



Skin cracking and postharvest water loss of Jalapeño chilli



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ABSTRACT

Water loss affects quality and limits marketable life of fresh produce. Chillies and peppers are susceptible to water loss that occurs through the calyx, pedicel, and skin surface. Flux through the skin is influenced by cuticular cracking, a common physical defect for Jalapeño. A high incidence of cracking was found to be caused by harvest date, with those fruit developed early in the season having the highest incidence. Although cracks developed corky suberisation, fluorescence microscopy showed the central portion of the cracks was unsuberised. The water vapour permeance ($\text{mol s}^{-1} \text{m}^{-2} \text{Pa}^{-1}$) of cracked Jalapeño was approximately three times higher than non-cracked fruit. However, the calyx and pedicel of Jalapeño were found to exhibit higher water vapour permeance than fruit skin for both cracked and non-cracked Jalapeño. After accounting for the surface area of each structure, the majority of water is lost via the fruit skin in cracked fruit, while water is equally lost from fruit skin and stem area (calyx and pedicel) in non-cracked fruit. A model was developed to predict Jalapeño shelf life (assuming that 5% water loss resulted in shrivel development) and used to conduct a sensitivity analysis on factors that influence time to shrivel development. Fruit weight and $P'_{\text{H}_2\text{O}}$ differences in the population had little effect on time to shrivel development. Cracking does reduce time to shrivel significantly but storage temperature and RH have such a big impact that water loss in Jalapeño remains best controlled through good cool chain management and packaging.

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1. Introduction

Chillies (*Capsicum* sp.) are used as a spice in many national cuisines due to their colour, pungency, flavour and aroma. A good quality chilli or pepper should be firm, with fresh calyx and pedicel and free from bruises, abrasions, and disease. Shrivelling and wilting can have important effects on visual quality of chillies (Bosland and Votava, 2000). Jalapeño is a common, medium heat, *C. annum* species that is cylindrical in shape and changes from dark green to red during maturation.

Cracking or cuticular scarring is found in many fruit such as apple, cherry, tomato, chilli and pepper. Severe cracking can lead to commercial loss (Bakker, 1988; Byers et al., 1990; Sekse, 1995; Aloni et al., 1998, 1999; Demirsoy and Demirsoy, 2004; Dorais et al., 2004; Opara et al., 2010). Skin cracking (or 'cuticular cracking' or 'lenticel cracking') occurs when fractures penetrate only the cuticular layer while flesh cracking (or 'splitting') occurs when cracks break into internal flesh (Opara et al., 2010). Skin cracking may

begin at lenticels (Teaotia and Singh, 1970). Cracking symptoms generally begin to appear when fruit attain their full size (Aloni et al., 1999; Dorais et al., 2004; Opara et al., 2010). Rapid growth rates, which generally occur under low crop loads, can induce more cracking in tomato (Bakker, 1988; Peet, 1992; Dorais et al., 2004) and cherry (Measham et al., 2012). Growing conditions such as fluctuations in RH and temperature can cause severe cracking in fruit e.g. apple (Verner, 1935), tomato (Peet, 1992) and pepper (Aloni et al., 1998; Moreshet et al., 1999). Fruit expansion and shrinkage due to temperature swings during fruit development have also been reported to cause cracking on pepper skin (Moreshet et al., 1999). Characteristics of fruit skin also may affect cracking. Tomato or cherry fruit with a stronger and more elastic cuticle are less likely to crack (Peet, 1992; Sekse, 1995; Demirsoy and Demirsoy, 2004; Matas et al., 2004).

Cracks present on fruit skin can change the structural integrity and reduce mechanical strength (Opara et al., 2010). In addition, cracked areas are likely to show accelerated water loss and shrivel development and provide an entry point for fungi (Reynard, 1951; Goode et al., 1975; Meyer, 1994). Overall, shelf-life of cracked fruit is shorter than non-cracked fruit.

In general, water loss of only 5% can cause wilting or shrivelling and limit marketable life of fresh produce (Wills et al., 2007). Water loss results from transpiration that is driven by the difference of

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water vapour partial pressure between the inside of the fruit and the external environment. To determine the rate of water loss from fruit, the water vapour permeance ($P'_{\text{H}_2\text{O}}$; $\text{mol s}^{-1} \text{m}^{-2} \text{Pa}^{-1}$) which characterises the barrier properties of the fruit surface to water vapour is measured (Maguire et al., 1999a). Fruit $P'_{\text{H}_2\text{O}}$ depends on such factors as cuticular structure (Kissinger et al., 2005), fruit maturity, RH and temperature (Utto, 2001). Mature bell pepper had lower fruit $P'_{\text{H}_2\text{O}}$ than immature fruit while the $P'_{\text{H}_2\text{O}}$ of calyx has been found to be 14 times higher than skin $P'_{\text{H}_2\text{O}}$ (Diaz-Perez et al., 2007). In addition, fruit skin irregularities (e.g. micro-cracking of cuticle) also affects $P'_{\text{H}_2\text{O}}$ and results in higher water loss (Maguire et al., 1999b). High variation of $P'_{\text{H}_2\text{O}}$ was found in apple as influenced by grower line, cultivar, harvest date and orchard but not by maturity (Maguire et al., 1999a, 2000) and was shown to correlate with variation in time to develop shrivel between individual fruit.

Chilli and pepper of different varieties have significantly different rates of water loss during storage (Lownds et al., 1993; Banaras et al., 1994; Lownds et al., 1994; Guerra et al., 2011). Temperature and RH greatly affect water loss in chilli and pepper fruit. A high rate of water loss was found in bell pepper and Jalapeño during storage at high temperature (20 °C) in comparison to low temperature (Lownds and Bosland, 1988; Lownds et al., 1994).

Cracking or cuticular scarring is generally found in the Jalapeño chilli variety (Johnson and Knavel, 1990). This research aims to (1) characterise Jalapeño cracking, (2) determine some pre-harvest factors that may influence cracking incidence and (3) quantify the effect of cracking on postharvest water loss of whole Jalapeño fruit. A model to predict water loss and subsequent likelihood of shrivel development in Jalapeño as influenced by fruit size, presence of cracking, water vapour permeance, and storage temperature and humidity was developed and used for sensitivity analysis to identify the factors that have the most influence on Jalapeño shrivel development. These results demonstrate where to focus efforts to prevent water loss and shrivel development in the postharvest supply chain for Jalapeño.

2. Materials and methods

2.1. Plant material

Work was conducted over two southern hemisphere summer seasons, 2007–2008 and 2009–2010. In 2007–2008, cracked and non-cracked Jalapeño fruit were supplied from a commercial chilli grower located in Napier, New Zealand. Fruit were harvested using commercial maturity indices of size and colour and sent to the postharvest laboratory within 24 h after harvest. These fruit were used for microscopy analysis and estimation of water vapour permeance.

In 2009–2010, Jalapeño were planted in a glasshouse at the Plant Growth Unit, Massey University, Palmerston North with monthly sequential seed plantings (August–October). Plants were manipulated to have two leaders and be either high (fruit on every node) or low (fruit on every 4th node) crop load. Plants were allowed to grow until they reached the supporting wire, which resulted in approximately 16–20 nodes. Fruit were harvested at 6, 8 or 10 weeks after fruit set (WAFS) with fruit being removed at the same maturity from each plant continuously during the season. Four replicate plants were used, resulting in a total of 72 plants being used (3 plantings $\times$ 2 crop loads $\times$ 3 harvest maturities $\times$ 4 replicates).

Two solutions were used for plant fertigation: 19.8 kg calcium nitrate, 13.16 kg potassium nitrate in 200 L water and 9.94 kg magnesium sulphate, 5.44 kg mono potassium phosphate, 600 g iron chelate, 100 g manganous sulphate, 7 g zinc sulphate, 6 g copper sulphate, 36 g boric acid, 1.6 g ammonium molybdate in 200 L water. These two solutions were mixed equally and diluted with

water at 1:100 and supplied by drip irrigation three times a day from 8 a.m. to 8 p.m. at 4 h intervals. All plants were sprayed with pyrethroid and organophosphate (Attack™, NuFarm, Auckland, NZ), pyridine azomethine (Chess™, Syngenta, Auckland, NZ) and dichlorvos (Nuvos™, Orion Crop Protection, Auckland, NZ) as required. The temperature of the glasshouse was maintained between 16 and 25 °C by heater and fan. Temperature and relative humidity (RH) during growth were recorded using TinyTag Ultra (Gemini) data loggers (Energy Engineering Ltd., West Sussex, UK). Flowering plants were periodically shaken to encourage pollination.

2.2. Microscopy analysis

Pieces of Jalapeño skin were immersed into FAA solution (formalin (37% formaldehyde) 10 mL: alcohol (ethanol) 50 mL: acetic acid 5 mL: water 35 mL) and evacuated for 5 min, then left to infiltrate for 24 h. FAA solution was substituted through an alcohol series (50%, 75%, 90% and 100% ethanol, at least 1 h per change) into Histoclear (Thermo Scientific, USA) and left overnight. Tissue was then embedded in paraffin wax at 42 °C and sectioned on a microtome (Sorvall JB-4, Microtome Service Company, New York, USA), equipped with a low profile metal blade. Wax was removed from 7 μm tissue sections through an ethanol series (100–35%) into water and stained by 0.1% (w/v) berberine hemi-sulphate in distilled water for 1 h, followed by 0.5% (w/v) aniline blue in distilled water for 30 min (Brundrett et al., 1988). Sections were observed on an Olympus light microscope with UV illumination using a BP495 filter and photographed within a few hours of staining.

2.3. Water vapour permeance estimation

Two populations of 30 selected Jalapeño (cracked and non-cracked) from the 2007–2008 season were assessed. These 30 fruit populations were randomly allocated to three groups of 10 fruit which represented untreated fruit (control), skin coated fruit (to estimate permeance of pedicel), and pedicel coated fruit. Coating was conducted with petroleum jelly (Vaseline, Unilever, London) to prevent water loss from this component of the fruit and hence allow calculation of water vapour permeance for the remaining portion of the fruit.

Individual fruit were weighed to 0.001 g precision (Model P503S Balance, Mettler Toledo, Australia) and placed in an airflow cabinet ($\approx 3 \text{ m s}^{-1}$). The magnitude of weight loss from each fruit at 20 °C was determined after 24 h. Dry and wet bulb air temperatures, and fruit surface temperatures during weight loss were determined with a thermistor probe (± 0.2 °C; Grant Instrument, Cambridge, UK) and all recorded by a Grant Squirrel logger (1200 series, Grant Instrument, Cambridge, UK).

Water vapour permeance ($P'_{\text{H}_2\text{O}}$) was calculated by rearrangement of rate of water loss equations.

$$P'_{\text{H}_2\text{O}} = \frac{r'_{\text{H}_2\text{O}}}{\Delta p_{\text{H}_2\text{O}} A} \quad (1)$$

where $P'_{\text{H}_2\text{O}}$ is the water vapour permeance of the fruit surface ($\text{mol s}^{-1} \text{m}^{-2} \text{Pa}^{-1}$); $r'_{\text{H}_2\text{O}}$ the rate of measured water loss (mol s^{-1}); A the surface area of fruit (m^2) and $\Delta p_{\text{H}_2\text{O}}$ the difference in partial pressure of water vapour between the environment ($p_{\text{H}_2\text{O}}^e$, Pa) and the fruit ($p_{\text{H}_2\text{O}}^f$, Pa). Fruit surface area was measured by scanning an image of a flattened cast of the fruit using ImageJ (National Institutes of Health, USA) to convert the scan pixel number to a surface area through an established calibration curve. The partial pressure of water vapour at saturation at a given temperature (T) is determinable using Eq. (2), with this being used as a reference

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