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Anti-browning and barrier properties of edible coatings prepared with electrospraying

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ABSTRACT

Electrospraying is an efficient practice for coating complex food products. Water-in-oil emulsion and chocolate based coatings were electrosprayed on food model systems (apple slices and candy tablets). The emulsion based coatings penetrated into the products, while chocolate based coating stayed on the target surfaces. These coatings were evaluated to prevent the browning and water loss from the apple slices. Emulsion based coatings were effective in preventing the browning of apple slices, depending on the composition of the continuous phase, but were unable to retard the water migration significantly owing to coating penetration inside the products, leaving a very thin film on the surface. In that respect, chocolate based coatings were more effective in reducing the water vapour flux compared to emulsion based coatings. The results indicated that solid lipid based coatings were more effective in water vapour flux reduction than liquid lipid based coatings.

Industrial relevance: Electrospraying is an efficient coating technique which can reduce the processing cost for industrial processes. This technique has been successfully applied for food product to increase the shelf life of minimally processed food. The result found in this study can be used at industry to obtain food product with desired sensory attributes along with prolonged shelf life.

1. Introduction

Minimal processed fruits and vegetables are popular with consumers who demand healthy alternatives to conventional snack foods. They are highly nutritious but mostly suffer from shorter shelf-life. Being living tissues, physiology, and biochemistry processes continue to take place after cutting, slicing, and coring or shredding. Damage to skin and cell wall, both due to handling or processing, can cause the loss of nutrients, ions, and accelerate the enzymatic reactions resulting in microbial growth, production of undesirable volatile compounds, colour & texture change, and weight loss. To avoid these, adequate processing and storage are necessary (Balla & Farkas, 2006; Raybaudi-Massilia, Mosqueda-Melgar, & Tapia, 2010; Tapia et al., 2008; Wu & Chen, 2013).

The most practical and common methods used to overcome these problems and to prolong the shelf-life of fresh-cut products are modified atmosphere packaging, dipping in the solutions of antimicrobials & antioxidants, or storage at low temperature (<5 °C). However, edible coatings, as an alternative approach, have gained much attention in the last decades. Edible coatings, from natural resources, are environmentally-friendly that can reduce the deleterious effect brought about by minimal processing and enhance the quality. Their barrier properties are aimed to extend shelf life by reducing moisture and solute migration, gaseous exchange, oxidative reaction rates, and suppressing physiological disorders on fresh-cut fruits. Moreover, edible coatings can also serve as carriers of food additives, e.g. anti-browning and antimicrobial agents, colourants, flavours, nutrients, and spices (Khan, Mujawar, Schutyser, Schroën, & Boom, 2012; Khan, Schutyser, Schroën, & Boom, 2012a; Khan, Schutyser, Schroën, & Boom, 2012b; Valencia-Chamorro, Palou, Río, & Pérez-Gago, 2011; Wu & Chen, 2013).

However, specific studies on fresh-cut fruits are rather limited and their industrial implementation is still incipient (Rojas-Grau, Soliva-Fortuny, & Martın-Belloso, 2009). In fresh fruits and vegetables, weight loss and respiration rate can be reduced by using edible coatings which can also increase their visible quality. Moreover, edible coatings can partly replace synthetic packaging and may even lead to natural and biodegradable materials applied to fruits. It will reduce the packaging requirement and waste disposal problems.

Edible coatings are being applied to food by spraying, dipping, and co-acervation and most recently also through, electrospraying which produces thin and uniform coating (Khan, Maan, Schutyser, Schroën, & Boom, 2013; Khan, Mujawar, Schutyser, Schroën, & Boom, 2012; Khan, Schutyser, Schroën, & Boom, 2012). In electrospraying, micro-droplets are generated by applying a potential difference over a droplet emerging from a nozzle (Jaworek, 2007, 2008). The charged droplets follow a trajectory to the nearest grounded surface as a result of

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electrostatic attraction, leading to a high transfer efficiency (80%) compared to conventional methods (Luo, Loh, Stride, & Edirisinghe, 2012; Maski & Durairaj, 2010; Oh, Kim, & Kim, 2008) which might reduce the processing cost.

Lipid-based materials have been successfully electrosprayed (Gorty & Barringer, 2011; Luo et al., 2012; Marthina & Barringer, 2012). However, to our best of knowledge, electrospraying of emulsions and lipid based coatings have neither been investigated for their barrier nor for anti-browning functionality on fresh food products. Therefore, our study aims at the formation of lipid-based coatings by electrospraying on fresh cut apples and candies (as model food targets) and subsequent evaluation of their moisture barrier properties and anti-browning activities. For this purpose, water-in-oil emulsion- and chocolate-based coatings were electrosprayed on target surfaces moving on a conveyer belt. Initially, the anti-browning activity of the coatings was determined on the apple slices with respect to the coating material properties. Later, water vapour permeability of the coatings was investigated and compared to conventional 'dip'-coating.

2. Materials and methods

2.1. Film preparation

Both, single and multiple nozzle systems (Terronics Development Cooperation, USA) were used to electrospray chocolate- and water-in-oil emulsion based coatings (see Table 1 for composition). Chocolate based coatings were applied at 60 ± 5 °C in preheated temperature-controlled cabinet that contained the feed pump and nozzles, while emulsions were sprayed at ambient temperature. Both coatings were fed into the nozzles a syringe pump (Harvard 11 plus, Harvard Inc., USA) and the nozzles were subjected to an electric potential of 20–25 kV using a high voltage source (Heinzinger Electronic GmbH). Electrospraying distributes coating material homogenously over the food samples that were placed on a grounded and moving conveyor belt at a velocity of 1 mm/s; the mass of applied coating material was measured after multiple (1–6) passes (Fig. 1) (Khan, Schutyser, Schroën, & Boom, 2012).

In this study, the model food surfaces were Golden Delicious apple and zwartwit candies (Fortuin Dokkum, The Netherlands). The Golden Delicious variety was chosen because of its relatively slower browning in preliminary trials compared to Jonagold apple cultivar. Please note that the actual amount of water in the water-in-oil emulsion based coating is negligible compared to the amount of water in the apples. While, the candies tablets ('zwartwit', Fortuin Dokkum, The Netherlands) had water activity (a_w) directly from the package is approximately 0.4. Thereby, it absorbed moisture from the environment which has relative humidity values >%. Tablets provide the surface area which is equal for all tablets, very smooth, and make it convenient for experimentation.

The apples were washed, dried with tissue paper, and cut into 8 mm thick slices with an electric food slicer. Sliced apples were immediately dipped into 0.1% ascorbic acid solution for 20 min prior to the coating process to delay browning. Apples, candies, sunflower oil, olive oil, and dark chocolate (Verkade Zaandam, Holland) were obtained from the super market. S Lecithin (American Lecithin Company, Oxford, CT, USA) was used as an additive to increase the conductivity of coating materials in order to facilitate electrospraying. Moreover, chocolate based coatings were prepared having 70% chocolate (Verkade Zaandam, Holland), 15% polyglycerol polyricinoleate (PGPR) (Givaudan, Vernier, Switzerland) and 15% butter (SOP int. Ltd., UK). Later were added in the chocolate to reduce the viscosity (Khan, 2013). The composition of the coating material is presented in Table 1.

Table 1
Composition of two coating materials (w/w) that were electrosprayed on food surfaces.

Water-in-oil emulsion		Chocolate-based coatings	
Water	10%	Chocolate	70%
Emulsifier	5%	Milk butter	15%
Oil	85%	PGPR	15%

10% protein was added in aqueous phase.

2.2. Film analysis

2.2.1. Colour analysis

Anti-browning activity of the emulsion based coating was measured by the colour analysis of the coated apple slices. The colour values were measured using Spectrawiz spectrophotometer (StellarNet, Inc., USA) according to L*a*b* colour space (CIELab). In this colour space, L* indicates lightness (0: black, 100: white), where +a* is redness, −a* greenness, +b* yellowness, and −b* blueness. Using these parameters, whiteness index (WI), chroma (C*), and total colour difference (ΔE) are calculated from the following equations to determine the effects of different coatings on apple slices.

$$WI = 100-\left[(100-L^*)^2 + (a^*)^2 + (b^*)^2\right]^{1/2} \quad (1)$$

$$C* = \sqrt{(a^*)^2 + (b^*)^2} \quad (2)$$

$$\Delta E = \sqrt{(L^*-L^*_{std})^2 + (a^*-a^*_{std})^2 + (b^*-b^*_{std})^2} \quad (3)$$

here std subscript refers to the colour values for uncoated samples. The results were expressed as average of at least ten measurements of three different spots on each apple slice. The samples were kept in room temperature during the colour measurement studies.

2.2.2. Barrier properties

A set of three coated and uncoated tablets (identical in size) and apple slices (chosen similar in size) were analysed for moisture uptake and loss respectively as a function of time at 60% and 70% relative humidity and 20 °C in a humidity chamber (Memmert GmbH). The water activity difference caused the moisture uptake by tablets and moisture loss for apple slices which were monitored daily by weighing the sets of tablets and slices. A minimum of three replicates were measured for each film preparation and the average results of relative water uptake were reported. The relative flux reduction due to the coatings was determined as follows:

$$\textit{Relative flux reduction}\ (-) = \left(1-\frac{M_c}{M_b}\right) \quad (4)$$

where M_c and M_b are the mass increase as function of time (g/h) of the coated and uncoated samples, respectively.

2.2.3. Statistical analysis of the experimental results

All the mean values were analysed by using SPSS software version 16.0 (SPSS Inc., USA). One-way analysis of variance was conducted to compare the mean values and Duncan post hoc multiple comparison test was applied with a significance level of $p < 0.05$ to evaluate the differences between samples.

3. Results and discussion

3.1. Colour analysis

The apple slices were coated with three types of emulsions which (do not) carry anti-browning agents (molasses, ascorbic acid) in aqueous phase by the dipping method. The coated and uncoated (control) slices were analysed and results are shown in Table 2. There is a significant decrease in WI values with the passage of time of control