



# Dynamic behaviour of starch-based coatings on fruit surfaces

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## ABSTRACT

A method to characterising the surface water relations of coated fresh fruit has been developed. Based on a modification of the Fick's law of diffusion, application of this method allows for a quantitative assessment of the impact of produce type and of production method of coating, and environment on water losses both of the fruit body and the coating. Resistances in the water vapour pathway were analysed to determine the effects of coating on the surface water relations of plums. Experiments were conducted, evaluating the dynamic behaviour of two different starch-based coatings both at high and low potential water losses. Applying three layer-coatings, both starch and starch-whey protein coatings increased the total resistance in the water vapour pathway of individual plums by 60–75% at high transpiration potentials. Even at low transpiration potentials, an increase of 11–20% was observed. The starch coating tended to have a slightly lower effectiveness than the coating enriched with 20% whey protein.

## 1. Introduction

The application of edible coatings can be an excellent technique for prolonging the shelf-life and preserving the quality and freshness of minimally processed foods (Chiumarelli and Hubinger, 2012; Versino et al., 2016). Surface coatings have already been experimental applied to many food products (Navarro-Tarazaga et al., 2011), especially fruits and vegetables. These coatings increase skin resistance to the diffusion of gases (O<sub>2</sub>, CO<sub>2</sub>, H<sub>2</sub>O), thereby delaying the natural physiological ripening processes (Banks et al., 1993; Valero et al., 2013), and protecting against water loss. Depending on the constituents, such membranes have different physical and chemical properties. Under low relative humidity conditions (below 75%), polysaccharides and proteins can successively replace plastic materials (Debeaufort et al., 1998). In addition, various active ingredients can be incorporated into the biopolymers of biodegradable membranes and safely consumed with the food product (Rojas-Graü et al., 2009). Among the renewable sources with film-forming ability, starch satisfies all the principal aspects, such as easy availability, high extraction yield, nutritional value, low cost, biodegradability, biocompatibility, and edibility with functional properties (Shah et al., 2016).

When using edible coatings on fruit surfaces, gas permeability is of particular importance. Edible starch coatings are distinguished by a

particularly low oxygen permeability and, in combination with a suitable plasticiser, a sufficiently low CO<sub>2</sub>-permeability. By contrast, the water vapour permeability is relatively high (Liu, 2005; Pagella et al., 2002). Edible coatings composed of two or more components have been developed to take advantage of the complementary functional properties of the constituent materials, and to overcome their respective drawbacks (Cazon et al., 2017; Guilbert and Gontard, 2005). Composite starch-based coatings have been successfully used to extend the shelf life of various fruits such as strawberries (García et al., 2001; Ribeiro et al., 2007), grapes (Fakhouri et al., 2015), plums (Eum et al., 2009) and avocados (Aguilar-Mendez et al., 2008). An improvement of both gas permeability and mechanical properties could be achieved by the combination of polysaccharides (e.g. starch) and whey proteins (Basiak et al., 2015; Yoo and Krochta, 2011).

There are a number of parameters that are used to describe the barrier properties of films, such as permeability, permeance, transmission rate, and resistance (Greener Donhowe and Fennema, 1994). Nevertheless, evaluations of the effectiveness of coatings on fruit surfaces (in relation to transpiration losses) can only provide reliable results if comparable properties of the coating and the fruit are considered. Therefore, water vapour permeability (WVP), widely used in coatings, is not particularly suitable for several reasons. The permeability of the coating (in the majority of cases determined by the cup

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method) is usually not directly measured on the fruit surface. Transferring data, it is assumed that saturated water vapour ( $RH = 100\%$ ) is present on the side, which is oriented towards the fruit (Han et al., 2004; Medeiros et al., 2012; Osorio et al., 2011; Xu et al., 2001).

The conditions on the fruit surface are dependent on the properties of the produce itself (e.g. water relations of the fruit, surface temperature), the properties of the surrounding air (temperature, humidity) and the flow conditions against and around the produce (Linke and Geyer, 2001). Thus, it can easily be shown that the surface conditions may considerably differ from the saturation state under certain circumstances.

In order to characterise the transpiration properties of fruit, WVP is generally not used because, on the one hand, the thickness of the epidermal layers cannot be measured non-destructively. On the other hand, the water distribution inside the fruit may not always be uniform. Water status profiles may be present depending on tissue properties and external conditions (Nguyen et al., 2006; Peiris et al., 1999; Veraverbeke et al., 2003). The air in intercellular spaces of the layers close to the epidermis is not necessarily saturated with water vapour. Consequently, the resistance to the transfer of water vapour on the fruit surface tissue, supplemented by the resistance of the coating, should be determined. These calculations are based on the assumption that the air in the intercellular spaces (in the centre of the produce) is saturated. This assumption is certainly justified in the freshness range considered here as long as there are no external indications of wilting (loss of gloss, shrinkage, softening).

The aim of the present study was primarily to develop an alternative method for the characterisation of water relations on the surface of freshly coated fruit. Thus, it should be possible to quantitatively assess the impact of all involved components (produce, coating, environment) on water loss of the fruit (and the coating), based on a modification of Fick's law of diffusion in terms of resistance (Cussler, 2003; Gates, 1980). In this context, the experiments were focused on measuring the dynamics of various changes (water content, thickness, resistance) that occurred on two different coating materials depending on the relevant properties of the produce and the ambient conditions.

Using a similar approach Ben Yehoshua et al. (1985) investigated the effects of coatings and films on citrus fruit (wax, HDPE film) using another modified Fick's equation. Because the convective mass transfer conditions are not described in detail here, the reference to environmental conditions is missed. Other authors used a comparable approach to demonstrate the effect of coatings on the postharvest behaviour of zucchini (Avena-Bustillos et al., 1994), and of apples and celery sticks (Avena-Bustillos et al., 1997). Within the scope of these experiments both the single-layer-coated and uncoated fruits or vegetables were stored at forced convection (air velocity of  $3.0 \text{ ms}^{-1}$ ) to disable the boundary layer resistance.

## 2. Materials and methods

### 2.1. Experimental design

In order to characterise the dynamics of water relations on the surface of fruit immediately after dipping, the weight changes of individual plums were recorded under pre-determined ambient conditions. At the same time, the surface temperature distribution was measured by means of a thermal imaging camera. Within a measuring cycle, the weight loss of individual fruit at unrestricted free convection was initially recorded over a 6 h period without a coating, and over 24 h periods thereafter with one, two and three layers consecutively. Overall, two different starch-based coatings were studied under two different ambient conditions (room temperature, relative humidity levels). Each measuring cycle was repeated three times (with 3 different plums), yielding a total test period of approx. 48 d.

To evaluate the effectiveness of the coating materials, various resistances in the water vapour pathway were analysed. In principle, the

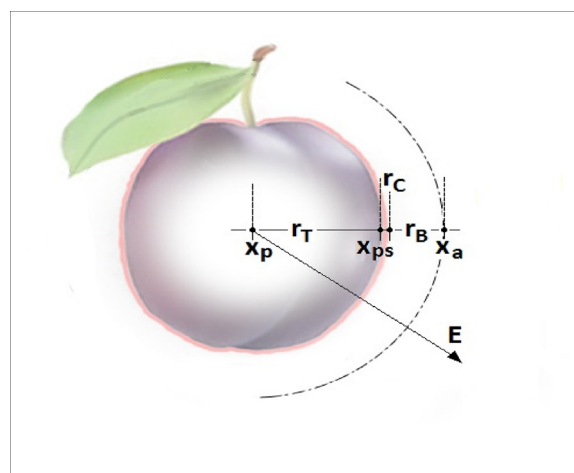


Fig. 1. Water loss potentials and resistances in the water vapor pathway of a coated plum fruit ( $E$  – area related transpiration rate;  $r_b$  – boundary layer resistance;  $r_c$  – coating resistance;  $r_T$  – tissue resistance;  $x_a$  – volume related water content of the ambient air in sufficient distance to the produce;  $x_p$  – volume related water content of air in the intercellular spaces in the center of the produce;  $x_{ps}$  – volume related water content of the air at the produce surface).

coatings may be considered as additional to the tissue resistance and the boundary layer resistance as a serial resistance (see Fig. 1). After dipping, only water from the surface of the coatings would initially evaporate until an equilibrium state between fruit, coating and surrounding air was established. From then on, water vapour would be released from inside the fruit to the environment again. Under constant ambient conditions, fruit transpiration is now somewhat lower due to the additional resistance.

Starting from an initial 95% water content of the coating, its decrease can be followed consistently to the equilibrium state. The equilibrium water content of both coating materials depending on outside conditions was determined in preliminary experiments for a wide range of external humidity levels (Basiak et al., 2017).

The initial film thickness was determined from the mass difference before and after dipping, assuming that the distribution of the film-forming solution on the fruit surface was uniform. As long as the equilibrium was not reached, the decrease (change) in the thickness of the coating was calculated from the respective mass loss.

For the investigations, plums (*Prunus salicina* L.) from South Africa were used, which were bought at a nearby wholesale market. The fruit (such as cv. *Angeleno*) normally arrive in Central Europe in a pre-mature stage and continue to ripen slowly. Thus, it can be assumed that the produce properties change only slightly during one 4 d measuring cycle. All fruits were very firm during the relevant period.

Individual fruit were equipped with a special holding mechanism (thin suspension wire) and mounted to the port of a BP 210S precision balance (Sartorius, Göttingen, Germany). For this purpose, the under-floor weighing function of the balance placed on a special rack was used. The balance (measuring range 210 g, resolution 0.001 g) was connected directly to a Almemo 2590-4S data logger (Ahlnborn, Holzkirchen, Germany) via the serial data interface. All mass changes, as well as the climate parameters of the surrounding air, were recorded at time intervals of 2 min.

At the beginning of the measuring cycle, the product, coating material and surrounding air were in thermal equilibrium (produce temperature = temperature of film forming solution = air temperature). Changes in the surface temperature of the fruit and subsequent changes in the temperature of the coating after dipping were measured by means of a ThermoCAM® HD 600 thermal imaging camera (Infratec, Dresden, Germany). Thermal images ( $768 \times 576$  pixels;  $< 0.03 \text{ K}$  thermal resolution) were recorded at 5 min intervals over a period of

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