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The effectiveness of *Opuntia ficus-indica* mucilage edible coating on post-harvest maintenance of 'Dottato' fig (*Ficus carica* L.) fruit

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ABSTRACT

Breba figs are highly perishable and their shelf-life is very short. In this study, breba figs (cv. 'Dottato') were treated with a mucilage solution of *Opuntia ficus-indica* cladodes, sealed in plastic bags, and stored at 4 °C for 14 days. The effect of the edible coating on the shelf-life and qualitative attributes of the fruit were evaluated by colors, content of total soluble solids, titratable acidity, total phenol, total carotenoids. Results showed that coating improves the quality of breba fig during storage. The edible coating was effective in maintaining fruit fresh weight, visual score values, fruit firmness and total carotenoid content. Coated fruit showed a significantly lower development of *Enterobacteriaceae* than control ones during the entire period of observation.

1. Introduction

The common fig (*Ficus carica* L.) is a traditional fruit crop native of the Mediterranean Basin and cultivated since long time in Southern Italy. Eating quality and consumers' acceptance of fresh fig fruits are best when they are almost fully ripe; skin color and flesh firmness are the most reliable maturity and quality indices (Caliskan & Polat, 2012, Crisosto, Bremer, Ferguson, & Crisosto, 2010). However, figs are particularly sensitive to softening, skin cracking and, thus, severe decay (Crisosto et al., 2010). The degree of skin damage is related also to the genotype and overripe fruit become undesirable due to fermentation products (Kong, Lampinen, Shackel, & Crisosto, 2013). 'Dottato' is the most representative Italian cultivar and its brebas (1st crop) are harvested between the end of June and the first week of July, while fruit of the second harvest ('Forniti') are harvested in August and September. Brebas have a higher epidermis perishability and a lower sugar content than main crop fruits (Kaynak, Gozlekci, & Ersoy, 1998). Fresh fruits are stored at 0 °C (Piga, D'Aquino, Agabbio, & Papoff, 1995) or 1–2 °C (Irfan, Vanjakshi, Keshava Prakash, Ravi, & Kudachikar, 2013) with a respiration rate of 0.4 to 8 mg of CO_2 kg^{-1} h^{-1} (Crisosto & Kader, 2004). The recourse to modified atmosphere enriched with CO_2 (Alturki, 2013; Colelli, Mitchell, & Kader, 1991) or the pretreatment with $CaCl_2$ at 4% (Irfan et al., 2013) has been recommended to maintain fruit quality. The use of edible coatings (EC) could be an alternative to preserve fresh fruit quality and to extend their shelf life. EC technique may reduce physiological disorders, gas exchange, moisture and solute migration, respiration and oxidative reaction rates (Baldwin, Nisperos, Chen, & Hagenmaier, 1996). Edible coatings were demonstrated to have good effectiveness in order to extend the apple fruit shelf-life (Rojas-Graü et al., 2007), strawberries (Han, Lederer, McDaniel, & Zhao, 2005), melon (Raybaudi-Massilia, Mosqueda-Melgar, & Martín-Belloso, 2008), mango (Chien, Sheu, & Yang, 2007), grape (Valverde et al., 2005), papaya (González-Aguilar et al., 2009) and banana (Bico, Raposo, Morais, & Morais, 2008) proving to be effective in prolonging their shelf life. Some coatings have been tested for their aptitude of inhibiting microbiological content (Ponce, Roura, Del Valle, & Moreira, 2008), to prolong fruit shelf life, and to reduce fruit respiration rate (Li & Yu, 2001). Natural EC based on *Aloe vera* extracts, chitosan (Elsabee & Abdou, 2013), methylcellulose and whey protein have been successfully applied to several fruit (Olaimat & Holley, 2012). Opuntia (*Opuntia ficus-indica*) cladodes have high mucilaginous substances (Sepúlveda, Sáenz, Aliaga, & Aceituno, 2007) with complex polymeric substances of carbohydrate nature, highly branched structure (Medina-Torres, Brito-De La Fuente, Torrestiana-Sanchez, & Katthain, 2000) and contain varying proportions of L-arabinose, D-galactose, L-rhamnose and D-xylose. Moreover, the dried mucilage contains on average 5.6% moisture, 7.3% protein, 37.3% ash, 1.14%, nitrogen, 9.86% calcium and 1.55% potassium (Sepúlveda et al., 2007). Notwithstanding its hydrophilic character, the mucilage, can act as a barrier to water transfer, retarding water loss and prolonging the firmness of flesh fruit (Del Valle, Hernández-Muñoz, Guarda, & Galotto, 2005) and in fresh-cut kiwi slices (Allegra et al.,

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2016). Treatment with *O. ficus-indica* (OFI) mucilage applied on fresh strawberries reduced respiration rate, weight loss, firmness, loss of color and fungal infection (Del Valle et al., 2005).

Considering the high perishability of breba figs, the objective of this study was to evaluate the effectiveness of OFI edible coating in reducing weight loss and maintaining texture and nutraceutical properties of fig fruit during a 14 d storage period at 4 °C.

2. Materials and methods

2.1. Plant materials

Breba fig (*F. carica* L.) fruits of cv. 'Dottato' were harvested in June 2014 from five-years-old own rooted trees grown in a commercial orchard located at San Cipirello (37°58′00″ N 13°11′00″ E) (Italy). Trees were spaced 6 m × 5 m apart and average fruit yield was 52 ± 5.0 kg tree^{-1}. During the last 4 weeks of ripening the average day/night temperatures were 29/20 °C. One hundred fruits were individually hand collected from 6 trees at commercial harvest maturity stage. Promptly after harvest, fruit were transported to the post-harvest laboratory of the University of Palermo and then dipped in sanitized water for 360 s (100 ppm of free chlorine). Defective fruit (bruised, other physical damage, incorrect maturity, and odd color) were discarded, and the remaining 75 figs were then selected by maturity and firmness on one sample of 10 fruits (22.5 ± 3.5 N). The coating treatment was made according to previous literature (Allegra et al., 2016), more particularly figs were first dipped in coating solution made of *O. ficus-indica* mucilage for 60 s, this solution consisted of a pure mucilage extract 30 g + 500 mL distilled water and 50 mL glycerol as a plasticizer (MC); the exceeding coating was drained and the coated figs were dried in a forced-air dryer (20 °C) for 5 min. Thirty-six fig fruits were dipped in distilled water and used as a blank (CTR). Breba fig treated with MC and CTR were placed in bi-oriented polystyrene (PS) macroperforated bags (Carton Pack s.r.l., Rutigliano, Italy). After being coated or dipped, figs were stored in a refrigerator at 4 ± 0.5 °C and 85% RH for 14 days to simulate shelf life conditions in a domestic refrigerator. For both the coated treatment and the uncoated control (CTR) and for any storage time, 36 fruits ($2_{fruit} \times 18_{bags}$) were used. Physicochemical and microbiological quality parameters were analyzed after coating/dipping (day 0) and at 3, 5, 7, 10 and 14 d of storage.

2.2. Preparation of the edible coating

O. ficus-indica Mill. cladodes were cut and cubed (2 cm^3). Samples were homogenized (20%, w/v) in distilled water with water in the ratio 1:1.5. According to Allegra et al. (2016), the solution was maintained at 40 °C for 90 min and centrifuged (model CS-6R CS6R) at 3000 rpm × 20 min. The supernatant obtained was boiled to halve the initial volume and ethanol at 99% was added in the ratio 1:2 (used to prepare the edible coating). The solution was then stored at 4 °C for 48 h to get a better aggregation of mucilage (Fig. 7). The last phase involved the elimination of the supernatant and the soaking of the pure mucilage (Allegra et al., 2016).

2.3. Microbiological analysis of mucilage and figs

Fig samples and mucilage were microbiologically investigated for total mesophilic microorganisms (TMM) and the undesired (spoilage and/or pathogenic) microbial groups according to previous work (Allegra et al., 2016). This method consist of the following steps: the fruit (25 g) and the mucilage (10 mL) were suspended in Ringer's solution (Sigma–Aldrich, Milan, Italy) to a ratio 1:10 (fruit:diluent), homogenized for 2 min at high speed with a stomacher (BagMixer® 400, Interscience, Saint Nom, France) and serially diluted. The cell suspensions were inoculated as follows: TMM on plate count agar (PCA), incubated aerobically at 30 °C for 72 h; *Enterobacteriaceae* on double-layered violet red bile glucose agar (VRBGA), incubated aerobically at 37 °C for 24 h; pseudomonads *on Pseudomonas* agar base (PAB) supplemented with 10 mg/mL cetrimide fucidin, incubated aerobically at 20 °C for 48 h; yeasts on yeast potato dextrose (YPD) agar, incubated aerobically at 25 °C for 48 h. All media and supplements were purchased from Oxoid (Milan, Italy). Count plates were carried out in duplicate for each trial.

2.4. Firmness

Fruit firmness was measured using a fruit texture analyzer (Instron 5564 USA) adapted with a flat tip. Each fig (six replicates for each treatments and sampling date) was compressed on the cheek with a 2.5-cm flat tip at a speed of 5 mm s^{-1} to a depth of 4 mm and the maximum value of force was expressed in Newton (N). Average values were calculated from the results of 6 measurements of each stage.

2.5. Weight loss

Weight loss of fruit was measured after the treatment (day 0) and at the different sampling dates (3, 5, 7, 10 and 14 d of storage).

2.6. Respiration rate and ethylene production at harvest

Ethylene production and fruit respiration rate were measured immediately after harvest both at 20 °C and after storage at 4 °C for 72 h. Ten fruit were weighed with a digital scale and placed individually in 705-mL sealed glass containers, according to Crisosto et al. (2010). In intact fruit following harvest, ethylene production (μL kg^{-1} h^{-1}) was measured in an acclimatized chamber at 20 °C. According to previous literature, gas samples (1 mL) were taken of effluent air from respiration jars, using a 1 mL syringe and injected into a gas chromatograph (GC, Agilent Technologies 6890, Wilmington, Germany) and fitted with a FID detector and an alumina column F1 80/100 (2 m × 1/8 × 2.1, Tecknokroma, Barcelona, Spain). The oven temperature was 140 °C while the injector and detector were kept at 180 and 280 °C, respectively. The respiration rate was determined, according to Agudelo, Restrepo, and Zapata (2016), with a portable gas analyzer (PBI Dansensor Checkpoint O_2 and CO_2 AS, Ringsted, Denmark) expressed as mL CO_2 kg^{-1} h^{-1}.

2.7. Color

The color of the skin was measured at the beginning of storage (time 0) and after 3, 5, 7, 10 and 14 d at 4 °C on six single fruit replicates for each treatments and sampling date. A portable colorimeter (Minolta CR 400 HEAD, Minolta, Osaka, Japan), equipped with an 8-mm measuring head and a C illuminant (6774 K), was used. According to previous work (Allegra, Barone, Inglese, Todaro, & Sortino, 2015) the instrument was calibrated using the manufacturer's standard white plate. Color changes were quantified in L^*, a^* and b^* color space. ΔE was calculated as $\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2}$ considering the difference between the color measured just after coating ($T0$) and the color measured 3, 5, 7, 10 and 14 d after storage. Average values were measured on 6 replicates for each stage.

2.8. Visual appearance score

Fruit sensory qualities (color, visible structural integrity and visual appearance) at each storage time were evaluated by six trained judges, using a 5-pt rating scale, according to Colelli et al. (1991), where 5 = very good, 4 = good, 3 = fair (limit of marketability), 2 = poor (limit of usability) and 1 = very poor (inedible). Six fruits were used as single replicate for treatment (MC and CTR) and time. Following previous literature, panelist were asked to give their score according