Postharvest Biology and Technology 87 (2014) 144–151

Contents lists available at ScienceDirect

Postharvest Biology and Technology

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

Non-invasive assessment of glossiness and polishing of the wax bloom of European plum

Adnan Mukhtar[a], Lutz Damerow[b], Michael Blanke[a,*]

[a] INRES – Horticultural Science, University of Bonn, Auf dem Hüegel 6, D-53121 Bonn, Germany
[b] Institute of Agricultural Engineering, Nussallee 5, D-53115 Bonn, Germany

ARTICLE INFO

Article history:
Received 13 July 2013
Accepted 26 August 2013

Keywords:
European plum (*Prunus domestica* L.)
Epicuticular wax
Non-invasive technique
Glossy
Sensor technology
Wax bloom

ABSTRACT

A number of fruit including plums develop a pronounced conspicuous layer of epicuticular wax responsible for their attractive visual appearance. During harvest, packaging and transport, this protective layer may be damaged or removed. The resulting appearance generates the impression of poor fruit quality. The aim of this research was to analyse and compare the influence of this wax bloom on storability using a new non-invasive technology and three modifications of the fruit surface. Weight loss was recorded of plums with the natural wax layer, polished by hand or wax removed chemically and stored at 20 °C room temperature or in a refrigerator at 5 °C. With 9.2 mg epicuticular wax/fruit or 302 μg/cm^2 surface, European plums were classified as highly waxy, which contributed to for their conspicuous wax bloom. The disappearance of the wax bloom viz. increase in glossiness, measured non-destructively with a special sensor, was associated with a doubling of luster levels from 150–250 arbitrary units (a.u.) to 300–600 a.u. after polishing, simulating postharvest handling. Luster levels decreased with time with the polished surface, but not with the natural wax layer, confirming the concomitant greatest weight loss during the 20 days storage of polished fruit. Weight loss was lowest in plums with the natural wax layer, refrigerated at 5 °C, while those stored at 20 °C lost more weight irrespective of surface treatment. This case study explains the relatively short shelf-life and effects of water loss of the plums under different temperatures and surface conditions with wax, polish and chemically treated. This affordable compact light-weight sensor technology offers the opportunity to detect the degree of glossiness and may be used for sorting a number of affected fruit.

1. Introduction

The epicuticular wax on the surface of higher plants may form a partial or continuous layer of amorphous or crystalline wax, giving the appearance of a surface coating, referred to as the wax bloom (Holloway and Baker,1969; Jeffree et al., 1975; Baker, 1982). When this wax bloom was further examined by scanning electron microscopy, the epicuticular wax crystals particular to various species and their aerial organs were observed (e.g. Blanke et al., 1996; Jenks and Ashworth, 1999). The structure and composition of these plant epicuticular waxes may be modified by environmental factors such as light, temperature and humidity (Baker, 1982; Riederer and Markstedter, 1996) and nutrition (Bacher and Blanke, 1999). Plants growing in an environment with high levels of radiation often have a thicker layer of epicuticular waxes (Baker, 1982; Richter and Fukshansky, 1996), and a higher density of trichomes and protecting phenols (Fernández et al., 2011). Phenols in both the plant cuticle and trichomes have been associated with UV-light reflection, as discussed by Fernández et al. (2011) for the peach fruit surface.

In certain plant species, a dense cover of epicuticular wax crystals is responsible for protection against high light or heat by reflecting incoming radiation (Rosenquist and Morrison, 1988; Muller and Riederer, 2005). Leaves with a dense or thick layer of epicuticular waxes can reflect 20–80% of the incoming radiation, while with a thin layer of epicuticular waxes, the reflection may only be ca. 10% (Richter and Fukshansky, 1996). The size, distribution and orientation of the wax crystals, and other surface features, also determines the extent to which light is reflected from the tissue surface (Rustioni et al., 2012).

Light reflection from the fruit surface is a complex phenomenon involving absorption, reflection and transmission (Notton and Blanke, 1992). In a strongly reflecting material, photons are often scattered in multiple directions before being absorbed. Light reflection is related to physical characteristics of the materials such as surface roughness, particle size, density, wax contents etc. and chemical constituents of the materials e.g. water, pigments, phenols and sugar contents etc. (Kortuem, 1969; Tuchin, 2000). When

* Corresponding author. Tel.: +49 228 735142; fax: +49 228 735764.
E-mail address: mmblanke@uni-bonn.de (M. Blanke).

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http://dx.doi.org/10.1016/j.postharvbio.2013.08.017

a light beam is incident upon a fruit surface, part of the photons re-emerge as a result of multiple reflection events inside the tissue and relate its shape with the medium of absorption (Qing and Zude, 2008). Reflection as a technique has been already applied to the prediction of fruit and vegetable quality (Qin, 2008), but the study of the glossy appearance of leaves or fruit has been grossly neglected.

The conspicuous wax bloom on plums (Supplemental Photo 1) is due to a cuticle composed of the biopolymer cutin and embedded wax, with epicuticular waxes in a crystalline structure as fibrils and small thin platelets (Skene, 1963) and an underlying wax layer of tubular platelets (Bain and McBean, 1967, 1969). The fibril form of wax on plums presents a large surface area by which the light falling on the surface is reflected (Skene, 1963). The epicuticular wax on the fruit surface is also important in reducing the amount of transpiration and acts as a major barrier against moisture loss (Schoenherr, 1976; Riederer and Markstedter, 1996). Certain factors such as temperature, harvesting time, field handling and physical properties of fruit including surface features might play an important role in water loss of horticultural crops (e.g. Wills et al., 1981). The rapid weight loss of freshly harvested plums is a major problem for both marketing and eating quality and a major cause of their short postharvest shelf-life (Lippert and Blanke, 2004).

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.postharvbio.2013.08.017.

The present work is based on the hypothesis that excessive handling of plums has adverse effects on shelf-life by enhancing water loss as dependent on surface structure and temperature. Since a new non-invasive, compact, affordably-priced technology became available in the packaging industry in 2012 to determine the presence or partial or complete absence of plastic films, e.g. shrink wrap, using their glossiness, the objective was to examine whether this technology may be suitable for measuring biological specimens such as fruit surface features using the wax bloom of plums as a model. Successful detection of surface features of plums subjected to extensive postharvest handling may be then used as a postharvest quality parameter. Therefore, different surface structures were studied such as the natural wax surface, polished and chemically treated, and related to their optical property and weight loss during storage. Different plum types and varieties with their distinct wax bloom were used as model fruit, but the results may be transferable to other fruit species with a wax bloom such as red grape berries, blueberries or a variety of cabbages. This study will aid understanding the optical properties of the wax bloom of fruit with respect to their glossiness and their potential usage as a non-invasive tool for fruit quality assessment.

2. Materials and methods

2.1. Fruit samples

Approximately 360 European plums (*Prunus domestica* L.) cvs 'Topper', 'Presenta', 'Topend', 'Hauszwetsche Wolf', mirabelle and greengage from the University of Bonn's experimental orchard at Campus Klein-Altendorf, were freshly harvested in August 2012 with minimal disturbance of the natural wax layer, or purchased from the market.

2.2. Determination of characteristics of the wax bloom of P. domestica L.

The wax bloom of fruit of the 'Topper' European plum was examined in the Horticultural Institute of the University of Bonn, Germany in August 2012. Plums were carefully peeled in thin tangential slices with a scalpel and studied under up to 1500× magnification by environmental scanning electron microscopy (ESEM, Philips B.V., Eindhoven, Netherlands) under low vacuum; a sputter coater (Edwards Ltd., Oxford, UK) was used for gold coating the specimen.

European plum epicuticular wax concentrations were determined by two 15 s immersions of intact fruit in chloroform and subsequent drying of the residue in a fume cupboard following the method of Baker (1974, 1982) for complete epicuticular wax removal; twenty fruit were used at a time and the fruit surface calculated assuming their shape as an ellipsoid.

Table 1
Properties of the new luster sensor type CZ-H72 (Keyence, Japan).

Parameter	Specification
Designation	Luster sensor
Dimension	ca. 5 cm × 2 cm × 2 cm
Lens cover	Glass
Wavelength of emitted light	665 nm
Type of light source	LED
Detector units	Luster levels 0–2260 units
Operating temp.	−10 ± 50 °C
Operating voltage	14.8 V
Power consumption	1.5 W
Measuring distance	15 mm
Measuring spot	3 or 5 mm
Response time	200 μs
Sensitivity to stray light	Insensitive up to 20,000 lx
Weight	50 g

2.3. Luster level measurement of modified plum surfaces

The term 'luster' is used here to describe the relative magnitude of shininess or glossiness of the respective fruit. This luster level of the plum surfaces was measured after harvest every second day for a period of 12 days. From each of the cultivars, 60 plums were selected and 6 values were measured for each plum. The luster level was first measured with the natural wax on the plum surface and then with a polished surface of the same plum fruit to simulate postharvest fruit handling. The luster level was also measured on the same plums over time to study the effect of water loss. Measurements were taken on six positions on the plum equator, where the surface was well preserved.

The luster level was measured using a system composed of a luster sensor CZ-H72 (Keyence, Japan) and amplifier CZ-V21AP (Keyence, Japan), as used in industrial applications. Red LED light (665 nm) is emitted and luster levels measured between 0 and 2260 arbitrary units (Table 1). To account for any variations in size and fruit shape, the distance between luster sensor and the plum was adjusted by a micromanipulator (Supplementary Photo 2) to a constant 15.0 mm resulting in a 5 mm spot size on the target (Fig. 1); power supply i.e. voltage was kept constant at 14.8 V.

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2.4. Response of the light sensor to color and surface roughness

The luster sensor was first examined for any side effects of color and surface roughness before applying it to fruit. The color response of the luster sensor was investigated by using the international RAL-K7 standards for 256 colors. The colors dark blue (plum), green (greengage) and yellow (mirabelle) were chosen as a close match with the colors of the respective fruit to examine the effect of the color on the luster level, because both polishing and chemical wax removal might also alter the color appearance of the fruit. The second examination was with standard industrial roughness