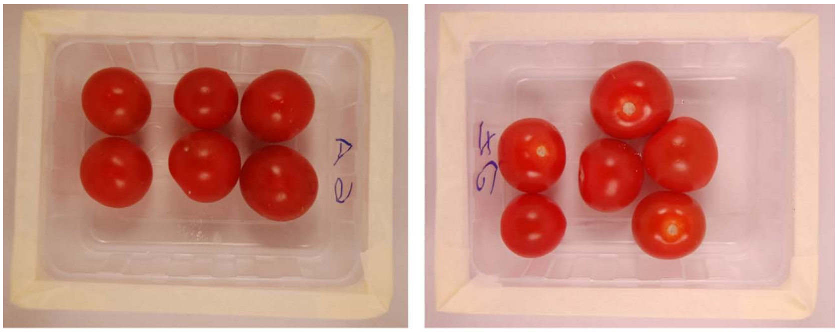


Illustration 1. Visual image demonstrating stored cherry tomatoes in a flexible transparent IBC film during EMAP determination.

2.3. *Multi-objective desirability optimisation (MDO) of EMAP system*

The MDO of Derringer and Suich (1980) was used in target desirability optimisation due to its capacity to predict desirables within the desired ranges. The aim was to achieve a desired EMAP for IBC with reduced O_2 and increased CO_2 levels within the recommended range (3–5%) for the package of fruits and vegetables (Robertson, 2013; Sandhya, 2010). Thus, different weights were assigned to O_2 and CO_2 predicted values Derringer and Suich (1980).

2.4. *Validation of optimally-designed EMAP system*

The optimally-designed IBC and OPP EMAP were validated qualitatively using characteristics intrinsic to cherry tomatoes, which are important for quality and shelf-life extension (Gwanpua et al., 2012; Selcuk & Erkan, 2015). By knowing factors which affect the package performance of cherry tomatoes during storage, optimal environmental conditions and adequate packaging materials can be selected to guarantee the maintenance of a high quality product during the desired shelf-life. In this experiment, 100 g of cherry tomatoes were placed in packages with IBC and OPP film with optimal conditions 0 and 1 perforation, 10 °C and 75 % RH. Weight loss, colour, pH and total soluble solids (TSS) of cherry tomatoes were determined at the beginning of the experiment (day 0) and every 4 days until the 24th day of storage, in each package corresponding to each day. Moreover, O_2 and CO_2 gas concentrations were measured in each day using PBI Dansensor (CheckMate 9900, Denmark) according to Sousa et al. (2017). Thus, further to the quantitative measurement, a qualitative parameter (mould growth) was factored in the performance evaluation.

2.4.1. *Weight loss*

The weight of cherry tomatoes in each package was measured using a precision balance (Kern EW 6200-2NM, Germany), with an accuracy of 0.001 g. The weight loss (W_L) was calculated based on the initial (W_0) and final weight (W_f) of the fruit, according to Eq. (1).

$$W_L = \frac{W_0 - W_f}{W_0} \times 100 \tag{1}$$

2.4.2. *Colour*

Visual flesh colour degradation of cherry tomatoes was assessed using a Minolta ChromaMeter (Model CR-300, Minolta Camera Co., Osaka, Japan), taking into account the saturation colour index (CI), which is dependent on Hunter colour parameters (a and b) (HunterLab, 2008) as shown in Eq. (2). Each reading was gotten by a cross-section placement of the tomatoes and recording the colour in the midpoint between central and distal parts of tomatoes.

$$\mathrm{CI} = \mathrm{a/b} \tag{2}$$

2.4.3. *Total soluble solids (TSS)*

The TSS content of the fruit was measured using a digital refractometer (Model: Refracto 30PX, Mettler Toledo, Japan). Each cherry tomato was sliced and squeezed to release the juice (> 2 drops) and put into the refractometer. The value of TSS content was expressed as °Brix (Javanmardi & Kubota, 2006). The °Brix was recorded as a mean of three values.

2.4.4. *pH*

Cherry tomatoes were previously homogenised with a blender, filtered and pH of the solution measured using a digital pH meter (Five Easy™ FE20, pH meter, China). An average of three replicates of the same solution of homogenized cherry tomatoes from each package was calculated.

2.5. *Statistical analysis*

A full factorial analysis of variance (ANOVA) was used to determine the significant ($p < 0.05$) impact of 4 factors at 2 levels on the headspace oxygen concentration. Statistical analysis was carried out to determine the effects of environmental conditions and package conditions on package performance by using Statistica 7.1 software (Statsoft Inc., Tulsa, USA). The same software was used to fit polynomial models to O_2 and CO_2, compute the effect of estimates necessary for evaluating the closeness of the experimental data to fit values. The second-order polynomial models were used to define O_2 and CO_2 desirability functions based on the desired range of 3–5%. The overall desirability (D) was targeted by asymmetric addition of the O_2 and CO_2 desirabilities.

3. Results and discussion

3.1. *Influence of EMAP design parameters on gas composition for cherry tomatoes*

The effect of design parameters (Table 1) on the dynamics of in-package headspace O_2 for cherry tomatoes stored using IBC film is presented in Fig. 1, showing that it reached equilibrium O_2 (2–3%) after 180 h (over 7 days) at 10 °C, with 0 and 1 perforation, for 75 and 95% RH respectively. It can be seen that although there was a slight deviation in O_2, which could be due to experimental error, the O_2 remained stable for the rest of the test period, suggesting that within margin of error the equilibrium was attained. Although the equilibrium O_2 at 95% RH was higher than at 75% RH for both non-perforated and perforated film, it was not significant as shown by the error bars (Fig. 1). This might be due to the barrier nature of IBC film with capacity to regulate O_2 (Briassoulis et al., 2013; Tumwesigye et al., 2016a). On the other hand, there is a possibility that the insignificant effect on a perforation at both 75 and 95% RH was influenced by the decreased film permeability (Mistriotis et al., 2011). It has been speculated that the perforation pattern regulates the gases and the area of water vapour permeability controls RH in EMAP designs (Mistriotis & Briassoulis, 2012). This might explain the patterns of

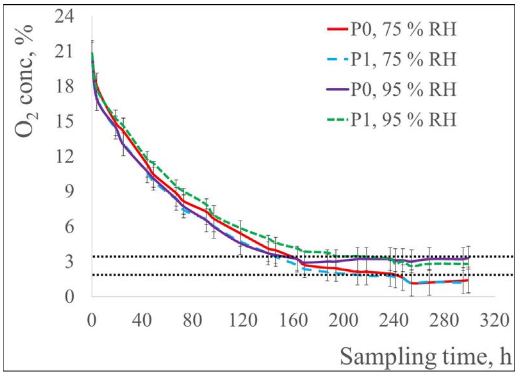


Fig. 1. Evolution of the dynamics of in-package headspace oxygen (%) of stored cherry tomato using intact bitter cassava (IBC) film with 0 and 1 perforations, at 10 °C, 75 or 95% RH. The vertical bars represent standard errors showing spatial relationship between two means.

equilibrium O_2 shown in Fig. 1. Further, the similarities in period of O_2 adjustment until 180 h across perforations and RH can be explained by the balance between film permeability rate and respiration rate of cherry tomatoes (Al-Ati & Hotchkiss, 2002). By and large, the equilibrium value falls within the recommended O_2 range (3–5%) for safe storage of tomatoes (Sandhya et al., 2010). Other previous reports under the framework of EU Project 'HortiBioPack' (2008) showed EMAP O_2 of 15–20% under storage conditions (18–20 °C, 60–65% RH) and targeted EMAP conditions (18–20 °C 80–90% RH) for cherry tomatoes (Briassoulis et al., 2013).

In contrast to IBC, continuous OPP film O_2 maintained a stead fall at 180 h without equilibrium attained (results not shown). This is perhaps associated with OPP high barrier properties limiting outside O_2 permeation and allowing on O_2 consumed by the product without replenishing (Sousa-Gallagher et al., 2013; Techavises & Hikida, 2008).

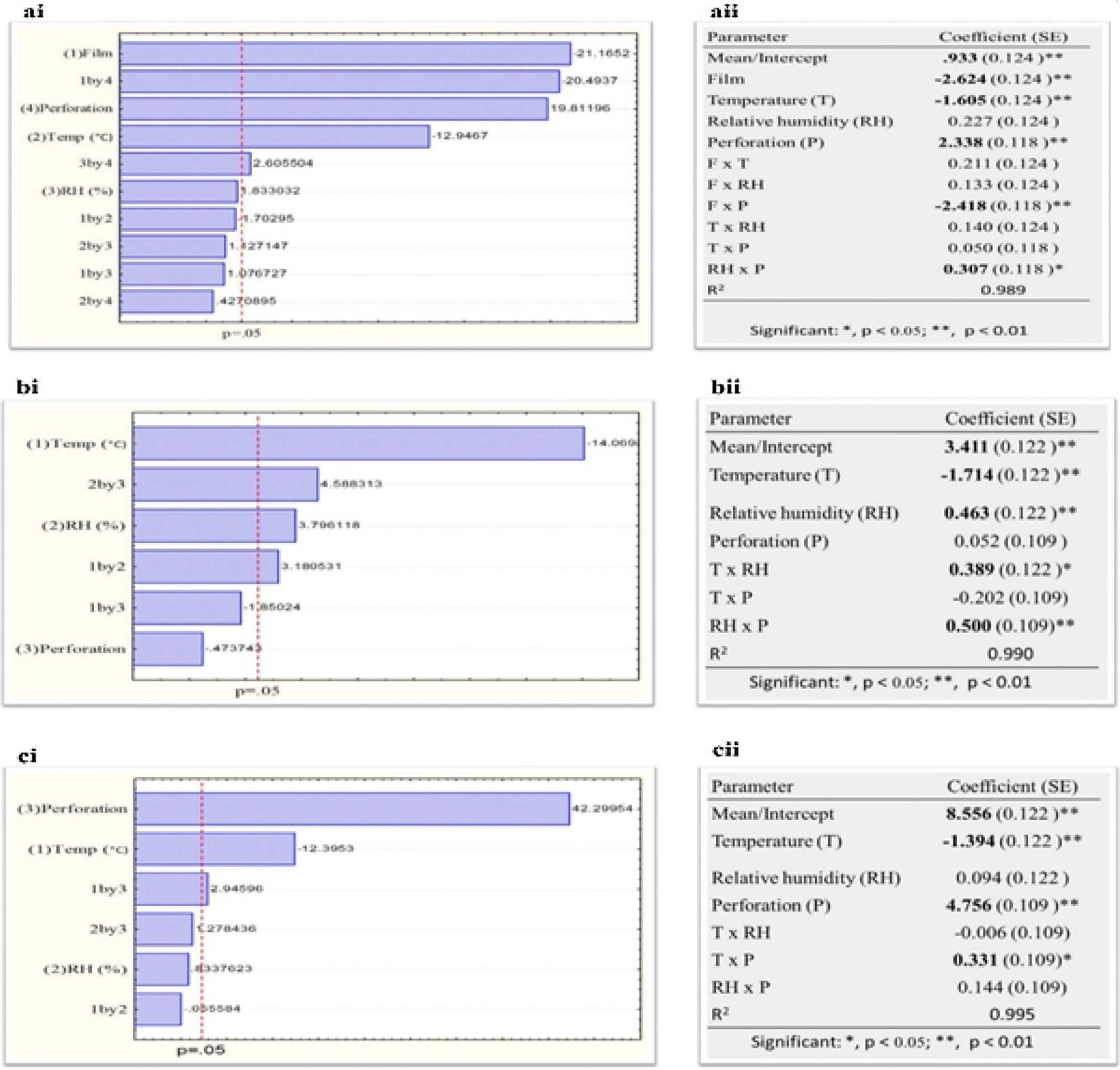
In a more in-depth analytical experiment, the biobased IBC film was compared with non-biobased OPP film. It can be seen from Pareto analysis that individual and combined EMAP design parameters had influence on equilibrium headspace O_2 (Fig. 2). The type of film, film-perforation interaction and temperature had highly significant ($p < 0.01$) negative effects, while perforating a film caused a significant positive impact on O_2 (Fig. 2ai). Further in-depth analysis of these results showed that the influence of the type of film and its perforation had a more pronounced influence than the effect of temperature (Fig. 2aii). Similar information has been reported between PLA and OPP films (Briassoulis et al., 2013) and breathable and non-breathable (Islam et al., 2014) when used in EMAP of fresh produce. The distinct differential effect might be due to extremely insensitivity to temperature of gas diffusion through perforations (Beaudry, 1999; Mannapperuma, Zagory, Singh, & Kader, 1989).

To determine which individual film parameters had more influence on O_2 composition, the data for IBC and OPP were analysed separately, and the results are shown in Fig. 2b and c. It is shown that temperature had a negative significant ($p < 0.01$) effect on O_2 in the IBC and OPP packages (Fig. 2bii and cii). Temperature and its interaction with perforation also showed less significant positive effect on OPP in-package O_2. It could be possible that temperature increased due to production of extra heat by respiring cherry tomatoes did not match rate of O_2 use and film permeation rate (Al-Ati & Hotchkiss, 2002). Alternatively, it could be explained by increased respiration rate due to increased product temperature than in the headspace atmosphere that lead into more O_2 consumption (Sousa et al., 2017). Another possibility could be the insensitivity of gas diffusion through the films. It is known that the mechanisms of gas movement through perforated and continuous films are by diffusion and permeation (Beaudry, 1999; Mannapperuma et al., 1989). Further, it is reported that the increase in gas permeability of continuous films is a function of temperature, as opposed to extremely insensitivity to temperature of gas diffusion through perforations (Beaudry, 1999; Mannapperuma et al., 1989). On the other hand, RH-perforation interaction, RH, and temperature-RH interaction influenced positively the IBC in-package O_2. Taken together, the results showed that perforations caused more pronounced impact in OPP in-package O_2 (average, 8.556%) (Fig. 2cii) than did the combined influence of temperature and RH in IBC O_2 (average, 3.411%) (Fig. 2bii). This was expected as perforations increase O_2 with increased temperature (Sandhya, 2010). But also it could be perhaps the effect of RH reducing the pore size in perforated IBC films causing it to behave like unperforated continuous IBC equivalent. In a restricted experiment in this study (data not shown) it was observed that the pore area/size was reduced at higher RH. The results could also mean that temperature provided a higher concentration gradient in-package and caused more loss of O_2 than the combined O_2-raising effects of RH-perforation, RH and temperature-RH (Mir, & Beaudry, 2002). Perhaps, this could explain the almost same equilibrium O_2 stability of perforated and non-perforated IBC film (Fig. 2a). Conversely, the perforated OPP tended to offset the temperature and gradient effects, thereby allowing more O_2 in-package (Mir, & Beaudry, 2002). In other words, OPP showed a contrasting effect of providing a higher equilibrium O_2 concentration than IBC, as shown by the positive value (Fig. 2cii).

Generally, when all the EMAP design parameters were compared, it was revealed that perforations had a higher influential behaviour on O_2 dynamics in the OPP in-package than temperature and RH (Fig. 3). This could be due to definitive relevance and stability of OPP perforations to retain pore size diameter and allow more permeation of O_2 regardless of temperature and relative humidity (Briassoulis et al., 2013). It might be also due to extremely insensitivity to temperature of gas diffusion through perforations (Beaudry, 1999; Mannapperuma et al., 1989).

It is shown that perforating IBC films did not have any influence on equilibrium headspace O_2, while using a single perforation in OPP had a significant influence on equilibrium headspace O_2 (Fig. 3ai and aii). Similar observation was reported by Mistriotis et al. (2011) and Briassoulis et al. (2013). This might be explained by the selective of IBC with respect to gases, but it could be also sensitivity and stability of OPP perforation to allowing more O_2 since it is a low barrier material (Briassoulis et al., 2013). Temperature had more marked effect on IBC than OPP in-package modulation of O_2 (Fig. 3bi), with IBC managing its O_2 to lower levels than OPP (Fig. 3bii). Similarly, it is shown that RH had a higher influence on IBC than OPP (Fig. 3ci). The result showed that on OPP packages the headspace O_2 concentrations are independent of RH (Fig. 3cii). Overall, increase in RH at 10 °C did not influence O_2 concentration on IBC packages, whereas, when temperature was raised to 20 °C, the increase in RH became important. This is possibly attributed to the reduction in the barrier properties that usually occur with broken hydrogen bonds between the polymer chains in the semi-crystalline IBC film amorphous region causing enhanced chain motion and increased energy level of permeating molecules (Siracusa, 2012; Tammelin et al., 2015; Tumwesigye et al., 2016a). It has been reported that when high water vapour permeability biobased films are used as packaging materials in EMAP systems, the permeable surface can be used to govern the in-package RH due to the much higher transpiration rate compared to respiration (Briassoulis, Giannoulis, & Mistriotis, 2012; Mistriotis & Briassoulis, 2012). This might also explain the observed above phenomena since IBC film has higher permeability to water vapour than OPP (Tumwesigye et al., 2016a).

The disparity in the impact of perforated and non-perforated IBC in-package O_2 might be due to either differences in gas concentration gradient across the film due to the presence of sufficient IBC film micro pores (Illustration 2) to allow for balanced permeability (Mir & Beaudry, 2002) or the antagonistic effect on pore size diameter that occur at high RH leading to less functional voids. If the former holds true, then it can be postulated that the mechanism of O_2 transfer through IBC film is by permeation, and thus IBC film is a continuous film (Beaudry et al., 1992; Kader, 1997; Mir & Beaudry, 2002). This can



aii

Parameter	Coefficient (SE)
Mean/Intercept	**.933** (0.124)**
Film	**-2.624** (0.124)**
Temperature (T)	**-1.605** (0.124)**
Relative humidity (RH)	0.227 (0.124)
Perforation (P)	**2.338** (0.118)**
F x T	0.211 (0.124)
F x RH	0.133 (0.124)
F x P	**-2.418** (0.118)**
T x RH	0.140 (0.124)
T x P	0.050 (0.118)
RH x P	**0.307** (0.118)*
R^2	0.989

Significant: *, $p < 0.05$; **, $p < 0.01$

bii

Parameter	Coefficient (SE)
Mean/Intercept	**3.411** (0.122)**
Temperature (T)	**-1.714** (0.122)**
Relative humidity (RH)	**0.463** (0.122)**
Perforation (P)	0.052 (0.109)
T x RH	**0.389** (0.122)*
T x P	-0.202 (0.109)
RH x P	**0.500** (0.109)**
R^2	0.990

Significant: *, $p < 0.05$; **, $p < 0.01$

cii

Parameter	Coefficient (SE)
Mean/Intercept	**8.556** (0.122)**
Temperature (T)	**-1.394** (0.122)**
Relative humidity (RH)	0.094 (0.122)
Perforation (P)	**4.756** (0.109)**
T x RH	-0.006 (0.109)
T x P	**0.331** (0.109)*
RH x P	0.144 (0.109)
R^2	0.995

Significant: *, $p < 0.05$; **, $p < 0.01$

Fig. 2. Main and interactive influence of equilibrium modified atmosphere packaging (EMAP) design parameters on equilibrium headspace O_2 concentration, as shown by Pareto analysis of ai) combined intact bitter cassava (IBC) and oriented polypropylene (OPP); bi) IBC, ci) OPP; and ANOVA of aii) combined IBC and OPP; bii) IBC; and cii) OPP.

also explain the slightly higher O_2 evolution of perforated film than non-perforated (Fig. 1) since it has been reported that gas transfer rate is a total of gas diffusion through the perforation and gas permeation through the polymeric film, with total gas flow through the perforations being much higher than gas movement through the film (Fishman et al., 1996). Relatedly, the change of O_2 with temperature in IBC film is evident that its permeability changes matched that of the cherry tomato respiration (Cameron et al., 1993; Sousa et al., 2017), and this is confirmed by the reports that O_2 permeability of continuous films increases with temperature (Beaudry, 1999; Mannapperuma et al., 1989).

Temperature has been shown to have a significant effect on product respiration rate and also on the packaging film permeability, but to a different extent (Sous et al., 2017; Sousa-Gallagher & Mahajan, 2013). This can pose a challenge for engineering packaging design. On the other hand, the results showed that OPP was not significantly influenced by changes in RH for the conditions studied. Same results have been reported when packing strawberries in OPP film (Tank, Oliveira, & Sousa-Gallagher, 2015). However, changes in environmental conditions could cause high variations in headspace O_2 which could compromise attaining the desirable headspace gas concentrations.

Most EMAP analyses rely on modifications of the packaging materials including use of different package material types, to predict responses via controlling and modifying parameters so as to attain the desired O_2 and CO_2 in-package (Mangaraj et al., 2014; Solitani et al., 2015). Other methods try to use mathematical models to describe the effects of a variety of factors, and often force to reach a compromise between different experimental variables in order to achieve the best gas composition in-package (Kwon, Jo, An, & Lee, 2013; Mangaraj et al., 2014). However, deployment of multi-objective optimisation with desirability can be an effective tool due to the extensive versatility to transform each response discretely and optimise them globally into an overall desirability function. In this study, desirable O_2 and CO_2 for EMAP design was determined via a targeted desirability optimisation experiment according to Derringer and Suich (1980) (Eq. (3)), and the results are presented in Figs. 4 and5. The significant terms for main and

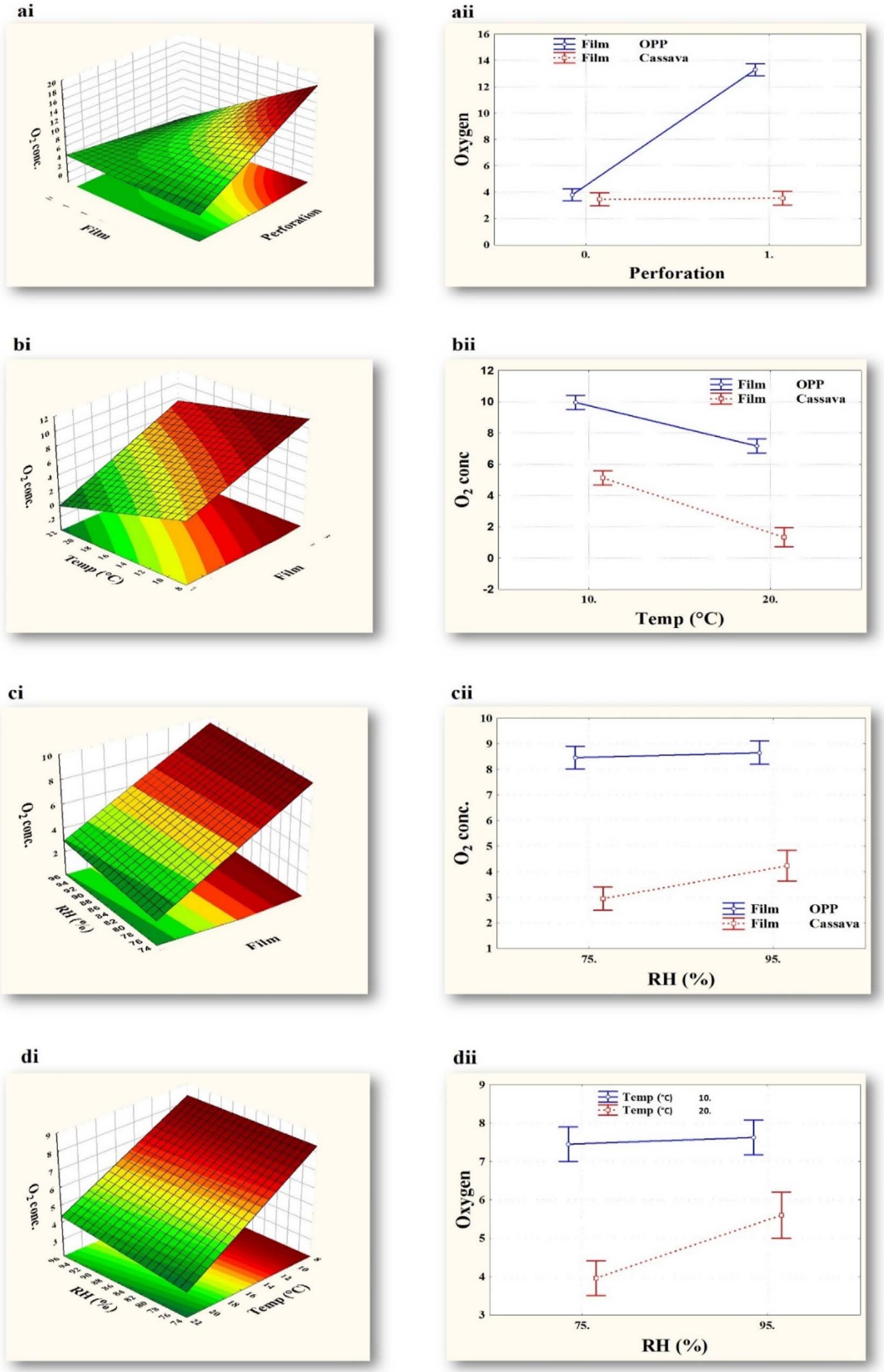


Fig. 3. Influence of a) film type-perforations; b) film type-temperature; c) film type-relative humidity (RH); and d) temperature-RH (for IBC), and their respective plots of marginal means on the dynamics of cherry tomato in-package headspace oxygen concentration using bio-based (cassava) and non-bio-based (OPP) films. The vertical bars represent standard error.

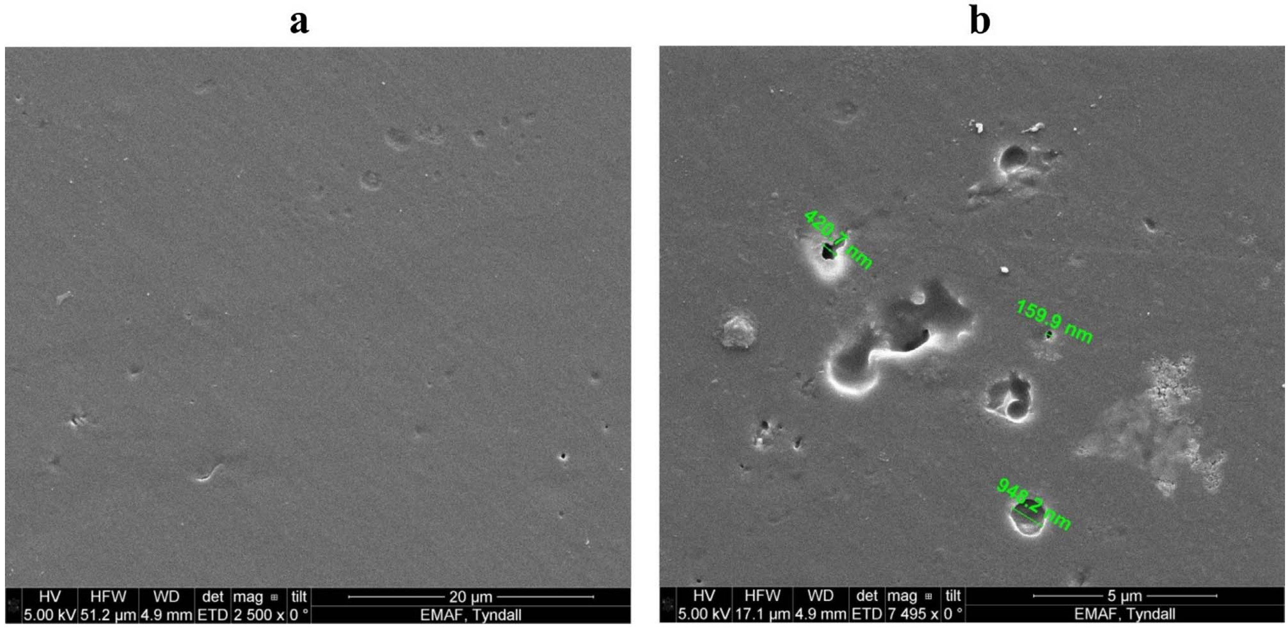


Illustration 2. Scanning electron microscopy (SEM) images showing pore distribution (a) and pore size diameter of IBC film.

interaction effects model fittings and choice, is shown in Fig. 4. Consequently, the main effects and combined two factor interactions was used in determining the relationship between design parameters and equilibrium headspace O_2.

As shown, the model sufficiently predicted the correlation between design parameters O_2, as best fit plots of combined parameters (Fig. 4a), IBC (Fig. 4b), and OPP (Fig. 4c).

$$d_i(\hat{Y}_i) = \begin{cases} 0 & \text{If}\hat{Y}_i(x) < L_i \\ \left(\frac{\hat{Y}_i(x) - L_i}{T_i - L_i}\right)^s & \text{If}L_i \leq \hat{Y}(x) \leq T_i \\ \left(\frac{\hat{Y}_i(x) - U_i}{T_i - U_i}\right)^t & \text{If}T_i \leq \hat{Y}(x) \leq U_i \\ 0 & \text{If}\hat{Y}(x) > U_i \end{cases} \tag{3}$$

The $\hat{Y}i$, Li, Ti and Ui denote the predicted response, lowest, target and upper values. The s and t explains crucial success of the target value, with $s = t = 1$; $s < 1, t < 1$; and $s > 1, t > 1$, showing desirability function increasing linearly towards T_i, convex and concave respectively.

Following, the IBC O_2 and CO_2 desirabilities were pooled, using the symmetric average, to provide the overall desirability (D) (Eq. (4)).

$$D = [(d_{O_2}(\hat{Y}_{O_2})) \times (d_{CO_2}(\hat{Y}_{CO_2}))]^{\frac{1}{2}} \tag{4}$$

where, $\hat{Y}O_2$ and $\hat{Y}CO_2$, second order polynomial response models for O_2 (Eq. (5)) and CO_2 (Eq. (6)). The dO_2 and dCO_2, individual O_2 and CO_2 desirabilities.

$$\mathbf{\hat{Y}O_2} = 3.4108–3.4282\ \mathbf{X_1} + 0{,}9250\ \mathbf{X_2} + 0.7750\ \mathbf{X_1X_2} + 1.0000\ \mathbf{X_1X_3}\ (R^2 = 0.9898) \tag{5}$$

$$\mathbf{\hat{Y}CO_2} = 5.5500 + 7.2500\ \mathbf{X_1}–2.3500\ \mathbf{X_2};\ (R^2 = 0.9953) \tag{6}$$

where, X_1, X_2 & X_3 denote temperature, relative humidity and perforations.

Regardless of the good fits, $R^2 = 0.9898$ and $R^2 = 0.9953$ for O_2 and CO_2 concentration in IBC films, perforations (Eq. (5)) and interactions (Eq. (6)) were not significant ($p > 0.05$), implying that IBC films were mainly influenced by temperature and relative humidity. This possibly verifies earlier idea that IBC films could support EMAP of cherry tomatoes when they are deployed as continuous films instead of being perforated. The increase in O_2 and CO_2 permeability with temperature increases of continuous films has been reported (Mir & Beaudry, 2002). Besides, over 98% of parameters and O_2 data explained the suitability and significance of the models ($R^2 > 98\%$).

The results showed that the desirable 3.72% O_2 and 4.89% CO_2 was achieved for IBC with temperature (10 °C), (75% RH), zero perforation, and 0.84 global desirability (Fig. 5a). By contrast, OPP desirable values were predicted at 6.27% O_2 and 9.84 % CO_2 (Fig. 4b), with temperature (10 °C), (75% RH), one perforation, and 0.92 global desirability. According to Harrington (1965), the quality of the desirability is: $D = 1$: ultimate satisfaction; $0.8 < D < 1$: excellent; $0.63 < D < 0.8$: good/or slight improvement over acceptable quality; $0.4 <$ D 0.63: acceptable, but poor; $0.3 < D < 0.4$: borderline;

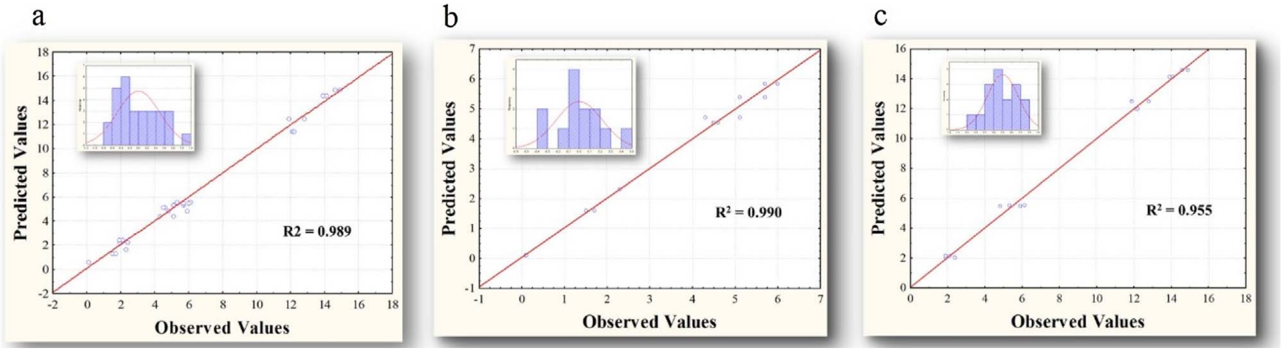


Fig. 4. Fittings used to determine the adequacy of main effect and two-way interaction models to predict O_2 for EMAP with a) combined IBC and OPP; b) IBC; c) OPP.

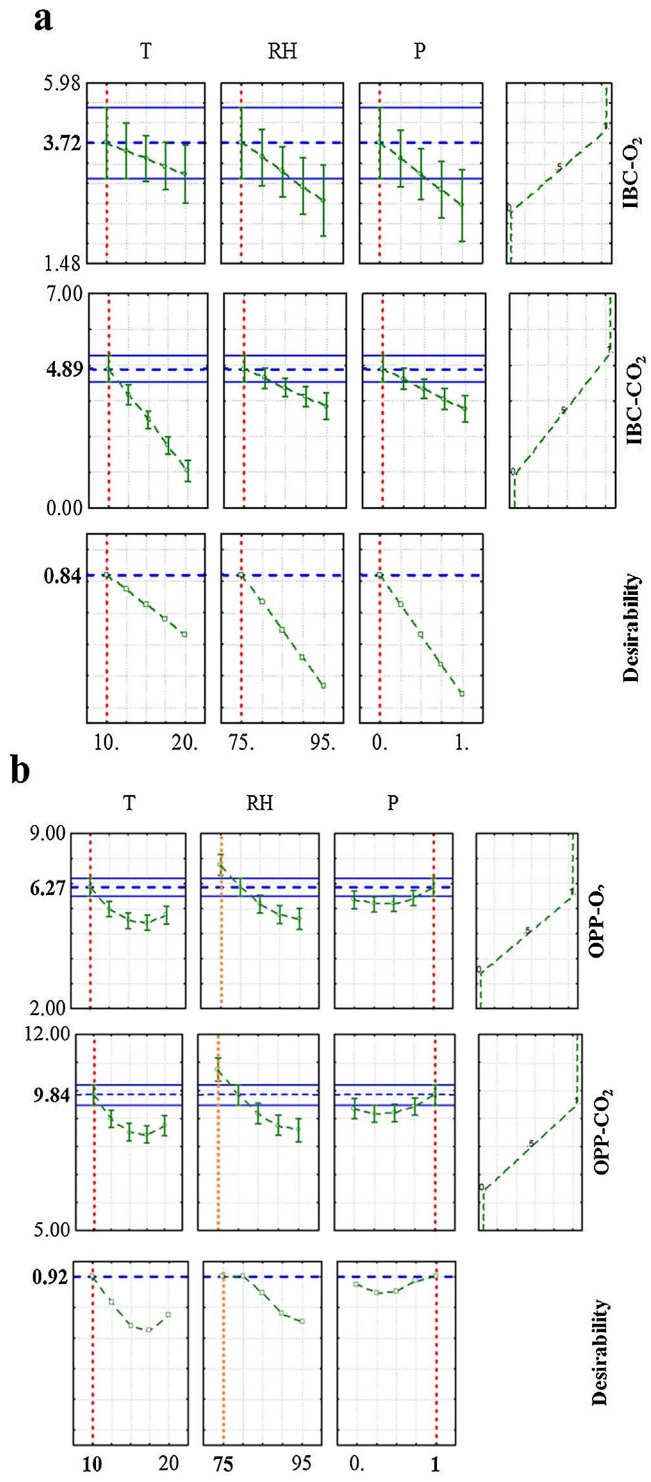


Fig. 5. Predicted optimal parameters, desired O_2 and CO_2 concentrations and desirable values used in optimization of EMAP as shown by profiles: ai) and aii) when using IBC and bi) and bii) OPP at optimum (75 % RH, 10 °C, zero perforation).

and D $<$ 0.3: unacceptable.

The O_2 and CO_2 values for cherry tomatoes are comparable to those reported in literature (Castellanos et al., 2016; Mistriotis et al., 2016). Further, 20–21 perforations (d, 200 mm) per 1000 g or 5 perforations (d, 200 mm) per 250 g of cherry tomatoes have been reported to generate a steady optimal CO_2 and O_2 EMAP of 4% (Mistriotis et al., 2016). Nonetheless, the EMAP O_2 for cherry tomatoes was higher (15–20%) in other study (Briassoulis et al., 2013).

3.2. Validation of simulated results

Once the optimum EMAP design conditions were selected, a new experiment was conducted using the optimal conditions (IBC and OPP film without perforations at 10 °C and 75% RH) to study the influence of storage period and package characteristics on the quality of cherry tomatoes.

It can be seen that no mould growth on cherry tomatoes was seen on IBC packages after the 15 days of EMAP storage (Fig. 6a). In contrast, in OPP stored cherry tomatoes mould growth appeared at stalk end scar within 15 days (Fig. 6b). Similar information of stem end scar as the starting of decay in cherry tomatoes has been reported (D'Aquino et al,. 2016; Mistriotis et al., 2016) However, the mould growth in IBC film packages appeared after 15 days at 20 °C, 95% RH, and after 19 days of storage at 10 °C, 95% RH. This corresponded with O_2 stabilisation at 20 days storage (Fig. 7a). The mould growth delay observed with IBC film-packages (Fig. 6a), might be partly due to optimum equilibrium headspace concentration (3–5% O_2 and CO_2) and fungicidal effect of CO_2 (Lopez-Briones, Varoquaux, Bureau, & Pascat, 1993). Conversely, the faster appearance in OPP film packages might be due to higher in-package RH that heightened mould growth (Mistriotis et al., 2016), but also in-package condensation as observed in this study. Thus, it can be inferred that, within storage under the conditions defined, IBC film can maintain EMAP in contrast to OPP. Boylan-Pett (1986) reported a shortened shelf-life of red-ripe tomatoes in an EMAP of low density polyethylene (LDPE) designed for optimal levels of O_2 and CO_2 compared to tomatoes stored in a flow-throw system with the same gas molar fractions. In a different study, mould growth on cherry tomatoes was observed after 13 day storage (Misra, Keener, Bourke, Mosnier, & Cullen, 2014). Thus, like any other biobased film packages, IBC film can provide a better EMAP of cherry tomatoes than OPP film and other non-degradable film packages (Mistriotis et al., 2016).

3.2.1. Package performance evaluation

A lower product weight was used to obtain headspace gas concentrations closer to the optimum range (O_2 and CO_2 3–5%). The evolution of headspace O_2 and CO_2 composition throughout storage time is shown in Fig. 7. Equilibrium was achieved within 8 days of storage for IBC film and 12 days for OPP film. This suggested that perhaps IBC film regulated better its permeability behaviour in such a way that O_2 consumed and CO_2 evolved during cherry tomato respiration matched IBC permeation, leading to faster equilibrium state (Kader, 1997). In this study, the decreased O_2 and increased CO_2, and their stabilisation in the in-package environment as storage proceeded beyond 19 days, was a good indicator that respiration rate decreased with time for the better of cherry tomato storage (Misra et al., 2014). For the OPP film, the headspace CO_2 concentration was higher than the desired level (3–5%), because the OPP film is more impermeable (Castellanos et al., 2016; D'Aquino et al., 2016). Although with IBC film the optimum equilibrium headspace concentration was achieved, this film was more susceptible to leakages due to changes in permeability with increase in-package humidity. This can be an advantage of IBC film to be applied in higher respiring products such as mushrooms and broccoli to maintain the necessary O_2 gradient for servicing high respiration (Fishman et al., 1996).

3.2.2. Quality evaluation of fresh cherry tomatoes

Desirable levels for both gases were achieved using IBC film, however it was necessary to evaluate the effective performance of packaging films by quantifying the quality parameters of the packed product (Gwanpua et al., 2012; Misra et al., 2014; Selcuk, & Erkan, 2015) (Fig. 8).

Weight loss is associated with deterioration of commercial value and quality of the produce (Briassoulis et al., 2013). It can be seen that product weight decreased with storage time (Fig. 8a). While there was more loss in IBC film than OPP film storage of cherry tomatoes, only

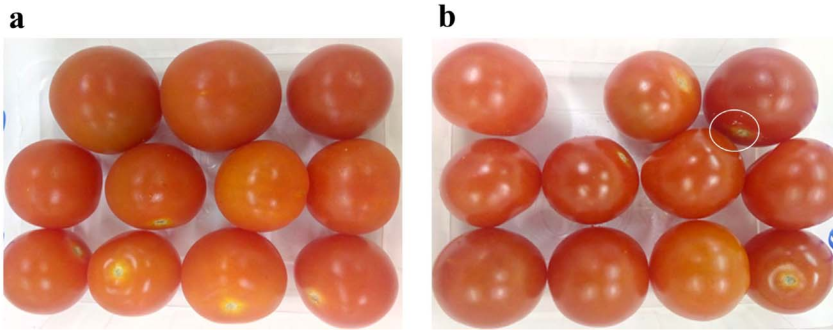


Fig. 6. Example of cherry tomatoes in packages with IBC (a) and OPP (b) film at 10 °C and 75% RH after 15 days of storage; the circle on the right shows visible fungus.

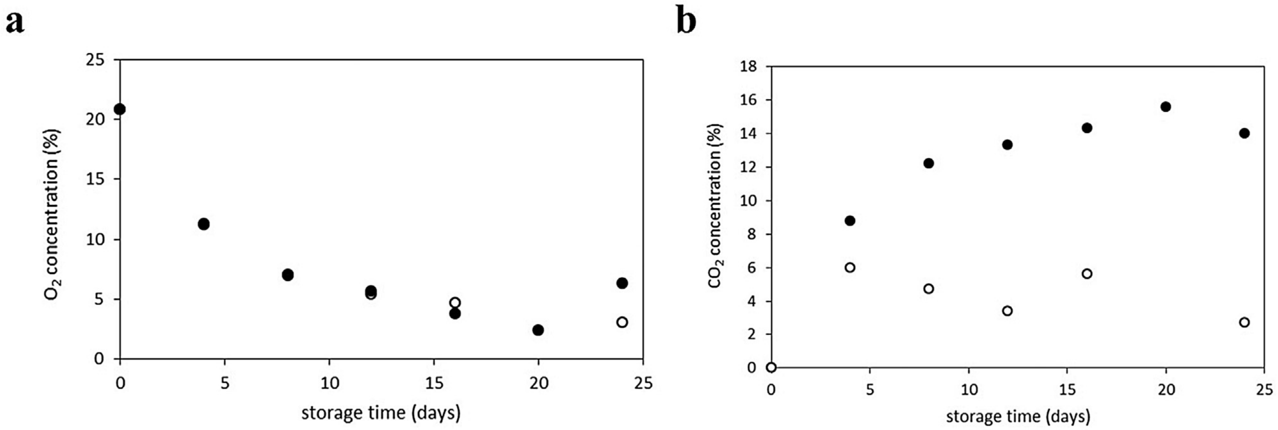


Fig. 7. Change in package atmosphere gas composition during storage at 10 °C using IBC (○) and OPP film (●), in terms of: a) O_2 and b) CO_2 headspace gas concentrations.

4–5% loss was attained within 24 days. The magnitude of weight loss can be accounted for possibly the higher transpiration rate of cherry tomatoes (Javanmardi & Kubota, 2006) and high IBC film permeability (Sousa-Gallagher et al., 2013; Techavises & Hikida, 2008). Also, this could be a consequence of possible leaks observed in this study leading to increased mass transfer area. In addition, the change in permeability could be mainly due to the swelling effect of the water molecules, changing its structure and consequently making the diffusion of vapour through it easier (Siracusa, 2012). Batu and Thompson (1998) also showed that tomato weight losses were related to film permeability. The maximum weight loss during the storage period was 0.32% and 4.38% for tomatoes packed using OPP and IBC film, respectively. Higher IBC film package weight loss than the OPP equivalent might be due to IBC water partial pressure difference caused mainly by transpiration between the surface of the fruit and the headspace surrounding it as a result of high film permeability (Castellanos et al., 2016). According to Kader and Saltveit (2003), circa 3–5% of produce postharvest weight loss is due to escape of CO_2 either through epidermis layers or gaseous pores. A significant ($p < 0.05$) effect was observed when using different package characteristics. The OPP film proved to be a good barrier to water vapour, thus resulting into low water loss rates in cherry tomatoes and accumulation caused by the limitation of EMAP (Akbudak, Akbudak, Seniz, & Erisi, 2007). However, neither OPP nor IBC packages exceed the maximum permissible water loss threshold for tomato fruit of 7 % (El-Ramady, Domokos-Szabolesy, Abdalla, Taha, & Fári, 2015). More than 3–5% of fruit and vegetable weight loss is normally associated with loss of characteristic freshness (Robertson, 2006). A weight loss of 8–10% for PLA-based EMAP of cherry tomatoes has been reported at 22–25 days of storage (Briassoulis et al., 2013). Accordingly, loss of 4.38% after 19 days of storage is a good indicator for an increased shelf-life of cherry tomatoes under IBC EMAP.

Colour parameter is by far taken as the most vital indicator of quality judged by consumers in market outlets (Misra et al., 2014). The evolution of tomato colour during the storage time is shown in Fig. 8b. Colour significantly ($p < 0.05$) increased with time, but package did not influence the colour of the fruit. Isaak et al. (2006) and Kudachikar, Kulkarni, Vasantha, Prasad, and Aradhya (2007) reported similar results in which MAP did not influence colour change in plantain and banana. Colour index is generally used to determine the stage of the fruit, wherein for these storage and maturity conditions it was near 1.1 for tomatoes packed using OPP and IBC film (Tadesse, Ibrahim, & Abtew, 2015; Weingerl & Unuk, 2015). The upward colour change trend with storage might be described by the hydroxylation of carotenoids and synthesis of xanthophylls (Gross, 1991). Batu (2004) reported that tomatoes at light-red stage presented a colour index between 0.6 and 0.95, and so they can be marketed very easily.

3.2.3. Total soluble solids (TSS) content

The TSS decreased in cherry tomatoes stored in both IBC film and OPP film EMAPs, but did not show much marked differences between 0 and 15 days of storage (Fig. 8c). Nonetheless, there was significant ($p < 0.05$) after 15 days of storage. Further, there was no significant ($p > 0.05$) difference between two EMAP packages until 15 days storage. It is also noted that there was an increasing trend in both EMAPs after 15 days of storage. Generally, TSS loss was < 2%. The trends could be attributed to low in-package O_2 and CO_2 (Erkan, Gübbük, & Karasahln, 2004; Majidi et al., 2014). Similar trends were observed for apple, peach and persimmon TSS after 9 months and 7 and 8 days of storage respectively (Erkan et al., 2004; Wright & Kader, 1997). The TSS increase in the first part (5 days) of storage may be due to insoluble polysaccharide hydrolysis into simple sugar (Mangaraj et al., 2014).

The pH is commonly used to assess tomato quality due to its influence on the processing conditions vital for producing safe products (Misra et al., 2014). A significant ($p < 0.05$) increase in pH was

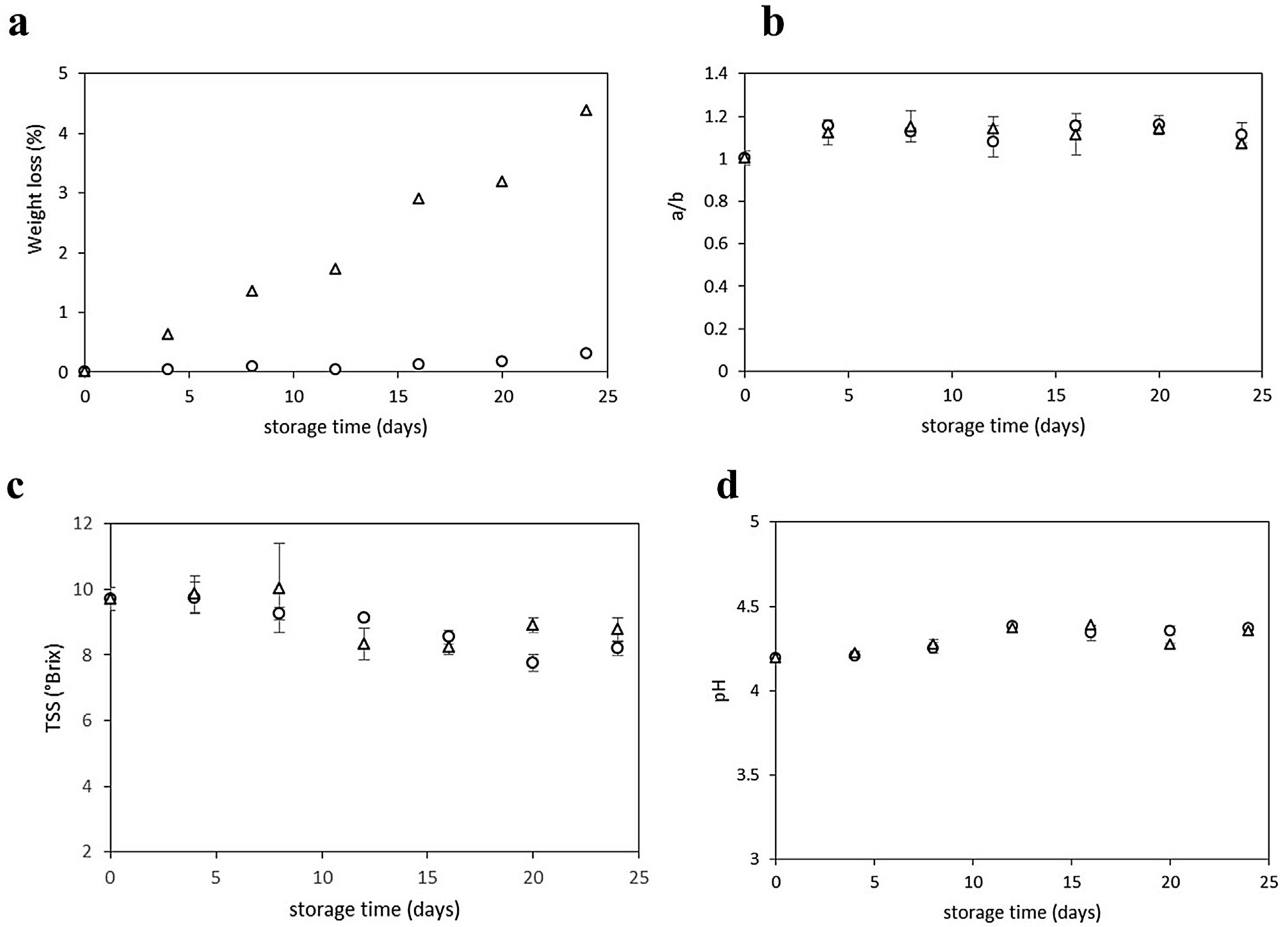


Fig. 8. Changes in quality parameters: a) weight loss, b) pH, c) TSS and d) colour index (a/b) of cherry tomatoes stored at 10 °C and 75%RH in packages with OPP (○) and IBC (Δ) films, during 24 days of storage. The vertical bars represent the standard error showing spatial relationship between two means.

observed during the storage period (Fig. 8d). However, film type did not significantly affect tomato flavour attributes. On the other hand, the interaction of storage period and type of film had a significant effect on pH. In general, there is a decrease in sugar content in the end of the storage period perhaps due to its use as a substrate in the product respiration. The pH value slightly increased over time (Fig. 8d), which indicates that the concentration of organic acids was declining with maturity due to the utilization of malic acid as substrate of respiration (Kaur & Dhillon, 2014; Lobit, Genard, Soing, & Habib, 2006). The most pleasing flavour of cherry tomatoes is often associated with a balanced ratio of sugar to acid, i.e. when the sugar content ranges between 5.5 °Brix and 9.5 °Brix and the pH between 4 and 4.5 (Neibauer & Maynard, 2002). The change could also be attributed to the metabolic changes and water loss in cherry tomatoes (García, Casariego, Díaz, & Roblejo, 2014). At these storage and package conditions, the fruit had fully fielded the necessary tomato market requirements. Increases in cherry tomato pH under natural storage conditions have been reported (Rodriguez-Lafuente, Nerin, & Batlle, 2010).

Knowledge of packaging material properties is important in evaluating their EMAP performance. Thus, assessment of IBC films in comparison to commonly used commercial (OPP, PLA) films in EMAP of cherry tomatoes was done and is shown in Table 2.

It can be seen that IBC film demonstrated comparable O_2 and CO_2 with the previous tested PLA and OPP based packages for EMAP of cherry tomatoes. The IBC film storage life of cherry tomatoes was comparable to PLA but longer than OPP when stored at same environmental factors of RH and temperature. The comparable results of IBC film with commercial PLA suggest IBC films could be applied in commercial containments of fresh produce in distribution chain temperatures (10–20 °C) and high humidity (> 90% RH).

4. Conclusion

This work allowed defining IBC film design EMAP requirements for cherry tomatoes. It was observed that perforation did not markedly change the IBC final equilibrium headspace O_2, implying that perforating the IBC film might not be necessary. Although temperature and RH were highly associated with shifts in equilibrium headspace O_2 they could not change the O_2 stability state noticeably, suggesting the ability of IBC film to match its permeability rate with respiration rate. This also demonstrates that IBC films can be deployed as alternative film packages for cherry tomatoes. The targeted IBC films desirable O_2 (3.72%) and CO_2 (4.89%) is a good promise for their use in EMAP of cherry tomatoes as well as high respiring products, within the CO_2 value confidence limits (Lopez-Briones et al., 1993). Nonetheless, it is highly recommended that IBC film EMAP is evaluated with high respiring products (e.g broccoli and mushroom) to determine the equilibrium gas range limits. The optimal IBC film EMAP storage duration of 15–19 days covering a range of recommended and abuse marketing conditions imply that this biobased film can offer new possibilitities in EMAP design requirements for packaging of a range of fresh produce. The slow weight loss, package-independence influence of colour and its minimal influence on pH and TSS over the entire storage time provide an alternative biobased packaging system for high value fresh horticultural produce. Qualitative-assisted validation (QLV) is an innovation, deviating from the conventionally-used quantitative validation (QTV), which merely provides a number without due consideration of the effect of the number on the actual material

Table 2
Comparison of packaging materials applied in the equilibrium modified atmosphere packaging (EMAP) of cherry tomatoes.

Property	Package type			
	Novel Bitter Cassava	Commercial		Reference
	IBC	PLA	OPP	
Equilibrium headspace O_2, %	3.72^{C}	1–20^{ix}	14–18^{vii}	^{i}Tumwesigye et al. (2016a)
Equilibrium headspace CO_2, %	4.89^{C}	3–4^{v,vi}	2–5^{vii}	^{ii}Innovia films
		4^{ix}		^{iii}Curtzwiler, Vorst,, Palmer, and Brown (2008)
Storage life, d	19^{C}	10^{ix}	21^{ix}	^{iv}Hishinuma (2009)
RH, %	75–95^{C}	80–90^{v,vi}	60–100^{vii}	^{v}Mistriotis et al. (2016)
		86^{ix}		^{vi}HORTIBIOPACK (2011)
Temp, °C	10, 20	19.5–20^{v}	20^{vii}	^{vii}D'Aquino et al. (2016)
		1-20^{ix}		^{viii}ASTM D638-10, (2010)
Water vapor transmission rate, g m^{-2} d^{-1}	438.6^{i}	375.0^{ii}	20.0^{ii}	^{ix}Briassoulis et al. (2013)
Oxygen transmission rate, cm^3 m^{-2} d^{-1}	812.9^{i}	524.9^{ii}	1693.3^{ii}	^{x}Jindal films
Carbon-dioxide transmission rate, cm^3 m^{-2} d^{-1}	822.9^{i}	3080.0^{iii}	nil	
Tensile strength, MPa	41.1^{i}	48.8^{viii}	81.6^{viii}	
Seal strength, (g(f)/25 mm)	323.0^{i}	815.0^{iv}	900^{x}	
Thickness (μm)	30	20–30	30	

^{C}Current study film-breathable area, 130 cm^2; zero perforation.
V, ix Film breathable area, 500 cm^2; micro-perforation, 5 of diameter, 200 μm.

properties. Moreover, QLV can be a vital verification tool for EMAP if it is pooled with QTV.

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