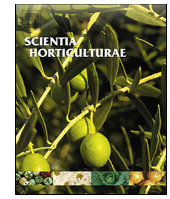
Scientia Horticulturae 242 (2018) 188–194

Contents lists available at ScienceDirect

Scientia Horticulturae

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



Peel water vapour permeance of Japanese plums as indicator of susceptibility to postharvest shriveling

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A R T I C L E I N F O

Keywords:
Maturity
Moisture loss
Prunus salicina Lindl.
Weight loss

A B S T R A C T

Moisture loss and postharvest shrivelling of some Japanese plum cultivars result in significant financial losses in the South African stone fruit industry. Even though fruit are stored at optimal temperatures and packaging solutions are implemented to reduce shrivel, the incidence of shrivel is still unacceptably high in susceptible cultivars. Fruit peel water vapour permeance (P_{H2O}) can be calculated to determine the proneness of a cultivar to moisture loss. Knowledge of the status of the P_{H2O} prior to harvest and the variation between cultivars, orchards and seasons could indicate whether newly developed cultivars are prone to postharvest shrivel. This could assist in determining the optimum handling protocols for susceptible cultivars to reduce potential moisture loss. The P_{H2O} of various cultivars were determined during 2015/16 and 2016/17. In addition, to establish whether a relationship exists between postharvest fruit moisture loss and shrivel, weight loss and shrivel incidence was recorded on individual fruit of the cultivars Sapphire, Laetitia and African Delight™ during 2016/17. P_{H2O} varied between seasons, cultivars and orchards. In 'African Rose', 'Ruby Sun' 'Ruby Star' and 'Sapphire', high P_{H2O} corresponded with known shrivel susceptibility. 'Songold', 'Fortune' and 'Angeleno' are not prone to shrivel and these cultivars had a low P_{H2O}. However, 'Laetitia' and 'African Delight™' had low P_{H2O}, even though both cultivars are prone to shrivel. Pre-harvest moisture loss and P_{H2O} could therefore not be used to predict shrivel susceptibility successfully for evaluated cultivars.

1. Introduction

Accumulated postharvest moisture loss leads to the manifestation of shrivelling in various fresh commodities (Crisosto et al., 1995; Crouch, 1998; Maguire et al., 2000; Mitchell and Crisosto, 1995; Mitchell et al., 1963; Nunes and Emond, 2007). However, some fruit or even cultivars of the same fruit type, are more prone to moisture loss and/or shrivelling than others. The driving force of postharvest moisture loss is determined by the vapour pressure deficit (VPD) between the fruit and the environment (Mitchell and Crisosto, 1995). VPD is controlled by the temperature and relative humidity (RH) of the air surrounding the fruit, the temperature of the fruit and velocity of the air moving over the fruit. Under high VPD conditions, water evaporating from fruit cells saturate the intercellular spaces within the fruit, creating a RH of nearly 100%. Water vapour then diffuses along the concentration gradient from this area of high vapour pressure to the surrounding atmosphere which is at a lower vapour pressure. The fruit peel and waxy cuticle act as the main protection against excessive moisture loss (Dietz et al., 1985; Konarska, 2013; Wills et al., 1989). This is especially important after harvest, when the fruit do not receive additional moisture from the tree via the peduncle to replace moisture lost to the atmosphere.

Loss in weight after harvest is mostly due to the loss of water vapour through evaporation and, to a lesser extent, the loss of carbon in the respiration process (Lara et al., 2014; Pieniazek, 1944). Thus, weight loss can be used as a measure of fruit moisture loss (Shibairo et al., 1997). Furthermore, the sensitivity of fruit to moisture loss is influenced by both external and internal factors. External factors include temperature, RH and air movement over the product (Pieniazek, 1944; Shibairo et al., 1997). Internal factors include the surface area to fresh weight ratio of the fruit, (Díaz-Pérez et al., 2007; Konarska, 2013), cuticle composition and the presence of open stomata, lenticels, cracks or wounds (Sastry, 1985). Maturity also influences moisture loss, with immature and over mature fruit losing moisture at a faster rate than mature fruit. Together, the internal factors influencing moisture loss determine the water vapour permeance (P_{H2O}) of the peel, which is a measure of how easily water vapour can move out of the fruit (Maguire et al., 1999a). Although packaging solutions exist to reduce shrivel in Japanese plums, shrivel incidence is still unacceptably high for most cultivars. This is most likely due to accumulated moisture loss, starting as soon as the fruit are harvested.

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https://doi.org/10.1016/j.scienta.2018.07.033
Received 10 April 2018; Received in revised form 20 July 2018; Accepted 31 July 2018
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The diffusion of water vapour across the cuticle requires water to dissolve in the lipophilic medium of the cuticle at the cell wall/cuticle interface, diffusion in the solid matrix, followed by desorption from the outer surface of the cuticular membrane (Kerstiens, 1996). Variation in the composition and molecular structure of the cuticle and cuticular waxes was therefore responsible for the variation in the P_{H2O} between cultivars and orchards (Maguire et al., 1999b). Structural and compositional changes occur in the fruit cuticle during development, which affects the permeance of the cuticle (Karbulková et al., 2008). In addition, environmental factors can also influence the P_{H2O} of fruit, with temperature being the main contributor (Riederer and Schreiber, 2001). The water permeability of the cuticular membrane can change rapidly when the lipids undergo a phase transition due to increasing temperatures (Schönherr et al., 1979). Above specific species-related transition temperatures, these changes can be irreversible, thus permanently changing the permeability of the cuticle. As the cuticular waxes contribute about 95% of the cuticle-mediated resistance to water diffusion in tomato fruit (Burghardt and Riederer, 2006; Leide et al., 2007), it appears that changes in lipid composition of the cuticle may have a significant impact on the P_{H2O}.

Fanta et al. (2014) developed a model to compute deformation of cells in tissues that are experiencing water loss. Loss of turgor of an individual cell also affects neighboring cells (Fanta et al., 2014). When cells lose turgor, the cell wall relaxes and all neighboring cells are also deformed. This may be the main reason why fruit shrivel after water loss (Nguyen et al., 2006; Veraverbeke et al., 2003), because the cuticle is considered to be relatively inelastic and it maintains its surface area, even during water loss (Fanta et al., 2014). Thus, when the underlying cells shrink and deform during moisture loss, the fruit peel gets a shrivelled appearance. This might explain why some cultivars are more prone to shrivel than others. A cultivar with high P_{H2O} might have stronger underlying cells or smaller intercellular spaces, which are more resistant to deformation during moisture loss, making it less prone to shrivel.

Limited information currently exists on the effect of pre-harvest factors on fruit permeability. Knowledge of fruit peel permeability and the influence of season and cultivar on permeability will contribute towards optimizing handling protocols for cultivars that are susceptible to shrivel.

2. Materials and methods

2.1. Trial layout and site selection

2.1.1. Trial 1: 2015/2016

The trial compared peel permeability of five Japanese plum cultivars, namely: African Rose (shrivel prone), Ruby Sun (shrivel prone), Fortune (not shrivel prone), Angeleno (not shrivel prone), Ruby Star (shrivel prone) from pre-optimum to optimum maturity. The optimum harvest date for each cultivar is presented in Table 1.

Fruit were sampled from commercial farms in the Franschhoek, Paarl and Simondium regions of the Western Cape. Five orchards were used for each cultivar and five uniform trees per orchard were randomly chosen for sampling. For 'African Rose' the farms La Terra de Luc (33°53'51.2"S 19°06'32.8"E), Keerweder (33°55'40.5"S 19°07'53.2"E), Môrelig (33°46'13.2"S 18°55'30.4"E), Bergvliet (33°49'54.2"S 18°57'51.6"E) and Babylonstoren (33°49'17.6"S 18°55'47.9"E) were used, and for 'Ruby Sun' La Terra de Luc, two orchards at Môrelig, Vredenburg (33°45'28.1"S 18°56'49.7"E) and Bergvliet were used. For 'Fortune', Keerweder, Bourgogne (33°55′33.26″S 19°07′03.02″E), La Bri (33°55'25.7"S 19°07'06.7"E), Cabrierre (33°54′58.42″S 19°07′08.17″E) and Bergvliet were used while for 'Angeleno' La Terra de Luc, Bergsig (33°56'15.9"S 19°07'04.2"E), Bourgogne, La Bri and Cabrierre were used. In the case of 'Ruby Star' the farms were La Terra de Luc, Bourgogne, La Bri, Cabrierre and Bergvliet. On each sampling date, five visually unblemished fruit, of equivalent size and maturity (fruit peel ground colour), was harvested per tree. Fruit sampling occurred on a weekly basis from three weeks before the anticipated optimum harvest date until the optimum harvest date. After harvesting, fruit were carefully placed into plastic bags and transported to the laboratory at the Department of Horticultural Science, Stellenbosch University. The fruit reached the laboratory within two to three hours after harvest. During harvesting and transport, care was taken to handle fruit as little as possible and to prevent disturbance of the waxy bloom.

Table 1
Optimum harvest dates of the cultivars in 2015/2016 and 2016/2017.

Cultivar	Harvest 2015/2016	Harvest 2016/2017
African Rose	19 Nov 2015	
Ruby Sun	17 Dec 2015	
Fortune	24 Dec–31 Dec 2015	
Angeleno	25 Feb–3 Mar 2016	
Ruby Star	11 Feb–18 Feb 2016	
Sapphire	–	13 Dec 2016
Laetitia	18 Jan 2016	16 Jan 2017
Songold	8 Feb 2016	31 Jan 2017
African Delight	–	13 Feb 2017

2.1.2. Trial 2(2015/2016 and 2016/2017)

The trial was carried out on 'Laetitia' and 'Songold' plums, sampled from the Welgevallen Research Farm, Stellenbosch, South-Africa (33°56′50.68″S 18°52′14.98″E) over two consecutive seasons (2015/2016 and 2016/2017). In addition, in 2016/2017, 'Sapphire' and 'African Delight™', sampled from Morgenzon Farm in Helshoogte, Stellenbosch, South-Africa (33°55'29.33"S 18°55'48.446"E). Fruit sampling was done weekly, from approx. three weeks before the anticipated optimum harvest date until the optimum harvest date. The optimum harvest date for each cultivar is presented in Table 1.

On each sampling date, 100 visually unblemished fruit of the same size and ground colour were picked from randomly selected trees for each cultivar. Fruit were transported in plastic bags to the laboratory at the Department of Horticultural Science, Stellenbosch University.

2.1.3. Trial 3 (2016/2017)

To establish whether a relationship exists between fruit moisture loss and shrivel in 'Sapphire', 'Laetitia', and 'African Delight™', 180 fruit at optimum maturity per cultivar were collected from a commercial pack-house in Franschhoek, South-Africa (33°54'24.4"S 19°06'47.0"E). The fruit were randomly divided into three groups of 60 fruit per cultivar and packaged in cartons according to commercial standards. The fruit were packed into count 30 pulp trays. Two layers were packed per carton and were covered with a perforated, high density polyethylene (HDPE) shrivel sheets to reduce moisture loss and a white riffled/corrugated sheet was placed on top to protect the fruit (PPECB, 2013). Twenty randomly selected fruit per carton were labelled and weighed (XB 320 M, Precisa Instruments Ltd., Switzerland). Fruit were cold-stored in regular atmosphere at RH of ± 95% according to standard practice as follows: 'Sapphire' 10 days at −0.5 °C, 7 days at 7.5 °C and then 25 days at −0.5 °C; 'Laetitia' 10 days at −0.5 °C, 7 days at 7.5 °C and then 32 days at −0.5 °C. 'African Delight™' was stored at a commercially used single-temperature regime of 56 days at -0.5 °C. After cold storage, fruit were weighed again and individually scored (visually) for shrivel incidence (Fig. 1). This was repeated until more than 10% of the fruit showed shrivelling symptoms. Fruit were stored at -0.5 °C continuously to force shrivel development.

2.2. Measurements

In the laboratory, each fruit was numbered, and the diameter recorded diagonally across the fruit suture with a digital calliper (Mitutyo, Japan). The shape of the fruit was assumed to be spherical.

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