Quality and physiology of two cultivars of fresh-cut figs in relation to ripeness, storage temperature and controlled atmosphere

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Abstract

The performance of fresh-cut figs was evaluated for two cultivars at two stages of ripeness (commercial and full ripe). Texture, but not external color, was a consistent indicator of ripeness. Fresh-cut figs (maroon-skin 'Brown Turkey' and yellow-green skin 'Sierra' cultivars) were prepared from sanitized fruit halved with a stainless steel knife, and stored in plastic clamshells in air at 0 or 5°C or controlled atmospheres (3% O_2 + 6, 12 or 18% CO_2) at 5°C. Cut pieces retained excellent quality for 6 days under all conditions. After 9 and 12 days, best quality was obtained in air at 0°C and in CA at 5°C with 12 or 18% CO_2, but these atmospheres did result in increased ethanol and acetaldehyde concentrations. Sugars decreased during storage in 'Brown Turkey' but not in 'Sierra' fruit and were different between ripeness stages. Respiration rates of fresh-cut figs were similar to those of intact fruits (4-7 and 8-10 µL CO_2 g^{-1} h^{-1} at 0 and 5°C, respectively). Ethylene production was similar between ripeness stages, but different between cultivars. Loss of visual quality was not associated with discoloration but with microbial growth on the cut surfaces similar to that on the external surface of intact fruits. This was due mostly to molds and CO_2 atmospheres retarded fungal growth. Temperature control was much more important than controlled atmospheres for fresh-cut fig shelf-life. Shelf-life was little affected by ripeness stage but full ripe fruit had higher sugar content. Figs performed well as fresh-cut fruit and could add flavor and diversity to cut fruit trays.

Keywords: color, firmness, sugar, fermentative volatiles, respiration, ethylene

INTRODUCTION

Major factors affecting fresh-cut fruit quality are similar to those of fresh-cut vegetables, such as cultivar, preharvest cultural practices, harvest maturity, post-harvest handling, processing and packaging (Cantwell and Suslow, 2002). However, fresh-cut fruit require additional assessment, usually related to the stage of ripeness at the time of processing to ensure good eating quality from a textural as well as a flavor perspective (Beaulieu and Gorny, 2014). Usually fresh-cut fruit processing involves removing the peel or epidermis, resulting in increased deterioration, softening and microbial decay. For soft fruits such as figs, there is no removal of an outer layer and therefore less processing injury. For fresh-cut figs, the fresh-cut form is likely not much more perishable than the intact fruit (M. Cantwell, unpublished data).

Figs (*Ficus carica* L.) are a delicious and nutritious but perishable fruit (Flaishman et al., 2008). Fresh-cut figs could provide variety to fresh-cut fruit trays. Ripeness at harvest is critical for good flavor quality in figs because sugars do not increase after harvest. Sensory liking of figs is directly related to acid and sugar content which is tied to ripeness at harvest (Melgarejo et al., 2003; Crisosto et al., 2010). Careful harvest to minimize mechanical injury of near ripe fruits and storage near 0°C are good practices for figs (Crisosto and Kader, 2014). Reported storage life varies considerably among fig cultivars (Flaishman et al., 2008; Crisosto and Kader, 2014), with from 1 to 4 weeks cited for fruit held at 0 to 2°C. For fresh

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figs, modified atmospheres and special sanitation treatments can be important to further extend quality and storage life at low temperatures (Colelli et al., 1991; Antunes et al., 2008; Villalobos et al., 2014; Guilleń et al., 2015).

The objectives of this study were to 1) characterize quality of ripeness stages likely to be used for fresh-cut preparation; 2) compare the physiology of intact and fresh-cut figs, and 3) determine quality changes of fresh-cut figs stored at 0 or 5°C in air or controlled atmospheres (CAs).

MATERIALS AND METHODS

Figs ('Brown Turkey' and 'Sierra' cultivars) were harvested twice early in the morning from commercial orchards, transported at ambient temperature to the lab and stored overnight at 0°C. Defective fruits (physical damage, incorrect ripeness, odd color) were eliminated and selected fruits of apparent uniform ripeness (based on external color and firmness, Table 1) were used. Fruit were rinsed with 100 ppm sodium hypochlorite solution (pH 7), drained and air dried under clean conditions at 7.5°C. The equipment used for processing and the storage containers were sanitized by immersion in 100 ppm sodium hypochlorite solution followed by rinsing in distilled water. The fruit were halved with a sharp stainless steel knife on a sanitized cutting board and placed in plastic clamshells.

Table 1. Weight, firmness, external color values, soluble solids, pH and titratable acidity of 'Brown Turkey' and 'Sierra' figs harvested at three ripeness stages. Data are averages of 3 replicates of 8 fruits each. Composition data are expressed on a fresh weight basis. Ripeness stages A and B were used in the fresh-cut fig storage tests.

Ripeness stage	Weight (g)	Firmness (N)	External color			SS (%)	pH	TA (%)
			L*	Chroma	Hue			
'Brown Turkey'								
Under-ripe	49.7	13.1	47.8	19.4	56.2	12.5	5.12	0.38
Commercial (A)	54.9	6.4	46.3	18.6	60.2	14.5	5.31	0.33
Tree ripe (B)	59.7	2.7	39.9	13.9	46.5	17.4	5.44	0.19
'Sierra'								
Under-ripe	44.5	7.9	60.0	36.8	113.7	19.1	5.53	0.26
Commercial (A)	48.6	5.4	63.2	39.0	112.2	20.1	5.62	0.18
Tree ripe (B)	45.0	3.2	67.3	42.3	106.7	23.1	6.11	0.13
LSD.05	3.7	1.3	2.2	2.1	16.9	1.9	0.17	0.05

The clamshells were placed in 20-L polycarbonate containers with a flow of filtered air at 0 or 5°C, and in a second experiment, figs in clamshells were stored in a flow of air at 0 or 5°C or in controlled atmospheres (3% O_2 + 6, 12 or 18% CO_2) at 5°C. Controlled atmospheres were prepared by mixing appropriate volumes of humidified oxygen, nitrogen and carbon dioxide gases in a flow system. Carbon dioxide and oxygen concentrations were determined sequentially on an infrared analyzer (model PIR-2000, Horiba, Kyoto, Japan) and an electrochemical oxygen analyzer (model S-3A, Applied Electrochemistry, Sunnyvale, CA, USA), respectively, and were maintained within 5% of the indicated gas concentrations. Respiration and ethylene production rates were determined on the intact and fresh-cut figs stored in air by measurement of CO_2 on an infrared analyzer and ethylene on a FID GC (Shimadzu Scientific Instruments, Columbia, MD, USA).

Figs at two ripeness stages, likely to be used for fresh-cut products, were characterized for weight, external L*a*b* color values (CR400 Chroma Meter, Minolta Instrument Systems, Ramsey, NJ, USA) with chroma and hue calculated as $(a^{*2}+b^{*2})^{1/2}$ and tan-1 (b*/a*), firmness (N force to compress the fruit 5 mm with a 25 mm flat cylinder on a TA-XT texture analyzer, Texture Technologies, Scarsdale, NY, USA), and composition.

For measurement of soluble solids, pH and titratable acidity, an equal amount of water was added to homogenize the fruit and the resulting slurry was filtered. Soluble solids were measured with a few drops of the filtrate on a digital refractometer, pH was directly determined on a pH meter, followed by titration of 10 mL of filtrate with 0.05% NaOH to an endpoint of pH 8.1, with % TA calculated as citric acid. For sugars, 5 g was frozen at -20°C, and then extracted with 95% ethanol for determination of total sugars by the phenol-sulfuric acid colorimetric method (DuBois et al., 1956) with glucose as a standard. For ethanol and acetaldehyde determinations, 5 g was weighed and placed in test tubes sealed with serum stoppers and stored at -80°C until it was thawed at 0°C and incubated for 1 h in a water bath at 60°C. Samples (0.5 mL) of headspace gas were injected onto a gas chromatograph equipped with a packed glass column containing 5% Carbowax 20M on 60/80 Carbopack as stationary phase, column temperature 85°C, and a flame ionization detector at 250°C. Acetaldehyde and ethanol were detected on the basis of their retention times and quantified by a range of standards of the compounds in water.

For quality evaluations, figs were transferred to room temperature for 1 h. Fresh-cut figs were evaluated after 0, 6, 9 and 12 days storage. Overall visual quality was scored on a 9 to 1 scale, where 9 = excellent, 7 = good, 5 = fair, 3 = poor and 1 = unusable. A score of 6 was considered the limit of salability. Macroscopic decay, off-odor, and other defects were scored on a 1 to 5 scale, where 1 = none, 2 = slight, 3 = moderate, 4 = moderately severe and 5 = severe. Aroma was evaluated on a 5 to 1 scale, where 5 = full, characteristic, 3 = moderate and 1 = complete loss of typical aroma. Aroma and off-odor were evaluated immediately after cutting into the halves with a knife.

Experiments were conducted in a completely randomize design with a minimum of 3 replicates of 6 halves each. Data were analyzed as means ± standard deviation or by ANOVA with mean separation by LSD.05.

RESULTS AND DISCUSSION

Characterization of ripeness stages

Fresh figs that are harvested and packed commercially likely include fruit of different stages of ripeness. Figs were considered commercially ripe when the fruit flesh gave slightly when touched, whereas tree-ripe fruit was riper and softer but not overripe, as described by Crisosto et al. (2010). Fruit that were clearly under-ripe, Stage A at minimum ripeness (commercial ripeness) and Stage B tree-ripe fruit were compared (Table 1). Fruit weight differed among ripeness stages in 'Brown Turkey', but not 'Sierra'. External color values were not sufficiently and consistently different with increasing ripeness to allow for separation of ripeness stages. The % soluble solids increased, and % TA and firmness decreased with advancing stage of ripeness (Table 1). Fruit of commercial ripeness had 14-17% lower sugar concentrations than figs that were tree-ripe (data not shown). Sugars were higher and acidity lower in 'Sierra' than 'Brown Turkey' figs (Table 1). Fruit firmness is a reliable indicator of ripeness stage as previously reported (Crisosto et al., 2010) and would be an important parameter for raw material evaluation for fresh-cut fig processing.

Intact and fresh-cut fruit physiology

Respiration and ethylene production rates were similar for intact and cut figs, but differed with temperature (Figure 1). Rates were similar at both stages of ripeness. Ethylene production was higher for 'Brown Turkey' than for 'Sierra'. Respiration and ethylene production rates were similar to those previously reported (Crisosto and Kader, 2014).

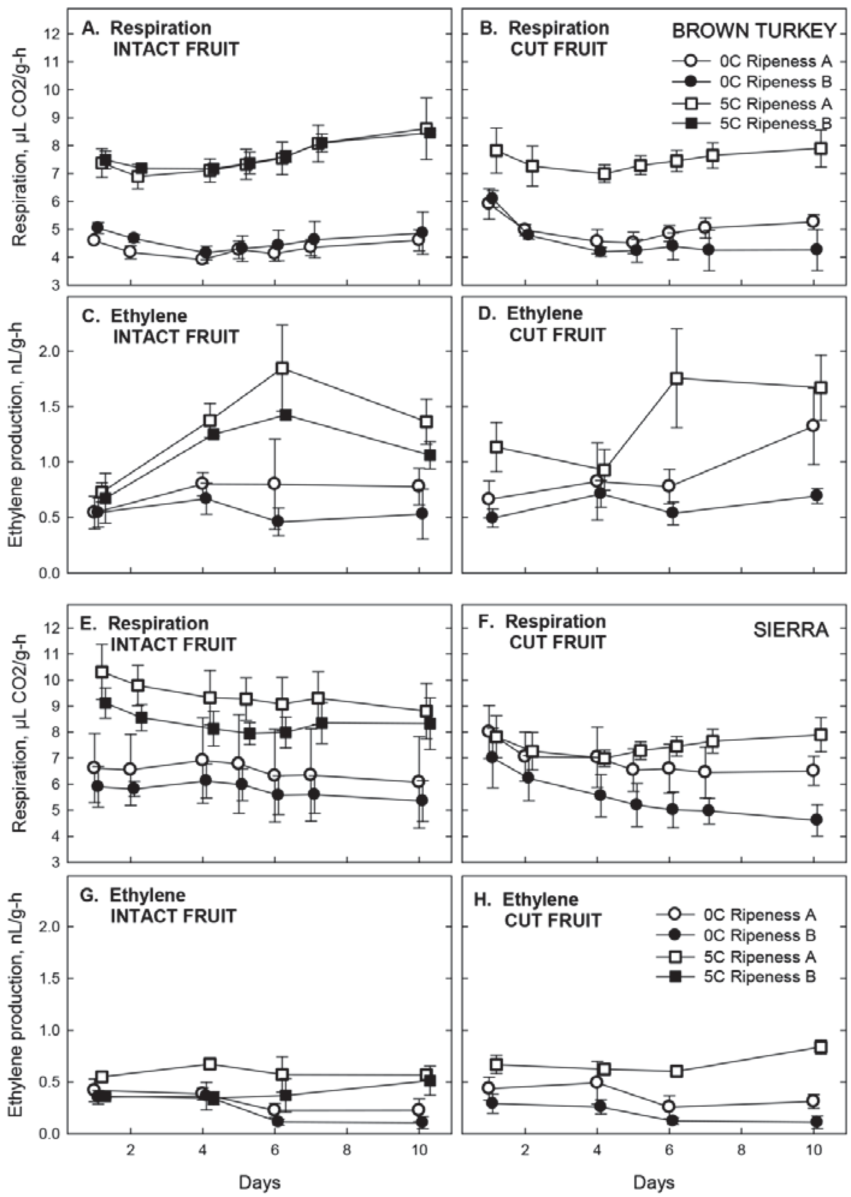

Figure 1. Respiration and ethylene production rates of 'Brown Turkey' (A, B, C, D) and 'Sierra' (E, F, G, H) intact and fresh-cut fruits at two stages of ripeness. See Table 1 for description of ripeness stages. Data are averages of 3 replicates ± SD.

Storage temperatures

Cut figs of both cultivars had excellent quality for 6 days at 0 or 5°C (Table 2). Storing cut figs at 0°C resulted in the highest visual quality scores after days 9 and 12 (Table 2), while storage at 5°C resulted in fresh-cut figs at the limit of marketable quality at 9 days. Ripeness stage had minimal impact on shelf-life. Sugar concentrations of the cut figs decreased significantly in 'Brown Turkey' fruit but not in the 'Sierra' fruit over 12 days (Table 2). At 9 days, the 'Brown Turkey' cut figs had a 14% and 23% decrease in sugar concentrations at 0 and 5°C, respectively (Table 2).

Table 2. Changes in visual quality, decay, discoloration and sugar concentrations of 'Brown Turkey' (BT) and 'Sierra' (S) fresh-cut figs at two stages of ripeness and stored in air at 0 or 5°C. Data are averages of 3 replicates of 6 halves each.

Temp.	Stage	Days	Visual quality		Decay		Discoloration		Sugar (mg g^{-1})	
			BT	S	BT	S	BT	S	BT	S
0°C	A	0	9.0	9.0	1.0	1.0	1.0	1.0	107.2	115.1
		6	9.0	9.0	1.0	1.0	1.0	1.0	98.3	112.3
		9	7.3	9.0	1.0	1.0	1.7	1.0	90.3	119.0
		12	7.0	8.3	1.0	1.0	1.0	1.0	91.6	114.9
0°C	B	0	9.0	9.0	1.0	1.0	1.0	1.0	123.4	140.2
		6	9.0	9.0	1.0	1.0	1.0	1.0	117.1	138.6
		9	7.5	9.0	1.0	1.0	1.7	1.0	110.4	137.3
		12	7.2	8.5	1.0	1.0	1.2	1.0	111.4	142.8
5°C	A	0	9.0	9.0	1.0	1.0	1.0	1.0	107.8	112.0
		6	8.7	9.0	1.0	1.0	1.0	1.0	105.4	117.1
		9	6.0	7.7	1.0	1.0	2.2	1.0	89.6	112.1
		12	4.3	6.0	1.7	1.5	1.7	1.3	85.7	96.8
5°C	B	0	9.0	9.0	1.0	1.0	1.0	1.0	126.9	137.2
		6	8.2	9.0	1.0	1.0	1.0	1.0	115.6	141.3
		9	5.5	6.7	1.0	1.0	2.2	1.3	106.4	126.0
		12	3.2	3.0	1.8	1.0	3.0	2.3	107.7	134.0
LSD.05			0.7	0.6	0.3	0.4	0.4	0.3	18.4	17.0

Controlled atmospheres

Figs of both cultivars at commercial ripeness (Stage A) had excellent quality for 6 days in air or CA (Figure 2). After 9 and 12 days, cut fruit at 0°C was best, but at 5°C atmospheres with 12 or 18% CO_2 maintained good visual quality. These results are consistent with previous fig CA/MA research (Colelli et al., 1991; Villalobos et al., 2012).

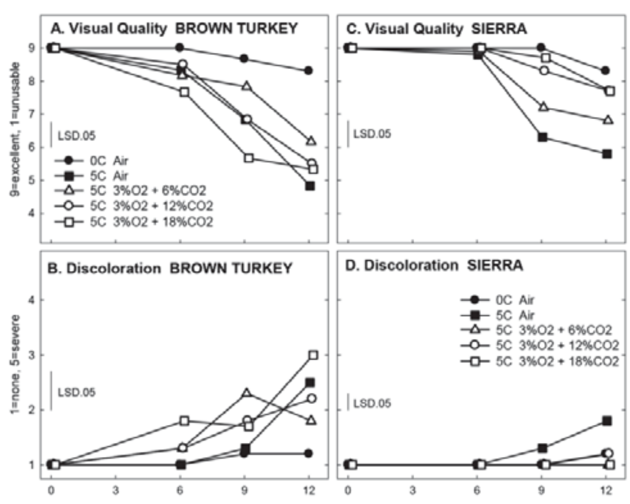

Figure 2. Changes in visual quality and discoloration of 'Brown Turkey' and 'Sierra' fresh-cut figs (Ripeness stage A; commercial ripeness) stored in air at 0 and 5°C or in controlled atmospheres at 5°C. Data are means of 3 replicates of 6 halves each.

There were differences between the two cultivars in response to CA. Decay was minimal over 12 days, but some discoloration was noted in CA treatments. The 12 and 18%

CO_2 atmospheres resulted in increases in fermentative volatiles, especially ethanol (Table 3), but concentrations were relatively low and likely not detrimental (Pesis, 2005). Generally, sugar content decreased less in CA-stored figs at 5°C than air-stored product (Table 3).

Table 3. Total sugar and fermentative volatile concentrations of fresh-cut 'Brown Turkey' (BT) and 'Sierra' (S) figs (Ripeness stage A) stored in air at 0 and 5°C or in controlled atmospheres at 5°C. Data are means of 3 replicates of 6 halves each.

Atmosphere and temperature	Days	Sugar (mg g^{-1} FW)		Acetaldehyde (µmol 100 g^{-1} FW)		Ethanol (µmol 100 g^{-1} FW)	
		BT	S	BT	S	BT	S
Initial	0	108.9	116.2	14.0	12.3	8.3	4.6
Air 0°C	6	104.5	122.9	38.3	81.4	23.1	233.1
	9	94.9	115.9	28.1	104.8	9.3	265.4
	12	92.0	110.8	26.1	75.7	13.0	244.1
Air 5°C	6	94.3	109.0	38.0	44.5	18.0	31.8
	9	84.2	101.0	18.6	33.3	9.2	37.2
	12	83.9	104.0	16.2	45.1	10.9	94.9
3% O_2 + 6% CO_2	6	92.2	121.9	40.3	83.5	115.4	446.4
	9	97.5	121.1	49.1	92.1	175.8	553.5
	12	95.0	115.1	33.8	107.4	180.0	485.2
3% O_2 + 12% CO_2	6	97.6	114.9	52.0	93.2	572.4	610.2
	9	94.5	100.7	38.1	94.3	658.0	751.5
	12	91.7	106.2	40.6	89.8	567.7	708.2
3% O_2 + 18% CO_2	6	93.3	113.4	66.4	98.7	559.0	641.7
	9	94.1	104.9	41.1	150.3	635.8	953.8
	12	92.4	98.2	55.0	99.4	666.4	987.2
LSD.05		14.3	ns	21.5	49.0	82.1	200.9

CONCLUSIONS

Intact and cut figs were similarly perishable. Storing sanitized fresh-cut figs at 0°C was the best option. At 5°C, the high CO_2 atmospheres provided some benefit and cultivar response differed. Although decay was minimal, methods to better sanitize the fruit surface could enhance shelf-life of cut figs. Ripeness at harvest affected fig texture and composition, and this would presumably affect sensory quality of the fresh-cut fruit. Therefore accurate determination of a relatively narrow window of ripeness will be critical to prepare fresh-cut figs with good eating quality as well as good shelf-life.

ACKNOWLEDGEMENTS

This research was partially supported by the California Fig Advisory Board.

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