Food Packaging and Shelf Life 6 (2015) 7–20

Contents lists available at ScienceDirect

Food Packaging and Shelf Life

journal homepage: http://www.elsevier.com/locate/fpsl

Perforation-mediated modified atmosphere packaging of fresh and minimally processed produce—A review

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ARTICLE INFO

Article history:
Received 16 September 2014
Received in revised form 8 July 2015
Accepted 9 August 2015
Available online 27 August 2015

Keywords:
Fruit and vegetables
Produce quality
Packaging
Mathematical model

ABSTRACT

The overwhelming global demand by consumers for convenience and fresh quality fruit and vegetables, heightens the need for appropriate postharvest technologies. In order to maintain freshness quality attributes, extend the shelf life of fresh/minimally processed produce and reduce postharvest losses. Perforation-mediated modified atmosphere packaging (PM-MAP) offers the benefit of avoiding in-package anaerobiosis, extending the shelf life and maintaining quality fresh or minimally processed produce. This article presents an overview on the role of postharvest hurdle technologies in food packaging, critical evaluation of MAP and PM-MAP dependent parameters and the role of mathematical models. Furthermore, the successful application of PM-MAP on fresh and minimally processed produce was highlighted and future research prospects and challenges were identified.

Contents

1. Introduction

Fruit and vegetables are a rich source of micronutrients, fibres, vitamins and remarkable content of phytochemicals (with antioxidant properties) such as anthocyanins, carotenoids, polyphenols and

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http://dx.doi.org/10.1016/j.fpsl.2015.08.003
2214-2894/

flavonoids. This makes them essential components of the daily human diet (Allende, Tomas-Barberan, & Gil, 2006; Opara & Al-Ani, 2010; Rico, Martn-Diana, Barat, & Barry-Ryan, 2007). Consumption of fresh fruit and vegetables is associated with a number of nutritional and health benefits. It is highly recommended as health diet to fight against sedentary life style and degenerative diseases such as cancer, cardiovascular diseases and ageing (Allende et al., 2006; Rico et al., 2007; Ramos, Miller, Brandão, Teixeira, & Silva, 2013). Over the last decade, there has been a rapid expansion of fresh and minimally processed produce industry with multiple digit growth (Allende, Luo, McEvoy, Artés, & Wang, 2004; Montanez, Rodriguez, Mahajan, & Frias, 2010; Siddiqui, Chakraborty, Ayal-Zavala, & Dhui, 2011). This has been attributed to change in consumers' life style and increase in consciousness of healthy diet, which result in high demand for healthy, fresh and ready-to-eat fruit and vegetables (Caleb, Mahajan, Al-Said & Opara, 2013a; Ramos et al., 2013; Rico et al., 2007).

One of the major challenge facing the production and marketing of fresh minimally processed produce is rapid quality deterioration and reduced shelf-life (Hussein, Caleb, Jacobs, Manley, & Opara, 2015). Life processes of fresh fruits and vegetables and fresh-cuts continue after harvest due to on-going metabolic activities including respiration and ripening which continue in cells or plant parts until senescence and death (Irtwange, 2006; Sandhya, 2010). These biological (internal) causes of deterioration lead into undesirable quality changes in harvested produce, which are characterized by changes in color, texture, flavour, and nutritive value (Kader, 2005). Additionally, rapid quality deterioration and reduced shelf life may also result from physiological disorders and presence of mechanical injuries, which represent major quality challenges for the marketing of fresh minimally processed produce (Siddiqui et al., 2011). Overall, inadequate management of these quality challenges may result in reductions in availability, edibility, quality as well as wholesomeness, contributing to the incidence of postharvest food losses and subsequent financial losses (Fallik, 2004; Irtwange, 2006; Kader, 2005; Mahajan, Caleb, Singh, Watkins, & Geyer, 2014; Opara, 2009; Opara, Al-Ani, & Al-Rahbi, 2012).

High levels of postharvest losses coupled with increasing global market demand for fresh fruits and vegetables press the need for appropriate postharvest technologies to reduce quality loss and extend shelf-life of whole fresh and minimally processed produce (Kader, 2005; Montanez et al., 2010; Opara, 2010a; Opara & Mditshwa, 2013). As one of the most promising postharvest technologies to reduce fresh food losses, researchers have examined the application of various aspects of modified atmosphere packaging (MAP) on different types of fresh produce. A good number of published reviews have addressed advancements in the use of MAP and its potential to preserve quality and extend shelf-life of fresh and minimally processed produce (Caleb et al., 2013a; Oms-Oliu, Raybaudi-Massilia, Soliva-Fortuny, & Martin-Belloso, 2008; Rojas-Grau, Oms-Oliu, Soliva-Fortuny, & Olga Martın-Belloso, 2009; Sandhya, 2010). Others have examined the influence of MAP on growth of resistant foodborne pathogens and subsequent outbreaks of foodborne diseases (Caleb et al., 2013a; Farber et al., 2003). In this review, the basic principles of MAP and parameters affecting the performance of MAP are discussed. This is followed by a detailed discussion of perforation-mediated modified atmosphere packaging (PM-MAP), including the principles, functions and applications to fresh and minimally processed produce.

2. Overview of postharvest technologies applied to reduce losses and extend shelf-life of fresh horticultural produce

The quality of fresh produce cannot be improved after harvest; nevertheless, it remains possible to slow down the rate of undesirable changes and maintain quality for a longer time (Kim, Silva, Tokitkla, & Matta, 2010). Postharvest technologies refer to various techniques applied to reduce losses, extend quality and shelf life of fresh and minimally processed produce (Opara, 2006, 2010b). In this regard, various postharvest technologies to preserve quality and extend shelf life during distribution and short-term storage of fresh and minimally processed produce have been reviewed (Mahajan et al., 2014; Ramos et al., 2013; Siddiqui et al., 2011; Soliva-Fortuny & Martin-Belloso, 2003). The use of chemical-based treatments such as washing with sanitizers, antioxidant treatments and ozonised water are among the postharvest preservation methods that have been successfully applied in the fresh fruit and vegetable industries (Francis, Thomas & O'Beirne, 1999; Garcia & Barrett, 2002; Garcia, Mount, & Davidson, 2003; Beltran, Selma, Tudela, & Gil, 2005). Furthermore, physical treatments such as application of heat (e.g. blanching, heat-shock and hot water dips) have been used to delay physiological deterioration of fresh produce such as pomegranate arils (Maghoumi et al., 2012) and citrus (Hong et al., 2014). Other physical methods include irradiation which is based on exposing food to different sources of radiant energy and ultraviolet light which have been reportedly used as antimicrobial treatments (Fallik, 2004; Hong et al., 2014; Maghoumi et al., 2012; Tahir, Johansson, & Olsson, 2009).

The application of a wide range of edible and antimicrobial coatings represents another group of important postharvest treatment technologies which have received considerable attention over the years (Bourtoom, 2008; Cagri, Ustunol, & Ryser, 2004; Dhall, 2013; Campos, Gerschenson, & Flores, 2011). Edible coatings incorporate thin layers of edible materials applied on food produce or at the interfaces between different layers of food components (Bourtoom, 2008; Falguera, Quintero, Jiménez, Muñoz, & Ibarz, 2011). Such coatings serve an important role as protection against microbial activity and oxidation, physical damage and prevention of moisture loss (Bourtoom, 2008; Falguera et al., 2011; Dhall, 2013). Smart or intelligent packaging (IP) is another interesting innovation that has gained interest in the horticultural food industry which may be designed to track produce, sense the external and internal environment of the package and communicate any changes to consumer or food manufacturer, thus monitoring the quality and safety status of produce (Caleb et al., 2013a; Yam, Takhistov, & Miltz, 2005). Intelligent packaging is also commonly referred to as 'interactive packaging' due to its ability to give information about produce quality along the chain, during transport and storage (Sandhya, 2010; Yam et al., 2005). Active packaging is another valuable technology which is characterised by the use of absorbers and emitters (or releasing systems) of active ingredients, ethylene scavengers/emitters and moisture absorbers in the package (Rodriguez-Aguilera & Oliveira, 2009). Active ingredients in an active package modify the atmosphere surrounding produce inside the package, thereby extending produce shelf-life (Vermeiren, Heirlings, Devlieghere, & Debevere, 2003). However, the practical application and widespread use of active and intelligent packaging systems is limited mainly due regulatory issues (e.g. application of antimicrobial packaging systems) and technical limitations such as high cost associated with these technologies (Realini & Marcos, 2014; Yam et al., 2005).

Increasing consumer awareness about health benefits and safety of food has driven the fresh produce industry to minimise the use of chemicals that have hitherto been commonly applied as sanitizing and preservative agents (Meyer, Suhr, & Nielsen, 2002; Ramos et al., 2013). Apart from the health concerns, it has been reported that the use of chemical sanitizers and washings cannot guarantee the microbial quality of produce without compromising sensory quality (Rico et al., 2007). As a result, most of the inorganic chemical treatments and washing sanitizers such as chlorine-based chemicals have recently faced critical challenges to gain