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Effects of Fruit Ripeness and Storage Temperature on the Deterioration Rate of Fresh-cut Peach and Nectarine Slices

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Abstract. **The effects of fruit ripeness and postcutting storage temperature on the deterioration rate of fresh-cut 'Flavorcrest' peaches and 'Zee Grand' nectarines [*Prunus persica* (L.) Batsch] were investigated. Based on visual quality, peach and nectarine slices from mature-green fruit (>40–53 N flesh firmness) had the longest shelf-life (8 days at 0 °C for peaches and 8 d at 0 , 5 , or 10 °C for nectarines). However, slices from mature-green peaches and nectarines as well as partially ripe peaches (>27–40 N flesh firmness) failed to soften to acceptable eating quality when held at 0 or 5 °C. Slices from overripe peach and nectarine fruit (0–13 N flesh firmness) were organoleptically acceptable at the time of cutting, but based on visual quality had a shelf-life of only 2 days or less (peach) or 3 to 6 days (nectarine) when stored at 0 , 5, or 10 °C. The optimal ripeness for preparing fresh-cut peach slices was the ripe (>13–27 N flesh firmness) stage and these slices at 0 °C and 90% to 95% relative humidity (RH) had a shelf-life of 6 days, while retaining good eating quality. The optimal ripeness for preparing fresh-cut nectarine slices was the partially ripe (>27–49 N) or ripe (>13–27 N flesh firmness) stages and these slices at 0 °C and 90% to 95% RH had a shelf-life of 8 days, while retaining good eating quality.**

Fresh-cut products (mostly vegetables) comprise ≈10% of all produce sold in the United States, and by the year 2000, 25% of all produce sold is expected to be in the fresh-cut form (Vance Publishing, 1996). Traditionally, chilled, ready-to-eat fruit products have been available packed in syrup and preservatives; such products have a shelf-life of up to 24 weeks (Heaton et al., 1969), but do have limited consumer appeal due to off-flavors derived from the use of chemical preservatives. Recently, numerous fresh-cut vegetable processors as well as fruit shippers have begun to produce and market "dry pack" fresh-cut fruit products, such as sliced apples, oranges, grapefruit, strawberries, pineapple, melons, peaches, and mixed fruits. Fresh-cut products offer retail consumers and food service operators convenience, portion control and labor savings. High-quality fresh-cut fruit products are, however, more difficult to produce than fresh-cut vegetable products because many fruits must be ripened before they are processed (Gorny and Kader, 1996). This is an important issue, for eating quality and shelf-life of fresh-cut fruit products are influenced by the stage of ripeness at cutting. Postcutting storage temperature is also an important factor to consider in maintaining quality.

The objectives of our research were to determine the optimum stage of ripeness at cutting and the optimum storage temperature to maximize shelf-life, based on eating quality, of fresh-cut peach and nectarine slices. Also, respiration and ethylene (C_2H_4) production rates were determined to gather baseline information for use in designing modified atmosphere packaging systems for such products.

Materials and Methods

Plant materials and ripening conditions. 'Flavorcrest' peaches and 'Zee Grand' nectarines (70 to 72 count per 11.5-kg box, mean fruit mass = 163 g), picked mature-green, were obtained from a commercial grower/shipper in the Fresno area, Calif., and transported to our laboratory in Davis, Calif. Nectarine fruit were harvested on 6 June and peach fruit on 20 June 1996. Fruit were ripened at 20 °C and 90% to 95% relative humidity (RH) in air + 1000 Pa C_2H_4. Stage or ripeness stage was based on assessing the flesh firmness of 20 fruit in each lot. Whole fruit flesh firmness (penetration force) was determined by measuring the force required for an 8-mm probe to penetrate the cheek of a whole peach or nectarine, with the skin removed, to a depth of 1 cm using a Univ. of California firmness tester (Western Industrial Supply Co., San Francisco). After ripening, fruit were forced air cooled to near 0 °C and held at 0 °C until cut.

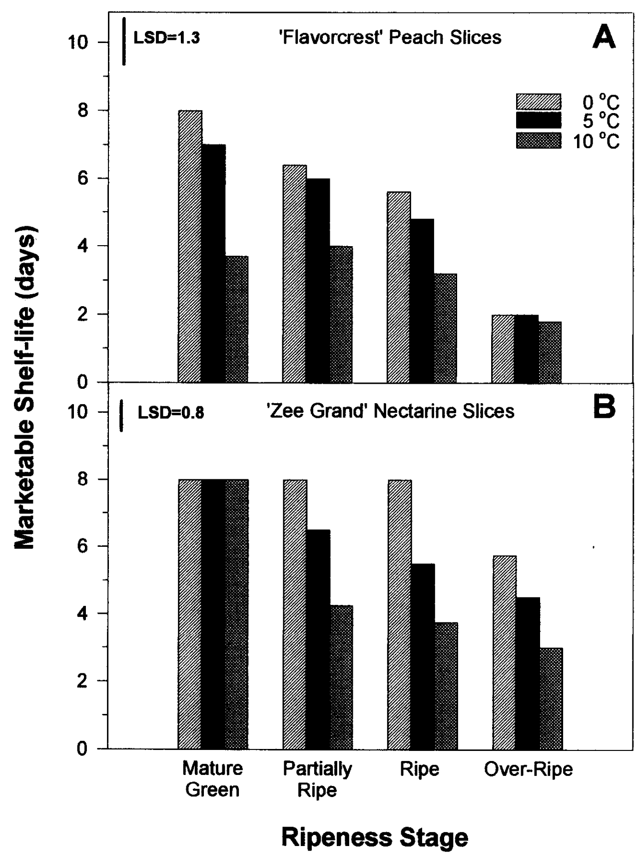

Fig. 1. Effects of ripeness stage and storage temperature on the shelf-life of fresh-cut (**A**) peach and (**B**) nectarine slices, based on the number of days to deteriorate to a quality score of 5 (limit of marketability) on a 1 to 9 subjective (hedonic) scale. Data shown are the means of three replicates. Vertical bar = pooled LSD at the 5% level.

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Fruit ripeness evaluation, cutting, and storage. After ripening and cooling, the firmness of each individual fruit was determined as above. The fruit were then segregated into the following four categories: overripe (0–13 N); ripe (>13–27 N); partially ripe (>27–40 N); and mature-green (>40–53 N). Each fruit was cut into eight slices (wedges) with a sharp stainless steel knife, and the wedge used to determine whole fruit firmness was discarded. Fruit slices were then dipped in 4 °C distilled water with 2.7 $mmol \cdot L^{-1}$ sodium hypochlorite for 2 min, gently dried by hand with cheesecloth, and then placed (20 slices per 2-L jar) at 0, 5, or 10 °C in a continuous flow (50 $mL \cdot min^{-1}$) of humidified air. Each jar of 20 slices was considered a replicate and three replicates were used per treatment.

Quality evaluations. At the start of the experiment, and after 2, 4, 6, and 8 d, peach and nectarine fruit slices were evaluated both objectively and subjectively. The visual quality in each replicate was determined based on the following subjective (hedonic) scale: 9 = excellent, just sliced; 7 = very good; 5 = good, limit of marketability; 3 = fair, limit of usability; and 1 = poor, inedible. A color photograph of slices rated via this scale was used by two or three judges to score slices based on fruit slice color, visible structural integrity and general visual appeal. A weighted average of individual fruit slice quality scores was used to determine the mean visual quality score for each replicate. CIE L*a*b* values were determined with a Minolta chromameter (model CR-200; Minolta, Ramsey, N.J.) calibrated to a white porcelain reference plate (L* = 97.95, a* = –0.39, b* = 2.00). "L*" value (brightness) was used as an indicator of browning intensity (Kuczynski et al., 1992; Lee et al., 1990). Hue angle (h°), calculated as the arctangent (b*/a*), which is effective for visualizing the color appearance of food products (Little, 1975; McGuire, 1992), was employed as an indicator of ripeness. Juice content was determined by the method of Lill and van der Mespel (1988) to assess the ability of slices to ripen. Firmness (penetration force) was determined by measuring the force required for a 3-mm probe to penetrate the cut surface (midpoint between endocarp and skin) slice, held perpendicular to the probe, to a depth of 1 cm using a Univ. of California firmness tester.

Respiration and ethylene production rates. The CO_2 and C_2H_4 production rates of each replicate were determined at the start of the experiment and again after 2, 4, 6, and 8 d. An infrared CO_2 analyzer (model PIR-2000R; Horiba Instruments, Irvine, Calif.) and a gas chromatograph (model 211; Carle Instruments, Anaheim, Calif.) equipped with a flame ionization detector were used to analyze for CO_2 and C_2H_4, respectively.

Results and Discussion

Peaches and nectarines of all ripeness classes had longer shelf-life at 0 °C than at 5 or 10 °C (Fig. 1). Fruit ripeness at cutting had a significant effect on shelf-life, with overripe

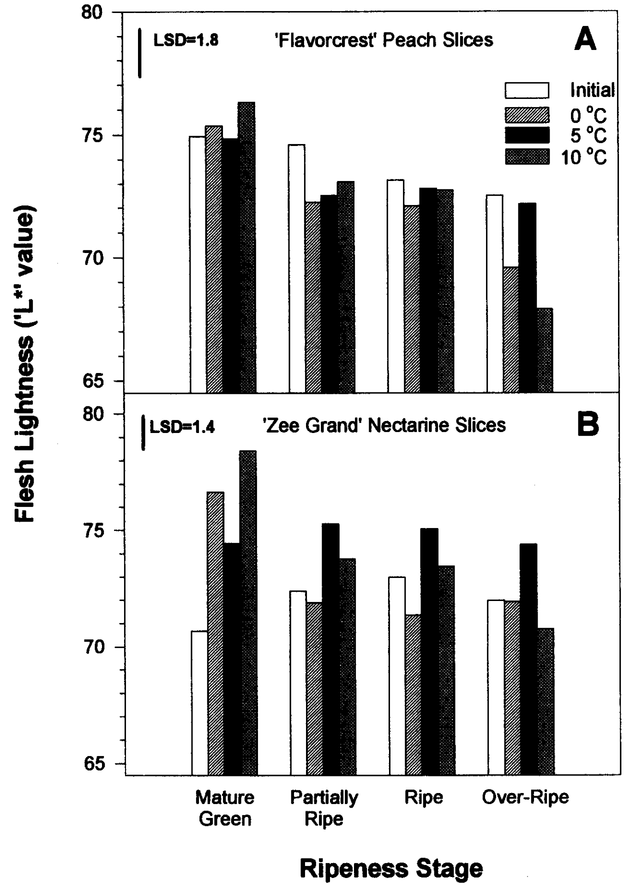

Fig. 2. Effects of ripeness stage and storage temperature on the flesh lightness (L* value) of fresh-cut (**A**) peach and (**B**) nectarine slices initially and after 8 d in storage. Data shown are the means of three replicates. Vertical bar = pooled LSD at the 5% level.

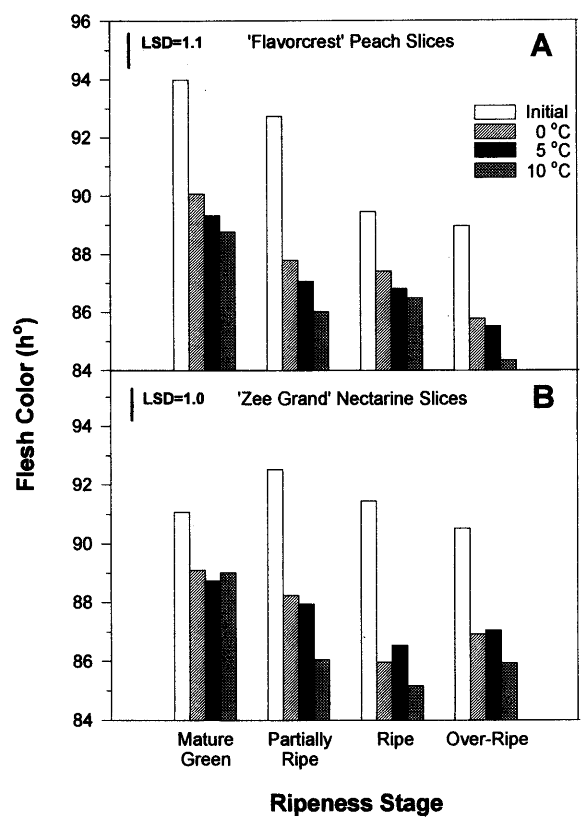

Fig. 3. Effects of ripeness stage and storage temperature on the flesh color hue angle (h°) of fresh-cut (**A**) peach and (**B**) nectarine slices initially and after 8 d in storage. Data shown are the means of three replicates. Vertical bar = pooled LSD at the 5% level.

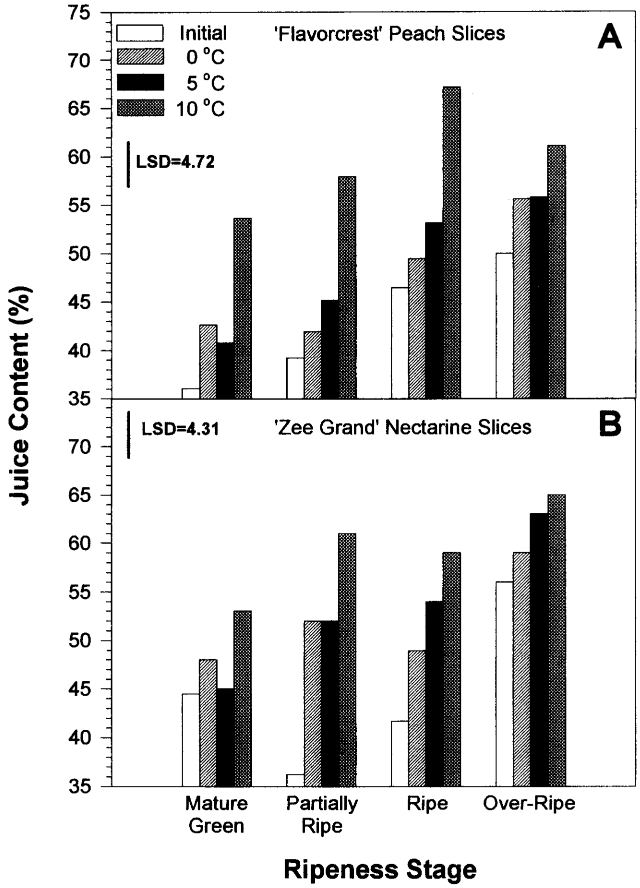

Fig. 4. Effects of ripeness stage and storage temperature on maximum juice content of fresh-cut (**A**) peach and (**B**) nectarine slices initially and during 8 d in storage. Data shown are the means of three replicates. Juice content (%) represents g juice expressed per 100 g fresh mass. Vertical bar = pooled LSD at the 5% level.

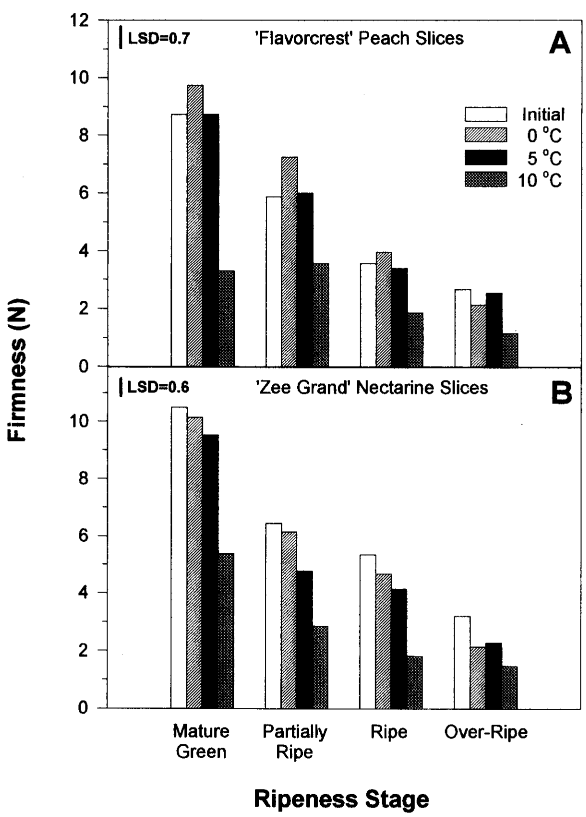

Fig. 5. Effects of ripeness stage and storage temperature on the flesh firmness (penetration force) of fresh-cut (**A**) peach and (**B**) nectarine slices initially and after 8 d in storage. Data shown are the means of three replicates. Vertical bar = pooled LSD at the 5% level.

slices having the shortest shelf-life (2 d for peaches and 3 to 6 d for nectarines), and the least ripe mature-green slices the longest shelf-life, based on visual quality (8 d at 0 °C for peaches and 8 d at 0, 5, or 10 °C for nectarines). Shelf-life at 10 °C was generally about half of that at 0 °C.

Storage temperature had little effect on the overall enzymatic browning intensity, as indicated by the lightness (L*) value, in the slices made from mature-green, partially ripe, and ripe peaches (Fig. 2A). Slices from overripe peaches held at 0 and 10 °C exhibited the most intense enzymatic browning of all ripeness classes tested, and discoloration was most severe at 10 °C. Partially ripe, ripe, and overripe nectarine slices exhibited significantly greater increases in cut surface lightness (L*) at 5 °C than at 0 and 10 °C (Fig. 2B). Slices of both species, irrespective of fruit ripeness stage at cutting, exhibited loss of sheen and gloss at the cut surface, and the symptoms appeared similar to those of white blush or chalking found in fresh-cut peeled carrots (Cisneros-Zevallos et al., 1995). Mature-green and partially ripe nectarine slices, as well as mature-green peach slices, increased in lightness (L*) during 8 d in storage. We propose that localized dehydration of ruptured cells at the cut surface is the cause of this problem in peach and nectarine slices just as in minimally processed carrots, since the total loss in mass by the slices was <0.2% over 8 d.

Storage temperature had a significant effect on the ability of slices to continue ripening, as indicated by the cut surface flesh hue angle (h°) in slices from mature-green, partially ripe, and ripe fruit (Fig. 3). Lower hue angle values indicate a less green, more yellow flesh color. At all ripeness stages, peach slices attained the lowest hue angle when held at 10 °C and the highest when held at 0 °C (Fig. 3A). After 8 d at 0, 5, or 10 °C mature-green peach slices attained hue angle values equivalent to the initial values of ripe or overripe slices. Nectarine slices cut from ripe stage fruit and held at 10 °C attained the lowest hue angle values among all ripeness classes tested (Fig. 3B). After 8 d at 0, 5, or 10 °C mature-green ripeness class nectarines had significantly higher hue angle values than did ripe or overripe fruit.

Ripe peach slices held at 10 °C attained the highest, and mature-green slices held at 5 °C, the lowest juice content (Fig. 4A). Irrespective of ripeness stage at cutting, peach and nectarine slices kept at 10 °C had a higher juice content than those held at either 0 or 5 °C (Fig. 4). Mature-green and partially ripe peach slices held for 8 d at 0 or 5 °C had significantly lower juice content than those held at 10 °C; this lack of juiciness may indicate poor overall eating quality. Partially ripe, ripe, and overripe class nectarine slices stored at 5 or 10 °C attained significantly higher juice contents than mature-green fruit slices held at 0 or 5 °C (Fig. 4B).

For all ripeness stages, peach and nectarine slices held at 10 °C lost firmness most rapidly (Fig. 5). Firmness of mature-green and partially ripe peach fruit slices stored at 0 and 5 °C

Table 1. Range of CO_2 and C_2H_4 production rates by peach and nectarine slices during 8 d of storage at indicated temperatures.

	Respiration rate[z] (nmol $CO_2\cdot kg^{-1}\cdot s^{-1}$)			Q_{10}	C_2H_4 production rate[y] (pmol$\cdot kg^{-1}\cdot s^{-1}$)			Q_{10}
Ripeness stage	0 °C	5 °C	10 °C	(0–10 °C)	0 °C	5 °C	10 °C	(0–10 °C)
Peaches								
Mature-green	37–50	75–100	211–236	4.7–5.7	12–37	50–112	273–670	18.1–22.8
Partially ripe	50–62	75–112	249–323	5.0–5.2	12–25	74–211	397–918	33.1–36.8
Ripe	50–62	112–137	224–659	4.5–10.6	12–37	124–285	434–1153	31.1–36.1
Overripe	62–75	100–286	311–572	5.0–7.6	25–50	36–285	918–1129	22.6–36.7
Nectarines								
Mature-green	25–37	75–87	124–286	5.0–7.7	1–3	12–37	87–334	73.0–134
Partially ripe	37–62	87–112	236–1007	6.4–16.2	12–25	50–149	285–930	23.8–37.2
Ripe	37–62	100–112	174–945	4.7–15.2	12–25	87–186	347–1079	27.5–28.9
Overripe	50–75	112–137	323–1132	6.5–15.1	12–37	74–236	558–1029	27.8–46.5

[z]To convert (nmol $CO_2\cdot kg^{-1}\cdot s^{-1}$) to (mg $CO_2\cdot kg^{-1}\cdot h^{-1}$) multiply by 0.080406.
[y]To convert (pmol $C_2H_4\cdot kg^{-1}\cdot s^{-1}$) to (mL $C_2H_4\cdot kg^{-1}\cdot h^{-1}$) multiply by 0.08064.

increased slightly during 8 d in storage (Fig. 5A), as reported for whole peach fruit that were returned to low temperatures after softening at room temperature (Werner et al., 1978). Firmness of ripe and overripe peach fruit slices stored at 0 or 5 °C changed little over 8 d (Fig. 5A). Lower storage temperatures significantly reduced firmness loss in mature-green, partially ripe, and ripe nectarine slices (Fig. 5B), but had little effect on reducing the softening of overripe slices.

Respiration rates generally increased with both fruit ripeness at cutting and storage temperature (Table 1). High Q_{10} values between 0 and 10 °C among all of the ripeness classes tested (Table 1) demonstrated that respiration is very susceptible to temperature abuse in fresh-cut peach and nectarine slices and even small increases in temperature will dramatically increase respiration rates.

Rates of C_2H_4 production also generally increased with fruit ripeness stage and storage temperature (Table 1). Slices held at 10 °C produced large amounts of C_2H_4, but storage at 0 or 5 °C greatly reduced the rates at all ripeness stages (Table 1).

The following criteria must be used to determine the optimal ripeness stage of whole fruit to use in preparing fresh-cut peach and nectarine slices: 1) maximum shelf-life of slices based on visual quality, and 2) acceptable eating quality of slices. Our data indicate that the optimal ripeness stages are ripe (>13–27 N) for peach and partially ripe (>27–49 N) or ripe (>13–27 N) for nectarine. These peach and nectarine slices, when held at 0 °C in 90% to 95% RH, had a shelf-life of 6 and 8 d, respectively, while retaining good eating quality [based on flesh hue angle (h°), juice content, and flesh firmness]. The efficacy of physical and chemical treatments to extend the shelf-life of fresh-cut peaches and nectarines warrants further investigation.

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