LWT - Food Science and Technology 80 (2017) 257–264

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Integrity of edible nano-coatings and its effects on quality of strawberries subjected to simulated in-transit vibrations

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A R T I C L E I N F O

Article history:
Received 24 November 2016
Received in revised form
9 February 2017
Accepted 17 February 2017
Available online 20 February 2017

Keywords:
Strawberry shelf life
Edible coating
Simulated local transportation
Liposome
Limonene
Curcumin

A B S T R A C T

Strawberries are a popular fruit with a pleasing color and flavor. However, its delicate tissue and high sugar content makes it highly perishable with visible mold. In this study, we have attempted to test feasibility of a new edible coating for extending shelf life of 'Chandler' strawberries subjected to simulated vibrations of local transportation. Six types of coatings were compared based on the quality of treated berries. Curcumin and limonene were used as natural antimicrobials and coatings were prepared from their liposomes and were over-coated with methyl cellulose. One set of each coating type were subjected to the simulated vibration of local transportation. The vibrated samples had lower shelf life than non-vibrated samples, indicating a robust coating which remains intact during road vibrations is required. Based on the number of berries with visible mold, limonene liposomes showed significantly lower fungal growth compared to the control on the 14th day of storage. Titratable acidity and total phenolic contents were also found to be higher in limonene coated strawberries compared to other coatings. Further study is suggested to test liposome coatings of limonene with different particle size to improve integrity of the coatings when strawberries are subjected to local transportation.

1. Introduction

Strawberries (*Fragaria x ananassa*) are a high demand fruit because of their pleasant aroma, brilliant color, and delicious taste. They are also a good source of natural antioxidants, vitamins, minerals and a significant amount of anthocyanins, flavonoids and phenolics (Heinonen, Meyer, & Frankel, 1998; Rice-Evans & Miller, 1996). The berries are harvested at full maturity in order to maintain sensory (visual appearance, firmness, color) and nutritional (phytonutrients, minerals and vitamins) qualities (Hernandez-Munoz, Almenar, Del Valle, Velez, & Gavara, 2008). One of the most important quality indicators in strawberries is the sugar to acid ratio, which characterizes degree of sweetness and depends on the maturity, cultivar and weather conditions of berries (Hu et al., 2012; Pineli, Moretti et al., 2011). Sugar to acid ratio in matured strawberries varies with the variety, usually within a range from 7:1 for fruits regarded as sweet and 6:1 for fruits regarded as acidic in taste (Wozniak, Radajewska, Reszelska-Sieciechowicz, & Dejwor, 1996). Due to its high respiration rate, soft texture and sensitivity to temperature and mechanical shocks and vibrations, strawberries have postharvest shelf life shorter than 1 week under ideal conditions at 0 °C. This results in high degree of perishability to several pathogens, which would in turn cause changes in pH, titratable acidity, total soluble solids (TSS), loss in color, firmness and weight resulting in spoilage and, shortening the shelf life.

Several attempts have been made to increase the postharvest quality of fruits and vegetables. The most common method for maintaining quality and preventing decay is the use of low temperatures under refrigeration (Han & Nie, 2004; Hernandez-Munoz, Almenar, Ocio, & Gavara, 2006). Similarly, use of low temperatures and modified atmospheric packaging (MAP) in combination with increased concentration of carbon dioxide (Manning, 1993) and paraffin-based active coatings by the use of essential oils for paper packaging of fruits and vegetables (Rodriguez, Batlle, & Nerin, 2007) are also in practice. These strategies, however, are expensive, time consuming, and cause change in visual appearance of fruits and develop off-flavor in fruits (Ke,

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http://dx.doi.org/10.1016/j.lwt.2017.02.033
0023-6438/

Zhou, & Kader, 1994). The need of alternative methods to minimize the risk of undesirable biological, physiochemical, and physiological changes of fruits and vegetables is desirable (Holcroft & Kader, 1999).

There has been an increasing trend in use of natural bioactive edible coatings composed of polysaccharides, proteins, lipids, resins or of various composites in post-harvest preservation of fruits and vegetables (Valencia-Chamorro, Perez-Gago, Rio, & Palou, 2010). Edible coatings such carnauba wax, whey proteins, gluten, shellac coatings, mucilage starch have exhibited beneficial roles in maintaining quality of fruits and vegetables (Raghav, Agarwal, & Saini, 2016). Apart from protection of products from mechanical and microbiological damage to the fruits, these compounds have shown to preserve post-harvest quality of fruits by preventing the loss of volatile compounds (Perez-Gago, Rojas, & DelRio, 2002). These coatings are developed from natural sources and are easily biodegradable, which meets the demand of consumers to have a safer food product (Pavlath & Orts, 2009, pp. 1–23). These coatings are of interest as coating materials due to their low-cost, biodegradability, and solubility in water (Debeaufort, Quezada-Gallo, & Voilley, 1998).

Researchers have demonstrated that the use of plant based essential oils and phenolic compounds as coating materials can be done in order to increase the shelf life, prevent microbial growth, and to prevent nutrients loss from foods (Salmieri & Lacroix, 2006). These compounds have shown strong antimicrobial and antifungal properties, which makes them a natural alternative for the prevention of pathogenic and spoilage organisms that may occur in foods (Lacroix, 2007).

Limonene ((R)-(+)-*para*-Mentha-1,8-diene) is an essential oil extracted from lemon peels and other citrus fruits (Moufida & Marzouk, 2003). It is commonly used as a food additive or flavoring agent and has a Generally Recognized as Safe (GRAS) status by US Food and Drug Administration (EPA, 1994). Similarly, it has exhibited fungicidal activities against *Botrytis* and *Asperigillus niger*, the most common spoilage causing molds for fruit (Sharma & Tripathi, 2008). A natural phenylpropanoid dimer Curcumin (1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione) is the principle curcuminoid of turmeric *Curcuma longa* L. which is used as a spice and traditional medicine in various parts of South and East Asia (Dogra, Choudhary et al., 2015). Several studies suggest curcumin to be an effective anti-proliferative, anti-oxidant and anti-inflammatory agent (Maheshwari, Singh, Gaddipati, & Srimal, 2006). Like limonene, curcumin is also considered as "Generally Recognized as Safe" for application in food and pharmaceutical formulations by US Food and Drug Administration.

Although having many food preservation qualities, the use of essential oils in food preservation is limited due to certain drawbacks. These include high costs and potential toxicity to the consumers. An approach to address these demerits while maintaining the efficacy of essential oils and decreasing their dose would be the incorporation of these chemicals in a formulation of edible coatings (Perdones, Escriche et al., 2016). A study by Sanchez-Gonzalez, Chafer, Hernandez, Chiralt, and Gonzalez-Martinez (2011), in development of an antibacterial composite films of Hydroxypropylmethyl cellulose (HPMC) and chitosan mixed with different essential oils (Lemon, tea tree and bergamot) showed that the antibacterial activity of chitosan was enhanced when it was used with a mixture of the polymer and essential oil. Similarly, chitosan films incorporated with essential oils inhibited growth of the Gram negative and positive bacteria *Escherichia coli, Listeria monocytogenes* and *Staphylococcus aureus*.

Application of nanomaterials have shown to have a potential impact in a wide range of industries (Michael, 2004; Wang, Liang, Du, Zhang, & Fu, 2004). In food industries too, the application of nano-technology to enhance the quality of fruits has been used extensively (Yang, Li et al., 2010). Fruits and vegetables with nanopacking have shown better physiochemical, sensory physiological and preservation properties compared with normal packaging (Huang and Hu, 2006; Li & Wang, 2006; Li, Li et al., 2009). Liposomes are amphiphilic vesicles containing polar heads and hydrophobic carbon tails basically designed by dispersal of phospholipids in water (Bangham, 1961). They can transport hydrophilic components by encapsulation in aqueous phase and hydrophobic components in stable state by inserting into hydrophobic domains (Brandl, 2001; Shin, Chung, Kim, Joung, & Park, 2013). Size of the liposomes can be controlled to the order of nanometers, providing desirable properties to deliver essential chemicals of hydrophilic and hydrophobic nature. Their application in food preservation includes the encapsulation of nutrients, proteins, enzymes, antimicrobials and flavors and controlled release in the food environment to maintain food quality and prevent microbial spoilage (Makwana, Choudhary, & Kohli, 2015).

Mechanical injuries during transportations of fruits and vegetables between the chain of harvesting and consumption are one of the major causes of decay of fruits and vegetables (Barchi, Berardinelli, Guarnieri, Ragni, & Fila, 2002). Strawberries are highly prone to in-transit vibration damage causing skin abrasion and bruising. From these abrasions and bruises on the tissues of berries, microbes are able to enter inside which in turn causes the degradation of berries and reduce the shelf life (Fischer, Craig, Watada, Douglas, & Ashby, 1992). Significant losses due to damage caused by in-transit vibration has been recorded in strawberries (Pierson, Allen, & McLaughlin, 1982).

In this study, fresh ripened berries were picked up from the local farms in Southern Illinois. The berries were stored in a cold room at 4 °C before any treatment and processing was done. Since the phenolic compounds, vitamin B and vitamin C are sensitive to the higher storage temperatures; refrigerated temperature at 4 °C is considered as safe level for storage.

The berries were treated with various types of natural coatings and subjected to simulated shock and vibration. The effect of different natural edible coating formulations on shelf life of strawberries was compared. The effects of mechanical shocks and vibrations of simulated road transport on the quality of berries were analyzed. Physiochemical and nutritional quality of treated berries were evaluated by the measurement of visible mold growth, total soluble solids, pH, titratable acidity, and total phenolic content at different time intervals.

2. Materials and methods

Fresh ripened strawberries 'Chandler' were purchased from local farms located in southern Illinois. The berries were inspected for bruises, visual fungal growth, and decay. Uniform sized berries were selected and stored at 4 °C prior to coating and mechanical vibration experiments. Steps for preparation of coating materials are shown in a flowchart form (Fig. 8).

2.1. Preparation of phytochemical solutions

Curcumin solution with a concentration of 50 mM was used as a coating material. Powdered curcumin was initially dissolved in 2–3 drops of ethanol. For example, for the preparation of 25 ml curcumin solution with concentration of 50 mM, 0.00046 gm curcumin powder was weighed and dissolved in ethanol followed by addition of 25 ml nano pure water.

Similarly, for the preparation of 25 ml limonene solution with the concentration of 50 mM 0.01703 ml D-limonene was poured in a volumetric flask and desired volume was made by pouring 25 ml