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Fruit skin side cracking and ostiole-end splitting shorten postharvest life in fresh figs (*Ficus carica* L.), but are reduced by deficit irrigation

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ABSTRACT

Side cracking and ostiole-end splitting skin damage affected decay development and the percentage of sound fruit during fresh fig (*Ficus carica* L.) postharvest handling and marketing. Modification of current grading standard tolerances according to cultivar is suggested to protect the consumers and improve marketable yield. The type and degree of skin damage varied among cultivars. For 'Brown Turkey', 'Kadota' and 'Sierra', slight skin-damage prior to cold storage increased decay and reduced postharvest life. In contrast, the postharvest life of 'Black Mission' fig was not significantly affected by a slight degree of skin damage prior to cold storage. Furthermore, postharvest decay incidence was associated with the degree of side cracking and ostiole-end splitting at harvest. Because fruit skin side cracking and ostiole-end splitting occur during fruit growth and development, prevention by regulated deficit irrigation (RDI) with 55% ET_c was studied for two years. In both seasons, fruit quality attributes were not affected by RDI, except for 'Brown Turkey', where size decreased by 21% during one season. RDI significantly reduced fruit skin side cracking and ostiole-end splitting in 'Brown Turkey' and skin side cracking in 'Sierra', increasing marketable fruit by 50% in 'Brown Turkey' and 18% in 'Sierra'.

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1. Introduction

Figs (*Ficus carica* L.) are soft fruits with thin skins that are highly susceptible to fruit skin side cracking and ostiole-end splitting during growth and development. These fruit skin damages are related to genotype and orchard conditions (Condit, 1947; Crisosto et al., 2011a). Some studies use the term cracking to describe both superficial cracks that occur on the fruit side, and end-cracks that expose the flesh (Lampinen et al., 1995). Cracking has been described as "the physical failure of the fruit skin" (Milad and Shackel, 1992) in the form of fractures in the cuticle or skin, which typically do not penetrate into the flesh. Splitting is an extreme form of cracking that penetrates into the flesh (Opara et al., 1997).

In current commercial cultivars consumers prefer fresh figs at the tree ripe maturity stage (Crisosto et al., 2010). Fresh figs harvested between commercial and tree ripe maturity are highly susceptible to postharvest deterioration and are more perishable than other crops (Turk, 1989) because they have an epidermis that is easily damaged and a high sugar content (Kaynak et al., 1998). Thus, the postharvest life of fresh figs is extremely short and the majority of fresh fig consumption takes place near the centers of production (Turk, 1989). Due to global markets and increased consumer interest in fresh figs, extending their postharvest life is desirable. Fresh fig deterioration can be delayed by low temperatures (Kaynak et al., 1998; Turk, 1989) and controlled atmospheres (Colelli et al., 1991) during storage and transportation. However, preventing deterioration due to decay is a challenging task due to a high incidence of fruit skin damage, the lack of registered postharvest products, and a strong consumer trend for organic fresh figs.

The establishment and enforcement of grading systems is used to prevent fruit losses during postharvest marketing and to protect consumers. The current grading systems for some major crops may lead to a high incidence of fruit wastage due to strict limitations. Whereas, grading systems for minor crops, like fresh figs, are not well defined to non-existent. The United Nations Economic Commission for Europe (UNECE) considers fresh figs with slight longitudinal cracks in the skin to be of good quality, Class I, while Class II figs allow more skin damage (UNECE, 2010). The California fig industry has no current grading standards for fresh figs as this industry is developing. Fruit with slight or moderate skin side cracking has been observed in the same box with sound fruit during commercial packaging and at the stores in California (Kong et al., 2012). However, the impact of cracking on postharvest life has never been evaluated. Usually, fruit skin side cracking and ostiole-end splitting provide entry sites for fungal decay and moisture loss (Opara et al., 1997; Crisosto et al., 2011a). In addition, under field conditions ostiole-end splitting provides an entryway for insects that vector diseases such as endosepsis that spread to healthy fruits. Endosepsis, caused by *Fusarium verticilliodes* commonly referred to

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as pink, brown, soft, and eye-end rots (Michailides and Morgan, 1998), has caused up to 50% of annual fig fruit losses in California (Hansen, 1928). This disease is brought into the fruit by the fig wasp pollinator (*Blastophaga psenes* L.) through the ostiole opening in 'Calimyrna' type figs. Due to endosepsis the fresh and dried fig industry is slowly moving away from cultivars requiring insect pollination to parthenocarpic type figs that do not require pollination (Michailides and Morgan, 1998). Current strategies to reduce decay incidence and extend the fig postharvest life include careful handling of the fruit to minimize skin damage (Crisosto et al., 2011a) and using postharvest sulfur dioxide treatments to protect the open wound (Cantin et al., 2011).

Any approach that reduces the number of fruit with skin side cracking and ostiole-end splitting on the tree will help maintain high production, reduce losses, and extend postharvest life. A relationship between fruit cracking and changes in levels of irrigation has been studied in nectarine, tomato, apple, and litchi. A high water supply triggered a high incidence of fruit cracking in nectarine (Gibert et al., 2007), tomato (Peet and Willits, 1995), apple (Opara et al., 2000) and litchi (Rab and Ul-Haq, 2012). In California, high irrigation rates in mature 'Black Mission' trees for the dried fig market, produced high fig yields, but also more culls (Goldhamer and Salinas, 1999). Various researchers have speculated that fig cracking and splitting are due to changes in tree water status (Condit, 1947; Melgarejo, 1996). However, information to support this is limited. In our preliminary fresh fig irrigation trial, regulated deficit irrigation (RDI) yielded a significantly lower percentage of fruit with skin cracking and ostiole-end splitting compared to standard irrigation rates (Crisosto et al., 2011b). RDI established at a specific stage of fruit development can reduce water usage, without affecting yield or fruit quality in prune (Lampinen et al., 1995) and peach (Goldhamer et al., 2002).

The main objectives of this study were to understand postharvest life limitations of fresh fig fruit, investigate the shelf life of fruit with varying degrees of skin damage, and evaluate the benefits of regulated deficit irrigation on reducing fruit skin damage incidence prior to packaging.

2. Material and methods

2.1. Postharvest market life evaluations

In 2006, fruit from the three cultivars 'Black Mission' and 'Zidi' (dark-skin) and 'Kadota' (green-skin) were harvested at commercial maturity from the United States Department of Agriculture (USDA), Agricultural Research Service (ARS) National Clonal Germplasm Repository. Immediately after harvest, the fruit was transported to the Kearney Agricultural Center (KAC) and placed in cold storage (0 °C and 85% relative humidity) for 7 d. The fruit was then transferred to a storage room (20 °C and 40% relative humidity) to simulate retail display at room temperature (shelf life) for up to 3 d. Fruit evaluations were performed immediately after removal from cold storage, and 1, 2 and 3 d thereafter. Fruits were evaluated for soundness, decay (fruits with *Rhizopus, Alternaria, Penicillium*, and/or *Botrytis*), and the presence of juice on the ostiole.

2.2. Fruit skin damage from side cracking and ostiole-end splitting and postharvest life

In 2012 fruit from four cultivars, 'Black Mission' and 'Brown Turkey' (dark-skin), and 'Kadota' and 'Sierra' (green-skin), growing under 100% ET_c at the KAC in Parlier, California (as described in Section 2.4) were harvested at commercial maturity according to color and firmness (Crisosto et al., 2010). The fruit were immediately brought to the F. Gordon Mitchell Postharvest Laboratory at KAC for grading into four categories, according to the degree of fruit skin damage resulting from side cracking (Fig. 1A) and ostiole-end splitting (Fig. 1B). These four categories were created based on the amount of fruit skin damage observed according to European grading standards. These categories were: none (no damage), slight damage (side cracking and ostiole-end splitting covering less than one-third of the fruit), moderate damage (side cracking and ostiole-end splitting covering between one-third and two-thirds of the fruit) and severe (side cracking and ostiole-end splitting covering more than two-thirds of the fruit). Side cracking scores were determined by the length of the crack compared to the length of the fruit (Fig. 1A). Ostiole-end splitting was based on the width of ostiole split compared to the diameter of the fruit (Fig. 1B).

None, slight, moderate and severe scores were handled as separate postharvest storage treatments, with four replications of ten fruits each. Figs were placed in cold storage (0 °C and 85% relative humidity) for 7 d. Then figs were transferred to room temperature (20 °C and 40% relative humidity) for 3 d, to simulate store shelf life conditions, prior to being evaluated. Fruit evaluations as described in Section 2.1 were performed.

2.3. Orchard layout

Cultivars 'Black Mission', 'Brown Turkey', 'Kadota' and 'Sierra' were planted in 2006 at KAC in Parlier, California. The planting design consisted of 10 rows, with four rows per irrigation treatment, separated by two center buffer rows. Each cultivar had five replicated trees grouped together as a unit and was randomly assigned within each row. The tree spacing was 5.4 m between rows by 2.4 m between trees, on sandy loam soil with a single drip line.

2.4. Irrigation treatments

In 2011 and 2012, two irrigation treatments were established based on crop evapotranspiration (ET_c), which was calculated by the reference evapotranspiration (ET_o) multiplied by a crop coefficient (K_c) (Fereres and Soriano, 2007). The ET_o data was collected from the California Irrigation Management System weather station #39 for Parlier, California. The K_c was based on a peach study that showed that the midday canopy light interception of a tree crop can be used to determine K_c (Ayars et al., 2003). The field was irrigated at 100% ET_c until at least 25% of the fruit were in stage II of fruit growth, which occurred during the first week of August. Then, RDI at 55% ET_c was imposed on five consecutive rows, while the other five rows continued receiving irrigation at 100% ET_c.

Fig fruit have three distinct growth stages. Stages I and III are periods of rapid fruit growth, while stage II shows almost no change in fruit size. Fruit growth stage II was determined when the weekly rate of change in fruit diameter was <1 mm per week for at least three weeks (Crane, 1948). Bearing fig shoots grow fruit at different maturity stages, simultaneously. Thus, each harvest period contained fruit corresponding to the fruit growth stage when irrigation treatments were initiated.

Midday stem water potential (MSWP), measured on covered leaves, was used to quantify plant water stress status (McCutchan and Shackel, 1992). One leaf per tree from the south side, near the base of the tree, was selected and placed inside a foil bag for at least 20 min prior to MSWP measurement to allow equilibration with the water potential in the stem (Fulton et al., 2001). The MSWP was measured weekly on three trees per cultivar located in the center row of each irrigation treatment using a pressure chamber (Plant Water Status Console 7″ 40 bar, Soil Moisture Equipment Corp., Santa Barbara, CA). MSWP was measured between 12 p.m. and 3 p.m., as such measurements are more affected by different