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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

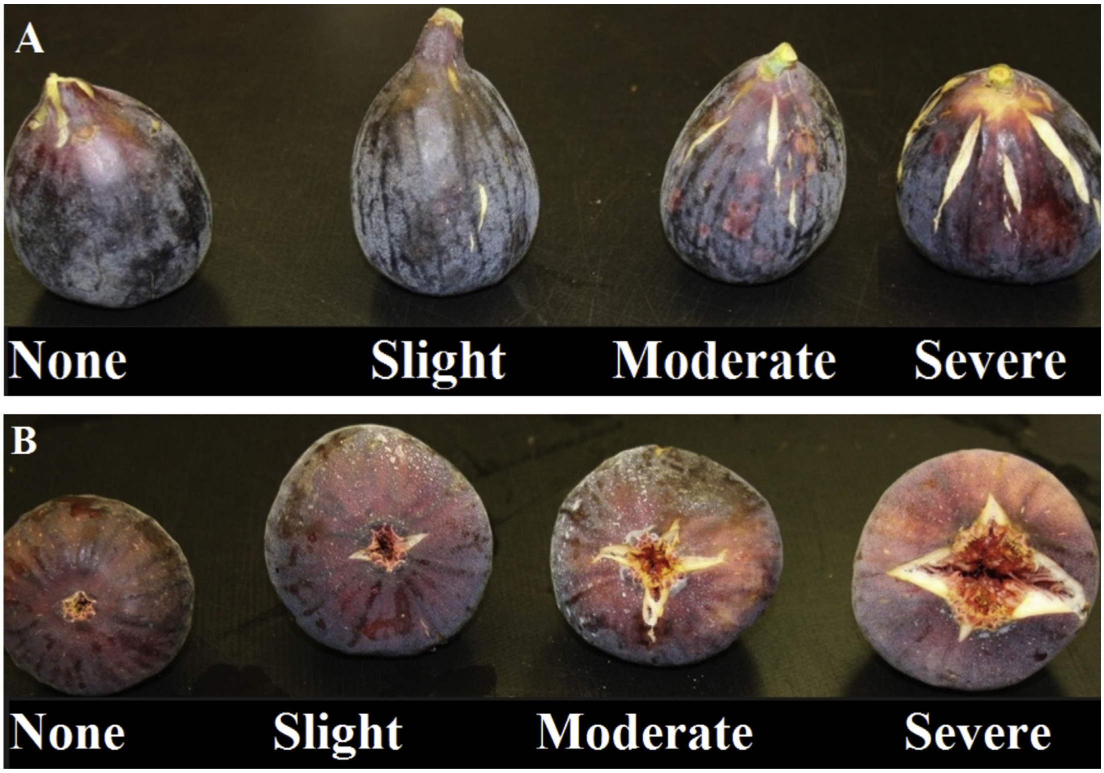

Fig. 1. Fresh fig fruit skin damage: skin side cracking damage scores from none to severe on 'Black Mission' (A). Ostiole-end splitting damage scores from none to severe on 'Brown Turkey' (B).

irrigation regimes than pre-dawn measurements (Goldhamer and Salinas, 1999).

2.5. Regulated deficit irrigation fruit evaluation

Fruit collection for each cultivar was carried out in the center row of each irrigation treatment on the same three trees used to determine MSWP. Yield, fruit count, weight, firmness, soluble solids concentration (SSC), titratable acidity (TA), and skin damage were evaluated. Fruit firmness was measured with a fruit texture analyzer (Guss, Strand, South Africa), as described by Souza and Oliveira Ferraz (2008). SSC and TA were obtained from a composite juice sample, obtained by squeezing five fruits in a hand press and filtering through cheesecloth. SSC was measured using a temperature-compensated digital refractometer (PR 32α, Atago Co., Tokyo, Japan). TA was measured with an automatic titrator (TIM 850, Radiometer Analytical, Lyon, France) and reported as percentage of citric acid equivalent. Skin damage evaluation included visual inspection of each fruit for side cracking, ostiole-end splitting, and fruits with both side cracking and ostiole-end splitting. Fruits were separated according to fruit skin damage into four damage categories: none, slight, moderate and severe as described in Section 2.2 (Fig. 1).

2.6. Statistics

The data was analyzed using statistical analysis software (SAS 9.3). Analysis of variance (ANOVA) was used to determine significant differences between treatments within the same cultivar. For the fruit skin damage from side cracking and ostiole-end splitting and postharvest life studies, ANOVA was based on 4 replications for each treatment to determine differences among skin damage scores. For the water stress and fruit skin damage experiment ANOVA was based on individual trees as replications to determine differences between the two irrigation treatments. Mean separations were detected by Tukey's Honestly Significant Test (HSD). Linear regressions were used to investigate the relationships between plant water status, reported as an average MSWP, and the average percentage of fruit skin damage as related to harvest period.

3. Results and discussion

3.1. Postharvest market life

Fruit removed from cold storage (0 °C and 85% relative humidity) to ambient air temperature had no decay or juice at the ostiole-end, the culls at that time were due to insect damage and cuts. Upon removal from cold storage (Day 0), ~99% of 'Black Mission' (Fig. 2A), ~75% of 'Kadota' (Fig. 2B) and ~90% of 'Zidi' (Fig. 2C) fruits were sound. Decay in fresh figs is typically not observed during cold storage at 0 °C but instead during subsequent warming; it can be reduced by a single application of sulfur dioxide prior to storage (Cantin et al., 2011). The percentage of sound fruit decreased rapidly over time for these three cultivars during simulated retail display at room temperature (shelf life). Decay and juice on the ostiole increased gradually with exposure to ambient air temperature conditions. Juice on the ostiole is an undesirable trait because juice outside of the fruit is a nutrient source for pathogens, making the fruit more susceptible to fungal decay, and thus considered a cull. The percentage of fruits with juice on the ostiole increased for all cultivars except 'Black Mission', affecting up to 60% of fruits by the end of ambient air temperature storage period. At the end of the 3 d ambient air temperature storage period, ~45% of 'Black

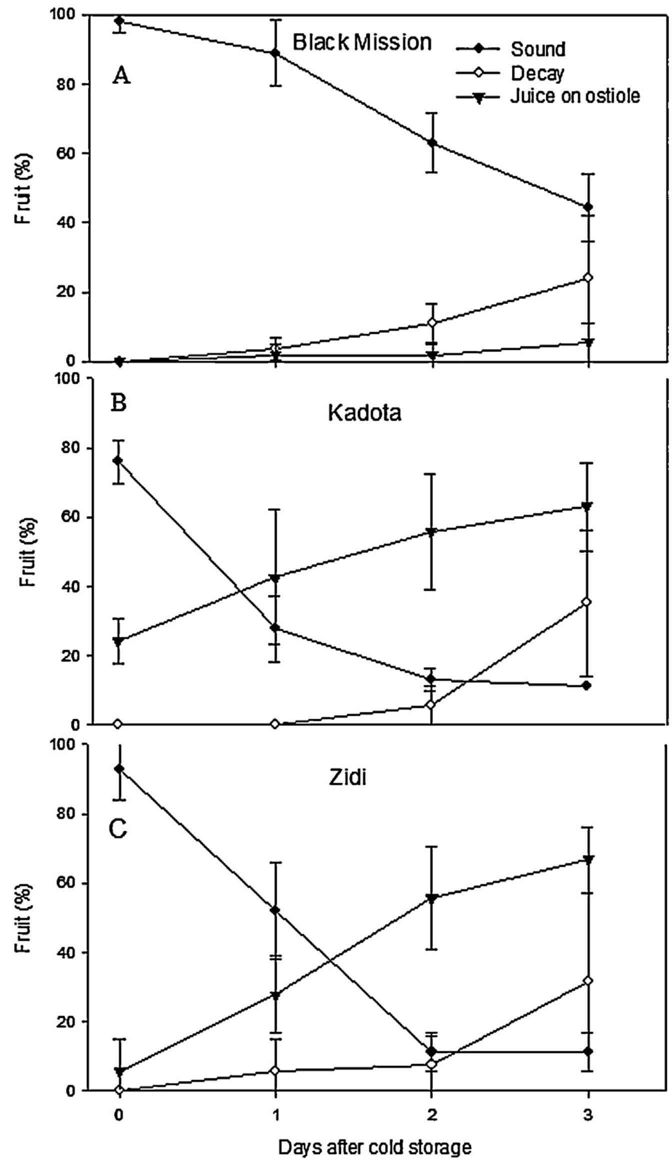

Fig. 2. Postharvest life of 'Black Mission' (A), 'Kadota' (B), and 'Zidi' (C) figs expressed as the percentage of sound fruit, decayed fruit, and fruit with juice on the ostiole measured after 7 d of cold storage at 0 °C and after 0, 1, 2 and 3 d at 20 °C (to simulate shelf life). Bars indicate standard deviations from each mean.

Mission' fruit remained sound, while the other cultivars were 90% culls. Thus, decay and juice on the ostiole contributed to a reduction in sound fruit.

The predominant types of skin damage (skin side cracking, ostiole-end splitting, and both) varied among cultivars and between seasons (Fig. 3). 'Brown Turkey' consistently had the highest cull incidence, followed by 'Black Mission' and 'Sierra', while 'Kadota' had the fewest culls. The position of damage on the fig has been reported previously (Kaynak et al., 1998; Crisosto et al., 2011a), but not the contribution of each type of skin damage to total culls. Over the two seasons, 'Black Mission' and 'Sierra' had approximately fifteen times more skin side cracking (~30%) than ostiole-end splitting (~2%) that made up the total cull fruit (Fig. 3). While 'Brown Turkey' and 'Kadota' had a similar incidence of skin side cracking and ostiole-end splitting. Individual fruits with both a side crack and an ostiole-end split were less than 8% of total culls for all cultivars, except 'Brown Turkey', which had ~19%.

3.2. Side cracking and ostiole-end splitting damage scores and postharvest life

As the degree of skin damage increased from none to severe the percentage of sound fruit decreased because of decay and juice on the ostiole (Table 1). Severe skin damaged fruit, which occurred only in 'Black Mission' and 'Brown Turkey', had 100% decay after storage. 'Black Mission' and 'Kadota' in the moderate skin damage category had 0–5% of sound fruit after 7 d at 0 °C plus 3 d at 20 °C, while, 40–55% of fruit in the slight and no damage categories were sound after storage. Thus, the presence of slight damage prior to cold storage did not significantly affect the percentage of sound fruit for these two cultivars. However, slight and moderate skin damage significantly reduced sound fruit in 'Brown Turkey' and 'Sierra'.

In fruits with moderate skin damage, decay incidence was very high in all cultivars, while juice on the ostiole was high for 'Brown Turkey', 'Kadota' and 'Sierra' (Table 1). In 'Black Mission', decay caused 95% of culls, as the incidence of juice on the ostiole was very low (~10%). Whereas, in 'Brown Turkey', culls were mainly due to juice on the ostiole (85%). In 'Kadota', the culls were affected equally by decay and juice on the ostiole (~90%). Similarly, the culls in 'Sierra', were due to both decay (69%) and juice on the ostiole (74%). The increase in the degree of fruit skin damage from none to severe was associated with the incidence of decay and juice on the ostiole.

The size of the ostiole opening has been a concern to the California fig industry because it is an entryway for insects that cause diseases such as endosepsis, which can spread to other fruits in the field. 'Black Mission' and 'Sierra' have a small (4 mm and 5 mm), closed ostiole, while 'Kadota' and 'Brown Turkey' fruit have larger ostiole openings of 6 mm and 11 mm, respectively. Although, 'Sierra' was selected in a UC breeding program for its closed ostiole end, our postharvest evaluation indicated that a "closed ostiole" does not reduce juice leakage after harvest.

European grading standards for marketing and commercial quality control of fresh figs including brebas categorizes slightly and moderately cracked figs into Class I and Class II, respectively, as both are considered marketable (UNECE, 2010). Class I figs may have slight longitudinal cracks and a split in the ostiole end, provided that the total length of the split and ostiole do not exceed 30 mm, which is similar to our classification of slightly damaged fruit. Class II figs may have longitudinal cracks, but the total length of the split and the ostiole is not to exceed 40 mm, which is comparable to our classification for moderately damaged fruit.

3.3. Irrigation treatments and water stress

Throughout both seasons, starting from the beginning of the growing season until the first week of August, all trees received full replacement of their water use (100% ET_c). During the first week of August, four rows in the plot began receiving an RDI treatment, which consisted of 55% ET_c water replacement. For all cultivars the plant MSWP, which was measured weekly, ranged between −0.40 and −0.93 MPa with an average of −0.65 MPa for fully-irrigated trees. In trees subjected to RDI, as water stress increased, MSWP decreased from −0.70 MPa in August to −1.20 MPa by October with a seasonal average of −1.0 MPa.

3.4. Water stress and fruit skin damage

For each tree, the average MSWP, measured at each harvest period was plotted against the average percentage of fruits with side cracking or ostiole-end splitting harvested during that period. There was a significant positive relationship between MSWP and fruit skin side cracking in 'Brown Turkey' (Fig. 4A) and 'Sierra'

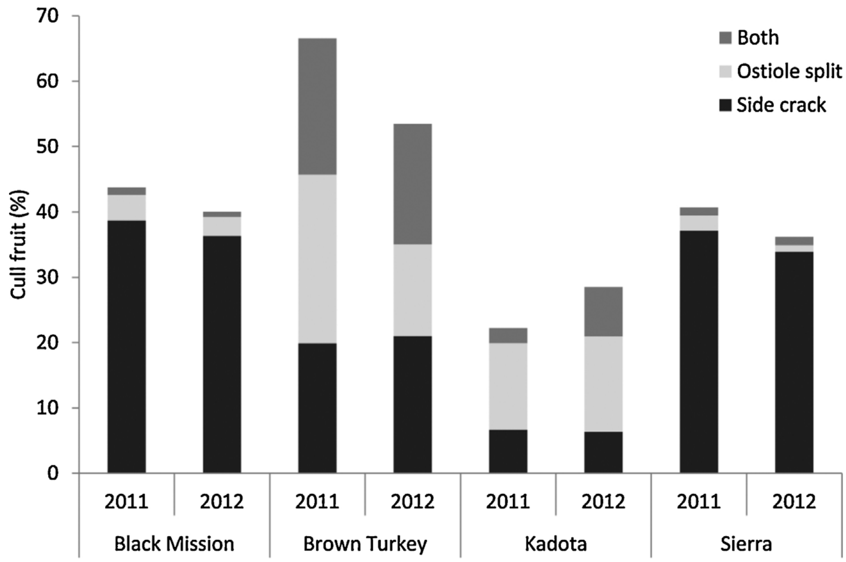

Fig. 3. Distribution of fruit skin damage types (side crack, ostiole-end split and both) on four fresh fig cultivars evaluated for two harvest seasons.

(Fig. 4B) during both seasons. In the RDI treatment, as the plant stress increased, the MSWP decreased along with skin side cracking. In cultivars 'Brown Turkey' and 'Sierra' trees with a MSWP of −0.6 MPa produced fruits with 15% and 35% skin side cracking, but as MSWP decreased to −1.0 MPa, the incidence of cracking was reduced to 5% and 20%, respectively. Additionally, there was a significant positive relationship between MSWP and ostiole-end splitting in 'Brown Turkey', as the MSWP decreased, ostiole-end splitting was reduced (Fig. 5). A similar situation occurred in a nectarine study, where deficit irrigation decreased fruit weight leading to less stylar end cracking (Gibert et al., 2007). By reducing the side cracking and ostiole-end splitting, the RDI treatment showed that a lower MSWP significantly increased the percentage of sound fruit in 'Brown Turkey' (Fig. 6A) and 'Sierra' (Fig. 6B).

Our postharvest life evaluation work demonstrated that skin damaged fruit were more prone to decay than sound fruit during postharvest handling. As skin side cracking and ostiole-end splitting occur on the fruit prior to harvest, minimizing skin damage through RDI during fruit growth and ripening will reduce the number of damaged fruit at harvest, and the likelihood that these damaged fruit will be included in packaging. The postharvest life of fig fruit under RDI was not evaluated. However, we speculate that because fig fruits are rich in phenolic compounds, especially the dark-skinned figs (Solomon et al., 2006), fruit grown under water stress conditions may be less susceptible to decay development during postharvest handling. Fruits with phenolic compounds have natural antimicrobial components that could prevent fungal colonization of the host fruit (Nicholson, 1992; Prusky, 1997). RDI increased the level of phenolic compounds in the skin of peaches (Buendía et al., 2008) and grapes (Santesteban et al., 2011). Therefore, fruit grown under RDI of 55% ET_c may have a different decay tolerance than fruit grown under full irrigation. This hypothesis on the potential development of plant disease resistance as a response to water stress should be evaluated in the future.

RDI did not influence fruit quality attributes SSC, TA, or firmness for any cultivars, which is consistent with data for peaches (Lopez et al., 2008). RDI reduced fruit weight in 'Brown Turkey' but only during the 2011 season by 21%. 'Brown Turkey' had significantly heavier fruit compared to the other cultivars. In our study 'Brown Turkey' fruit weighed about 58 g while 'Black Mission' fruit

Table 1
Influence of four fruit skin damage scores at harvest on the percentage of sound fruit, decayed fruit, and fruit with juice on the ostiole in four fresh fig cultivars evaluated after 7 d at 0 °C plus 3 d at 20 °C.

Cultivar	Skin damage scores[a]	Sound (%)	Culls	
			Decay (%)	Juice on ostiole (%)
Black Mission	None	50 a[b]	40 b	10 a
	Slight	55 a	45 b	0 a
	Moderate	5 b	95 a	15 a
	Severe	0 b	100 a	6 a
Brown Turkey	None	70 a	10 c	20 c
	Slight	16 b	63 b	48 b
	Moderate	5 b	50 b	85 a
	Severe	0 b	100 a	100 a
Kadota	None	55 a	20 c	35 b
	Slight	40 a	55 b	40 b
	Moderate	0 b	90 a	89 a
Sierra	None	55 a	5 b	45 a
	Slight	20 b	65 a	35 a
	Moderate	6 b	69 a	74 a

[a] Severe category occurred only in cultivars 'Black Mission' and 'Brown Turkey.'
[b] Means with different letters indicate highly significant differences between treatments at $P \leq 0.01$ according to Tukey's Honestly Significant test within each cultivar.

Table 2
Influence of regulated deficit irrigation on total yield, percentage of sound fruit and percentage of marketable fruit for Europe and California, according to grading standards based on fruit skin damage scores for two seasons.

Cultivar	Treatment (ET_c)[a]	Total yield (ton/ha)		Sound[b] (%)		Marketable[c] Europe (%)		Marketable[d] California (%)	
		2011	2012	2011	2012	2011	2012	2011	2012
Black Mission	100%	6.4 a[e]	5.2 a	56.3 a	60.0 a	93.0 a	84.3 a	74.7 b	73.0 b
	55%	6.3 a	4.2 a	64.4 a	77.5 a	95.3 a	85.1 a	85.1 a	87.1 a
Brown Turkey	100%	23.4 a	17.2 a	33.5 b	46.5 b	68.4 b	77.6 b	33.5 b	46.5 b
	55%	19.6 a	10.1 b	85.6 a	94.2 a	94.5 a	99.3 a	85.6 a	94.2 a
Kadota	100%	39.0 a	23.0 a	77.8 a	71.5 a	97.4 a	90.2 a	77.8 a	71.5 a
	55%	28.6 a	17.1 a	74.8 a	71.6 a	96.4 a	91.7 a	74.8 a	71.6 a
Sierra	100%	9.8 a	10.0 a	59.3 b	63.8 b	97.4 a	92.8 a	59.3 b	63.8 b
	55%	7.5 a	10.8 a	76.1 a	81.5 a	97.6 a	99.0 a	76.1 a	81.5 a

[a] Irrigation based on evapotranspiration of the crop.
[b] Percentage of fruit without any defects.
[c] Percentage of fruit with slight and moderate skin cracking that is marketable according to the UNECE standard.
[d] The suggested percentage of fruit that is marketable according to this study's postharvest results.
[e] Means with different letters indicate significant differences between treatments at $P \leq 0.05$ according to Tukey's Honestly Significant test within each cultivar.

weighed 36 g, 'Kadota' 39 g and 'Sierra' 40 g. This reduction in fruit weight in 'Brown Turkey' contributed to a decrease in the total yield with the RDI treatment. However, we calculated that while 'Brown Turkey' orchards given 100% ET_c, yielded approximately 20 ton/ha, less than half of that was marketable as fresh fruit. The same trees given RDI 55% ET_c treatment yielded about 15 ton/ha, with 85 to 95% of that fruit rated as sound and up to 96% of the crop considered marketable in Europe (Table 2). Meanwhile cultivars with smaller fruit ('Black Mission', 'Kadota' and 'Sierra') had no difference in total yield between the two irrigation treatments (Table 2).

The RDI treatment had a significantly higher percentage of sound fruit in 'Brown Turkey' and 'Sierra', with the amount of sound fruit improved by 50% and 18%, respectively. When slight and moderately skin damaged fruits are included, 84–99% of 'Black Mission', 'Kadota', and 'Sierra' fruit produced under RDI and full irrigation would be considered marketable according to the European grading standards. 'Brown Turkey' was the only cultivar with severe skin damage that showed a significantly higher percentage of marketable fruit according to the European grading system with the RDI treatment.

Our studies demonstrated that fruits with slight or moderate skin damage in cultivars 'Brown Turkey', 'Kadota', and 'Sierra' had significantly more decay than non-damaged fruit during shelf life. Thus, in these cultivars only fruits free of skin damage should be packaged for the fresh fig market in California (Table 2). Since 'Black Mission' is more tolerant to skin damage, fruits with slight skin damage can be added to the container without affecting postharvest life. The addition of slightly damaged figs increased the percentage of marketable fruit from 65 to 80% in 'Black Mission' in the current study. RDI treatment had a significantly higher amount of marketable fruit according to the suggested California standards than the fully irrigated treatment for all cultivars except, 'Kadota'.

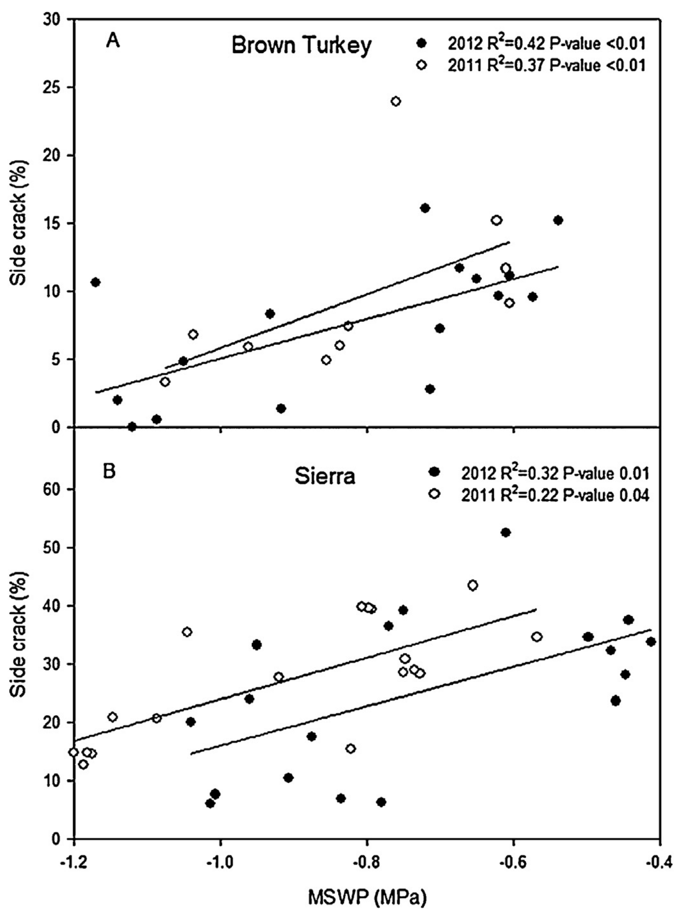

Fig. 4. Relationship between midday stem water potential (MSWP) and the percentage of fruit with side cracking in 'Brown Turkey' (A) and 'Sierra' (B) for two harvest seasons. Each point represents the average irrigation treatment MSWP during three harvest periods and the average percentage of fruit with side cracking for each tree measured.

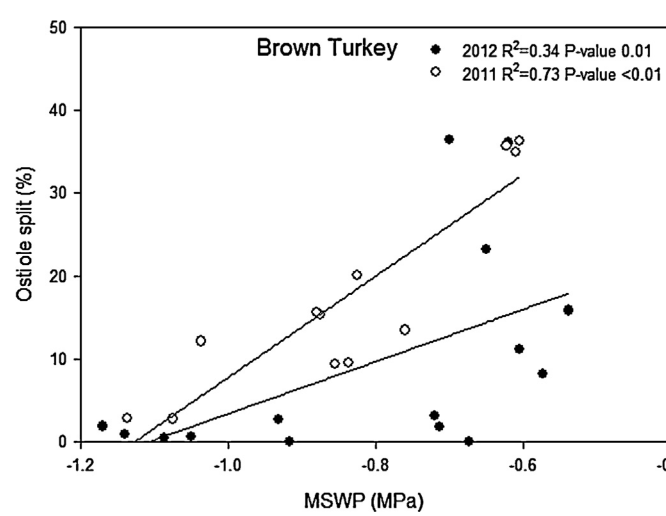

Fig. 5. Relationship between midday stem water potential (MSWP) and the percentage of ostiole splitting in 'Brown Turkey' figs for two seasons. Each point represents the average irrigation treatment MSWP during three harvest periods and the average percentage of fruit with ostiole-end split for each tree measured.

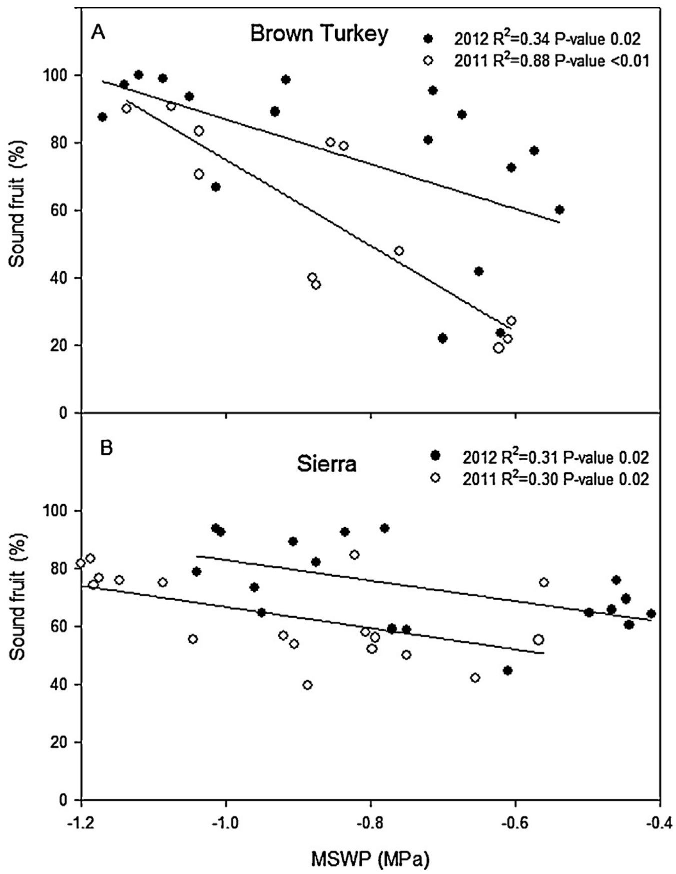

Fig. 6. Relationship between midday stem water potential (MSWP) and the percentage of sound fruit (figs free of skin damage) in 'Brown Turkey' (A) and 'Sierra' (B) for two seasons. Each point represents the average irrigation treatment MSWP during three harvest periods and the average percentage of sound fruit for each tree measured.

4. Conclusions

The shelf life of fresh figs is very short and limited by decay and juice leaking from the ostiole end. In two separate controlled cold storage and shelf life studies (one conducted in 2006 on fruit from the USDA ARS National Clonal Germplasm Repository, and one conducted in 2012 on fruit from the 100% ET_c treatment from KAC), decay originating from skin side cracking and ostiole-end splitting reduced fruit postharvest life. Although the type and degree of defects varied by cultivar, our results show that fruit held at 20 °C increases decay development rapidly, thus proper temperature management is essential during storage and display for all fresh figs and should be held at 0 °C.

Although the current European grading system for fresh figs permits slight and moderate skin damaged fruit to be sold, California fresh fig cultivars showed that the percentage of fruit with postharvest decay increased as the degree of skin damage increased from none to severe. Postharvest decay of 'Brown Turkey', 'Kadota' and 'Sierra' fruit was greatly affected by slight, moderate and severe skin damage indicating that only sound fruit should be allowed for these cultivars. Because skin damage occurs on the fruit at harvest, preventing fruit skin damage is essential to maintain the postharvest life of that fruit. RDI with 55% ET_c treatment, applied when 25% of fruit were ripening, reduced fruit skin damage and increased the percentage of sound fruit in 'Brown Turkey' and 'Sierra', without negatively impacting other quality attributes. Minimizing the skin damage through RDI during fruit growth and development will increase the percentage of sound fruit.

Our results indicate that 'Black Mission' figs can tolerate slight skin damage without significantly decreasing quality after storage. 'Black Mission' figs have several desirable characteristics: dark skin, a small ostiole that prevents insects from entering the fruit; little to no juice leakage from the ostiole during storage; and skin that is not influenced by irrigation. Therefore, genotype selection is an important approach to develop the fresh fig industry.

Proper enforcement of grading standards is essential to maintain fresh fig postharvest life. Changes in irrigation management can decrease the incidence of side cracking and ostiole-end splitting on some cultivars as well as reduce orchard water usage. Further detailed work on understanding the relationship between fruit growth development stage, water stress, and the decay susceptibility of the postharvest life of water stressed fruit are recommended.

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References

Ayars, J.E., Johnson, R.S., Phene, C.J., Trout, T.J., Clark, D.A., Mead, R.M., 2003. Water use by drip-irrigated late-season peaches. Irrig. Sci. 22, 187–194.
Buendía, B., Allende, A., Nicolás, E., Alarcón, J.J., Gil, M.I., 2008. Effect of regulated deficit irrigation and crop load on the antioxidant compounds of peaches. J. Agric. Food Chem. 56, 3601–3608.
Cantin, C.M., Palou, L., Bremer, V., Michailides, T.J., Crisosto, C.H., 2011. Evaluation of the use of sulfur dioxide to reduce postharvest losses on dark and green figs. Postharvest Biol. Technol. 59, 150–158.
Crane, J.C., 1948. Fruit growth of four fig varieties as measured by diameter and fresh weight. Proc. Soc. Hortic. Sci. 52, 237–244.
Colelli, G., Mitchell, F.G., Kader, A.A., 1991. Extension of postharvest life of 'Mission' figs by CO_2-enriched atmospheres. HortScience 26 (9), 1193–1195.
Condit, I.J., 1947. The Fig. Chronica Botanica Co, Waltham, MA.
Crisosto, C.H., Bremer, V., Stover, E., 2011a. Fig (*Ficus carica* L.). In: Yahia, E.E. (Ed.), Postharvest Biology and Technology of Tropical and Subtropical Fruits vol 3: Cocona to Mango. Woodhead Publishing Ltd., Cambridge, UK, pp. 134–158.
Crisosto, C.H., Phene, B., Kong, M., 2011b. Maintaining and utilizing UC Davis fig-industry research at the Kearney Agricultural Center. Proc. California Fig Inst. Res. May(12) (2011), 1–9.
Crisosto, C.H., Bremer, V., Ferguson, L., Crisosto, G., 2010. Evaluating quality attributes of four fresh fig (*Ficus carica* L.) cultivars harvested at two maturity stages. HortScience 45, 707–710.
Fereres, E., Soriano, M.A., 2007. Deficit irrigation for reducing agricultural water use. J. Exp. Bot. 58, 147–159.
Fulton, A., Buchner, R., Gilles, C., Olson, B., Bertagna, n., Walton, J., Schwankl, L., Shackel, K., 2001. Rapid equilibration of leaf and stem water potential under field conditions in almonds, walnut and prunes. Hortechnology 11, 609–615.
Gibert, C., Chadoeuf, J., Vercambre, G., Genard, M., Lescourret, F., 2007. Cuticular cracking on nectarine fruit surface: spatial distribution and development in relation to irrigation and thinning. J. Am. Soc. Hort. 132 (5), 583–591.
Goldhamer, D.A., Salinas, M., Crisosto, C., Day, K.R., Soler, M., Moriana, A., 2002. Effects of regulated deficit irrigation and partial root zone drying on late harvest peach tree performance. Acta Hortic. 592, 343–350.
Goldhamer, D., Salinas, M., 1999. Black Mission fig production improved by heavier irrigation. Calif. Agric. 53, 30–33.
Hansen, H.N., 1928. Endosepsis and its control in caprifigs. Phytopathology 18, 931–938.
Kaynak, L., Gozlekci, S., Ersoy, N., 1998. A research on storage and pomological properties of some fig (*Ficus carica* L.) cultivars grown in antalya conditions. Acta Hortic. 480, 277–282.
Kong, M., Reyes, H., Zagra, G., Mitchell, A., Phene, B., Lampinen, B., Norton, M., Crisosto, C., 2012. Water stress and fruit developmental stage affect fruit cracking and ostiole-end splitting of figs (*Ficus carica*). Proc. Calif. Fig Inst. Res. 2011, 45–60.
Lampinen, B.D., Shackel, K.A., Southwick, S.M., Olson, B., Yeager, J.T., Goldhamer, D., 1995. Sensitivity of yield and fruit quality of French prune to water deprivation at different growth stages. J. Am. Soc. Hortic. Sci. 120, 139–147.
Lopez, G., Arbones, J.C., Mata, M., Vallverdu, X., Girona, J., Marsal, J., 2008. Response of peach trees to regulated deficit irrigation during stage II of fruit development and summer pruning. Span. J. Agric. Res. 6, 479–491.

McCutchan, H., Shackel, K.A., 1992. Stem-water potential as a sensitive indicator of water stress in prune trees (*Prunus domestica* L. cv. French). J. Am. Soc. Hort. Sci. 117 (4), 607–611.
Melgarejo, P., 1996. La higuera (*Ficus carica* L). Universidad Politécnica de Valencia. Orihuela, España.
Michailides, T.J., Morgan, D.P., 1998. Spread of Endosepsis in Calimyrna fig orchards. Ecol. Population Biol. 88 (7), 637–647.
Milad, R.E., Shackel, K.A., 1992. Water relation of fruit end cracking in French prune (*Prunus domestica* L. cv French). J. Am. Soc. Hortic. Sci. 117, 824–828.
Nicholson, R.L., 1992. Phenolic compounds and their role in dissease resistance. Ann. Rev. Phytopathol. 30, 369–389.
Opara, L.U., Hodson, A.J., Studman, C.J., 2000. Stem-end splitting and internal ring-cracking of 'Gala' apples as influenced by orchard management practices. J. Hort. Sci. Biotech. 75 (4), 465–469.
Opara, L.U., Studman, C.J., Banks, N.H., 1997. Fruit skin splitting and cracking. Hortic. Rev. 19, 217–262.
Peet, M.M., Willits, D.H., 1995. The role of excess water in tomato fruit cracking. HortScience 30, 65–68.
Prusky, D., 1997. Mechanism of resistance of fruits and vegetables to postharvest diseases. ACIAR Proc. 80, 19–33.
Rab, A., Ul-Haq, I., 2012. Irrigation intervals affect pysiochemical quality attributes and skin cracking in litchi fruit. Turk. J. Agric. 36, 553–562.
Santesteban, L.G., Miranda, C., Royo, J.B., 2011. Regulated deficit irrigation effects on growth, yield, grape quality and individual anthocyanin composition in *Vitis vinifera* L. cv. 'Tempranillo'. Agric. Water Manage. 98, 1171–1179.
Solomon, A., Golubowicz, S., Yablowicz, Z., Grossman, S., Bergma, M., Gottlieb, H.E., Altman, A., Kerem, Z., Flaishman, M.A., 2006. Antioxidant activities and anthocyanin content of fresh fruits of common fig (Ficus carica L.). J. Agric. Food Chem. 54 (20), 7717–7723.
Souza, F.C., Oliveira Ferraz, A.C., 2008. Firmness indexes for quality evaluation of fig fruit. In: International Conference of Agricultural Engineering, Campinas, Brazil.
Turk, R., 1989. The effects of harvest time and precooling on fruit quality and cold storage of figs (*F. carica* L. cv. 'Bursa Siyahi'). Acta Hort. 88, 279–284.
United Nations Economic Comission for Europe (UNECE), 2010. UNECE Standard FFV-17 concerning the marketing and commercial quality control of fresh figs. Accessed on 15 July 2011. http://www.unece.org/fileadmin/DAM/trade/agr/standard/fresh/FFV-Std/English/17FreshFigs_2010.pdf