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Increasing 'Blackamber' plum (*Prunus salicina* Lindell) consumer acceptance

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Abstract

'Blackamber' plum (*Prunus salicina* Lindell) consumer acceptance and market life were highly dependent on harvest date. For fruit within the most common industry ripe soluble solids concentration (RSSC) range (10.0–11.9%), ripe titratable acidity (RTA) played a significant role in consumer acceptance. Plums within this RSSC range combined with low RTA ($\leq$0.60%) were disliked by 18% of consumers, while plums with RTA $\geq$1.00% were disliked by 60% of consumers. Plums with RSSC $\geq$12.0% had $\sim$ 75% consumer acceptance, regardless of RTA. Fruit harvested between 35.6 and 17.8 N had high consumer acceptance because of lower RTA and higher RSSC than earlier harvested fruit. Ripening plums before consumption decreased TA by approximately 30% from the TA measured at harvest. In some cases, this decrease in TA during ripening may increase the acceptability of plums that would otherwise be unacceptable.

Development of chilling injury (CI) symptoms limited market life of fruit harvested early (44.5–35.6 N) and late (17.8–13.3 N). Late harvested fruit were more likely to develop flesh translucency (overripe or bladderiness) when stored at 5 °C, whereas early harvested fruit had low consumer acceptance and were more prone to develop flesh bleeding/browning during storage at 0 or 5 °C.

Based on this work, 'Blackamber' plums are well adapted to late harvest but proper postharvest temperature management, including ripening, and marketing within its market life potential are necessary to avoid the onset of storage disorders and maintain flavor.

Keywords: In store consumer test; Fruit quality; Market life; Flesh browning; Gel breakdown; Flesh translucency; Chilling injury

1. Introduction

Plums (*Prunus salicina* Lindell) have the potential to contribute greatly to human nutrition because of their richness in fiber and antioxidants (Kim et al., 2003; Stacewicz-Sapuntzakis et al., 2001). Despite news of

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their benefits to human health, consumption of plums in the USA has remained very low, averaging only 0.64 kg per capita per year over the last 22 years (US Department of Agriculture, 2003). This low rate of consumption has been attributed to a lack of fruit ripening before consumption, poor flavor, and internal flesh problems attributed to chilling injury (CI) (Bruhn et al., 1991). Plums are susceptible to chilling injury (Abdi et al., 1997; Crisosto et al., 1999; Dodd, 1984; Robertson et al., 1991; Taylor et al., 1993, 1994, 1995) similar to many peaches and nectarines (Mitchell and Kader, 1989; Smith, 1934; Von Mollendorff, 1987). We believe that plum consumption may increase by offering fruit that are tasty, ripe and free of chilling injury.

Fruit maturity controls quality attributes, such as soluble solids concentration (SSC), titratable acidity (TA), firmness, and market life potential (Crisosto et al., 1995). In general, ripe soluble solids concentration (RSSC) and ripe titratable acidity (RTA) determine consumer acceptance. Fruit softening (loss of firmness) is related to bruising susceptibility and is an important factor when considering the latest date fruit can be successfully harvested. Unfortunately, there is no detailed information available on the role of maturity in both CI and consumer acceptance for plums (Abdi et al., 1997; Dodd, 1984; Taylor et al., 1993).

The objective of this work was to determine the ideal harvesting period for ‘Blackamber’ plums based on consumer acceptance and market life potential in order to increase plum consumption. ‘Blackamber’, a black, high acid plum was used in this work because it is highly susceptible to CI (Crisosto et al., 1999) and has a reputation for low consumer acceptance within the trade.

2. Materials and methods

During the 2002 season, studies to understand the relationship between plum maturity, consumer acceptance and market life were carried out using mature ‘Blackamber’ Japanese plum (*P. salicina* Lindell) trees growing at the Kearney Agricultural Center (Parlier, CA). The trees were planted on 1.8 × 5.5 m spacing and trained to a two leader perpendicular Kearney “V” conformation. Five replications of six trees each were selected for this study, and these trees received standard commercial horticultural care throughout the growing season. Fruit were harvested for quality, storage and sensory analysis on June 20, June 26, July 2 and July 8. On each harvest 25 fruit were selected from each tree and these combined within each replication to yield 150 fruit per replication per harvest date.

2.1. Quality attribute measurements

Ten fruit from each of the five replications on each harvest date (June 20, June 26, July 2 and July 8) were used to determine fruit mass (g), flesh color, soluble solids concentration, titratable acidity, and flesh firmness. After weighing the fruit with an electronic balance, the skin was removed from both cheeks, the tip, suture and shoulder using a vegetable peeler. Flesh color was measured on both cheeks with a Minolta colorimeter (Minolta, CR-200, Japan) and is expressed as hue angle (h°), lightness (L*) and chroma (saturation) according to the Commission Internationale de l’Eclairage (CIE). Next, at each position where the skin had been removed flesh firmness was measured using a UC firmness tester with a 7.9 mm tip. Then, a longitudinal wedge (from stem end to calyx end) was removed from each fruit, pressed through cheesecloth, and the SSC of the juice was measured with a temperature compensated refractometer (model ATC-1, Atago Co., Tokyo, Japan). Juice from each replication was pooled to form a composite sample, and TA was measured with an automatic titrator (Radiometer, Copenhagen, Denmark). All fruit quality data was subjected to analysis of variance (ANOVA) prior to the LSD mean separation using the SAS program.

2.2. Market life evaluations

To measure market life potential, another 120 fruit from each replication on each sampling date were subdivided into two storage treatments with 60 fruit stored at 0 °C (85% RH) and 60 fruit at 5 °C (85% RH). Plums were stored under these conditions for up to 6 weeks according to our previously published protocol (Crisosto et al., 1999). After 2, 4 and 6 weeks storage, 20 fruit per replication were removed from each storage temperature and warmed to 20 °C. Flesh firmness of 10 fruit per treatment-replication was evaluated immediately as previously described. The remaining 10 fruit per treatment-replication were ripened at 20 °C and 85% RH until flesh firmness reached 8.9–17.8 N. Extra fruit

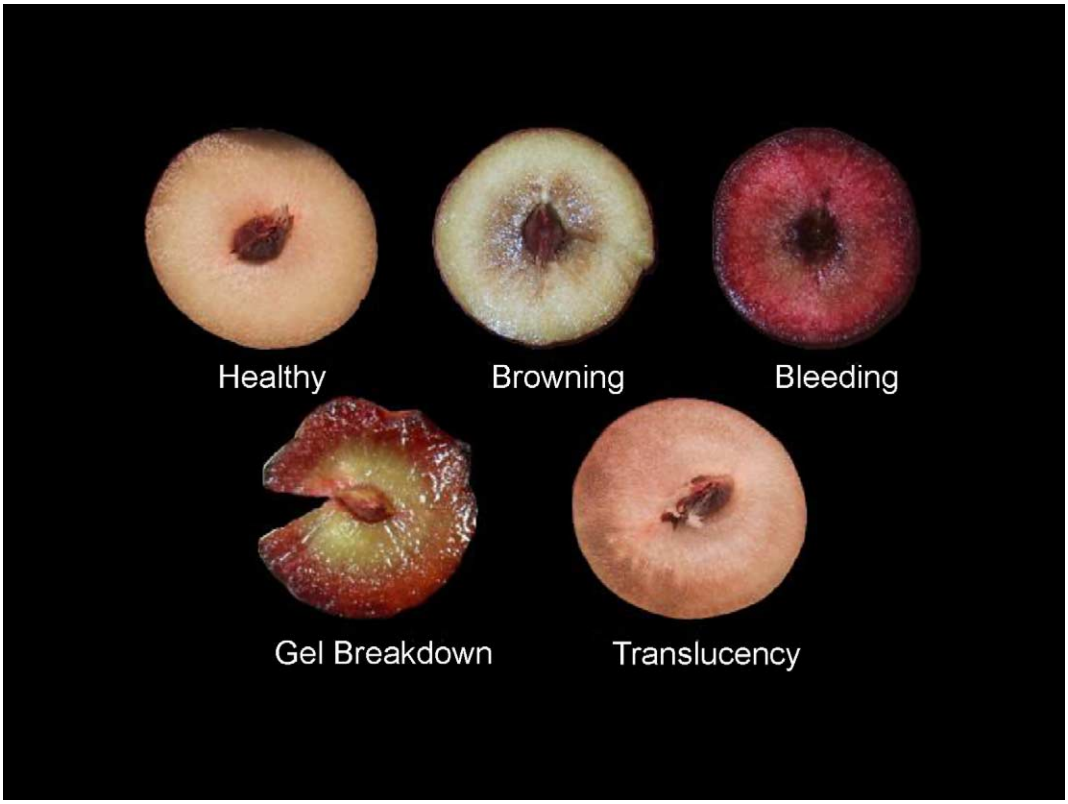

Fig. 1. 'Blackamber' plum chilling injury symptoms observed during cold storage: flesh browning, flesh bleeding, gel breakdown, flesh translucency (overripe or bladderiness).

samples from each treatment were used to determine the end of the ripening period for each treatment. When ripe, chilling injury symptoms, such as gel breakdown, flesh browning, flesh bleeding, and flesh translucency (overripe or bladderiness) were visually evaluated immediately after cutting fruit in half (Fig. 1). Fruit were determined to have gel breakdown when the tissues between the pit and the middle of the mesocarp were soft, translucent, and lacking in juice when squeezed. Flesh browning was evaluated as a brown coloration originating near the pit and extending out into the flesh. Flesh bleeding was evaluated as an accumulation of red pigment either around the stone or immediately beneath the epidermis. Plum flesh translucency occurred as "water soaked" areas observed mainly in the outer mesocarp immediately under the epidermis as a consequence of the fruit being overripe. In these translucent areas, the vascularization within the otherwise clear tissues could easily be observed. In some fruit, translucent areas were also observed within the inner mesocarp, but in most of these cases these tissues turned brown or formed gel.

Plums that had a dry appearance and little or no juice expressed upon hand squeezing were considered mealy. These fruit were also informally tasted for a feeling of mealiness (like sand in the mouth) and/or "off flavors" to corroborate visual assessment. Fruit that remained hard after ripening and from which little or no juice could be expressed upon hand squeezing were considered leathery.

Market life potential, based on losses as a consequence of CI symptoms, was subjectively defined as the number of weeks each cultivar could be stored at 0 °C (maximum) or 5 °C (minimum) before CI became limiting (Crisosto et al., 1999). The end of market life was determined to occur when more than 25% of the fruit had symptoms of chilling injury as described by Mitchell and Kader (1989).

2.3. 'In-store' consumer test

An 'in-store' consumer test was conducted in which 100 consumers were surveyed in a major supermarket in Fresno Co., CA. Each consumer was presented four ripe 'Blackamber' plum samples—one sample from each harvest date—as previously described (Crisosto and Crisosto, 2001). At the supermarket, the SSC of each fruit was measured as previously described and the fruit were separated into the following four classes: 8.0–9.9%, 10.0–11.9%, 12.0–13.9%, >13.9%. In this way each consumer was presented fruit samples representing the entire range of SSC. A portion of juice from each fruit was also frozen for analysis of TA in the laboratory. The ripe soluble solids concentration and ripe titratable acidity were measured for each fruit presented to the consumers and correlated with their response. This technique reduces the error that results from fruit to fruit variability that is masked when using average RSSC and RTA values. For each fruit sample, the consumer was asked to taste it, then to indicate if he/she "likes", "neither likes nor dislikes", or "dislikes" the sample. Then, the consumer was asked to indicate his/her degree of liking/disliking: slightly, moderately, very much, or extremely. The consumer's response was recorded using a 9-point hedonic scale (1-dislike extremely to 9-like extremely). Consumer acceptance was measured as both degree of liking (1–9) and percentage acceptance. Percentage acceptance was calculated as the number of consumers liking the fruit sample (score > 5.0) divided by the total number of consumers within that sample (Lawless and Heymann, 1998). In a similar way the percentage of consumers disliking and/or indifferent to that sample was calculated. The degree of liking data was subjected to analysis of variance prior to the LSD mean separation using the SAS program.

3. Results and discussion

3.1. Quality attributes

At harvest time and during storage, flesh firmness did not differ between positions of measurement on the fruit. During the harvesting period, flesh firmness decreased from 44.9 to 12.9 N during this period of ripening "on" the tree. Fruit fresh mass increased significantly until the third harvest date, but not significantly thereafter (Table 1). Fruit flesh color measured as hue angle and L* decreased significantly during the harvesting period. This indicates that the flesh color became less pale green and lighter yellow during this period of ripening "on" the tree. In our previous work, we found that flesh color is a better indicator of maturity than other fruit quality parameters including skin color (Crisosto, 1998). In fact, in 'Blackamber' plum the skin color becomes completely dark purple relatively early during maturation before the beginning of the commercial harvest period.

SSC and TA measurements changed significantly during "on" the tree ripening. SSC increased from 10.3% on June 20 to 11.9% on July 8, while TA decreased significantly from 1.15% to 0.42% during this

Table 1
'Blackamber' plum fruit size, flesh firmness and flesh color measured at harvest; and soluble solids concentration (SSC), titratable acidity (TA as % malic acid) and sugar-to-acid ratio (SSC:TA) measured at harvest and on ripe fruit collected on different harvest dates

Harvest date	At harvest								After ripening[a]		
	Fruit mass (g)	Cheek firmness (N)	Flesh color			SSC (%)	TA (%)	SSC:TA	SSC (%)	TA (%)	SSC:TA
			L*	Chroma	Hue angle						
Harvest 1 (6/20/02)	109.2	31.58	67.9	28.8	100.3	10.3	1.15	9.2	10.3	0.78	13.2
Harvest 2 (6/26/02)	118.0	23.13	67.5	28.9	95.7	10.6	0.70	14.2	10.8	0.47	23.8
Harvest 3 (7/2/02)	121.4	16.01	64.6	28.5	89.2	11.7	0.50	24.2	11.7	0.43	27.4
Harvest 4 (7/8/02)	122.3	12.90	62.8	28.3	85.7	11.9	0.42	28.2	12.3	0.33	37.5
P-value	<0.0001	<0.0001	0.0001	0.6640	0.0001	0.0001	<0.0004	<0.0022	<0.0092	0.0001	0.0001
$LSD_{0.05}$	4.1[b]	2.22	1.4	NS	0.8	0.5	0.24	3.7	1.09	0.06	3.7

[a] Fruit ripened at 20 °C and 85% RH until flesh firmness reached 8.9–17.8 N.
[b] Mean separation by LSD test at $P > 0.05$.

same period of time. This resulted in a significant increase in the sugar-to-acid ratio (SSC:TA) from 9.2 on June 20 to 28.2 on July 8. SSC did not change significantly during the ripening process; however there was an approximate 30% reduction in TA during ripening (Table 1). As TA decreased during ripening and SSC did not change, the ripe SSC:TA ratio increased from 13.2 for fruit harvested June 20 to 37.5 for fruit harvested July 8. Acidity, skin astringency and firmness decrease during ripening while aroma develops contributing to an increase in consumer acceptance (Crisosto, 1999; Meredith et al., 1992). In a previous maturity study conducted in the same 'Blackamber' research plot in 1989 (Mitchell, 1990), cheek firmness decreased from 46.70 N on the first harvest date (June 11) to18.25 N on the last (July 2). SSC increased from 8.6% to 11.3% during this same period of time. As in our study, fruit size did not increase after the third harvest date (June 25).

Our previous work (Crisosto et al., 2001) demonstrated that 'Blackamber' plums, which are more susceptible to impact bruising than 'Fortune', 'Royal Diamond' and 'Angeleno' plums, with flesh firmness ≤13.3 N exposed to impact forces of 245 X G (simulating impacts occurring during standard packingline operations) were susceptible to bruising injury. Plums with flesh firmness >13.34 N were highly resistant to impact injury.

3.2. Market life potential

Different expressions of CI, such as flesh browning, flesh mealiness, gel breakdown, flesh translucency (overripe or bladderiness), and flesh bleeding were observed during cold storage (Fig. 1). The onset of these symptoms was associated with fruit maturity and storage temperature. The onset of CI symptoms was delayed when fruit were stored at 0 °C rather than at 5 °C. Maturity affected market life of 'Blackamber' plums when stored at either 0 or 5 °C. Fruit harvested on the first harvest date (June 20) had a shorter market life than fruit harvested later (Table 2). Maximum market life was 3 weeks shorter for fruit harvested on the earliest date than for fruit harvested on any of the later dates. The predominant CI symptoms that developed at 0 °C were flesh mealiness and flesh bleeding/browning. Minimum market life was only 2 weeks for fruit harvested on June 20, June 26 and July 8; and 3 weeks for fruit harvested on July 2. For all four harvests, flesh bleeding/browning and gel breakdown/translucency limited minimum market life. In addition, for the two later harvests mealiness was limiting at 5 °C. Thus, early harvested fruit had a short market life (up to 2 weeks) under both storage temperatures. Late harvested fruit had limited market life (up to 3 weeks) only when stored at 5 °C. These results agreed with our previously reported findings that the onset of CI symptoms occurred after 5 and 2 weeks in California grown 'Blackamber' plums stored at 0 and 5 °C, respectively (Crisosto et al., 1999).

Table 2
Market life of 'Blackamber' plums harvested on four different dates then stored at 0 or 5 °C

Harvest date	Maximum market life[a] (weeks at 0 °C)	Minimum market life (weeks at 5 °C)
Harvest 1 (6/20/02)	2[2,3]	<2[3,4]
Harvest 2 (6/26/02)	5[3]	2[3,4]
Harvest 3 (7/2/02)	5[3]	3[1,3,4]
Harvest 4 (7/8/02)	5[3]	2[1,3,4]

[a] End of market life based on chilling injury (CI) determined when ≥25% of the fruit became mealy[1] or leathery[2], or had flesh bleeding/browning[3] or gel breakdown/translucency[4]. Superscript indicates limiting condition.

Previous research in South Africa (Hartmann et al., 1988) pointed out that 'Songold' plum tissue breakdown occurred immediately under the fruit's epidermis. In other work carried out in Australia on 'Radiant', 'Gulfruby' and 'Shiro' plums, it was concluded that early harvested fruit had poor quality and late harvested fruit were more susceptible to CI (Abdi et al., 1997).

3.3. In store consumer test

Degree of liking was significantly related to RSSC, RTA and the RSSC:RTA. RSSC ranged from 8.0 to 18.0% with a mean of 12.0%, and RTA ranged from 1.21 to 0.15% with a mean of 0.62% within the population of fruit used in this consumer test. Based on industry-wide fruit quality surveys over the previous 5 years, the average RSSC has ranged from 10.8 to 11.7% (data not shown). There was a significant interaction between RSSC, RTA and degree of liking. For this reason, data were further analyzed using three levels of RTA (Table 3). Within this range of quality attributes 'Blackamber' plums were liked from "dis-

Table 3
Acceptance of 'Blackamber' plums by American consumers at different levels of ripe soluble solids concentration (RSSC) and ripe titratable acidity (RTA) measured as percentage malic acid

Quality attributes	Degree of liking (1–9)[a]	Acceptance (%)	Neither like nor dislike (%)	Dislike (%)
RTA ≤ 0.60%				
RSSC < 10.0%	4.7	32.3	29.0	38.7
RSSC 10.0–11.9%	6.2	56.4	25.6	17.9
RSSC 12.0–13.9%	6.9	68.9	26.2	4.9
RSSC ≥ 14.0%	7.8	88.6	10.1	1.3
RTA 0.61–0.99%				
RSSC < 10.0%	4.8	24.6	40.4	35.1
RSSC 10.0–11.9%	5.3	34.5	36.5	28.8
RSSC 12.0–13.9%	6.3	61.1	25.0	13.9
RSSC ≥ 14.0%	7.3	85.7	9.5	4.8
RTA ≥ 1.00%				
RSSC < 10.0%	3.7	8.3	33.3	58.3
RSSC 10.0–11.9%	3.3	11.1	22.2	66.7
$LSD_{0.05}$	1.1[b]	–	–	–
P-value	0.0001			

[a] Degree of liking: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.
[b] Mean separation by LSD test at $P > 0.05$.

liked moderately" (mean score = 3.3) to "liked very much" (mean score = 7.8) and consumer acceptance increased from 8.3 to 88.6%. RTA did not affect degree of liking when plums had RSSC ≥12.0%. Plums with RSSC ≥12.0% were always "liked slightly" (mean score = 6.3) to "liked very much" (mean score = 7.8) by consumers. However, when plums had RSSC of 10.0–11.9%, RTA played a significant role in consumer acceptance. Plums with RSSC of 10.0–11.9%, combined with low (≤0.60%) or moderate (0.61–0.99%) RTA, were "liked slightly" (mean score = 6.2) to "neither liked nor disliked" (mean score = 5.3) with an acceptance of 56.4% and 34.5%, respectively. 'Blackamber' plums with RSSC of 10.0–11.9% combined with a RTA ≤0.60% had a degree of liking similar to plums with RSSC of 12.0–13.9%. 'Blackamber' plums with RSSC of 10.0–11.9% and a RTA ≥1.00% had the lowest degree of liking—"disliked moderately" (mean score = 3.3) and had a consumer acceptance similar to plums with a RSSC <10.0% and RTA ≥1.00%. Plums with RSSC <10.0% had the lowest level of consumer acceptance regardless of RTA. The percentage of consumers that chose the "dislike" option ranged from 1.3 to 66.7% and this was also related to RSSC and RTA. The percentage of consumers that chose the "dislike" option is high in comparison to other commodities and it may be explained by a potential bias against dark colored plums. For plums which had RSSC ≥12.0%, disregarding RTA, the percentage of consumers that chose the "neither like nor dislike" option was approximately 18%. Less than 7% of the consumers disliked these fruit.

Studies have associated high consumer acceptance of fruit with high soluble solids concentration in peaches (Testolini, 1995; Hilaire, 2003), and sweet cherries (Crisosto et al., 2003). However, consumer acceptance was more closely related to SSC:TA than SSC alone within a given range of RSSC for early 'Hayward' kiwifruit (Crisosto and Crisosto, 2001), and early 'Redglobe' table grapes (Crisosto and Crisosto, 2002). A similar situation was observed in this plum cultivar. When RSSC was ≥ 12.0%, consumer acceptance was not dependent on RSSC:RTA but when RSSC was ≤ 12.0%, SSC influenced consumer responses.

3.4. Conclusions

'Blackamber' is a plum cultivar that is well suited to late harvesting because of its low susceptibility to bruising during postharvest handling operations, such as harvesting, packing and transportation (Crisosto et al., 1999). This recommendation should be extended to other Japanese plums, such as 'Fortune', 'Friar', 'Royal Diamond', and 'Angeleno', that are even less likely to bruise during postharvest operations. Our work suggests the use of firmness as an indicator of how late to safely harvest ("Tree Ripe"), thereby maximizing orchard quality for other plum cultivars too. However, the decision when to harvest should also take into account other factors, such as fruit drop, environmental conditions, hand labor availability, market prices, distance to market, potential transportation damage, and temperature management at the receiving location.

To maximize flavor and storage potential, 'Blackamber' plums should be harvested when they reach a minimum SSC within the range of 10–12% and a titratable acidity $< 0.70\%$, but with a firmness ≥ 14.0 N. Any fruit in the population with firmness ≤ 14.0 N will likely be bruised during standard postharvest operations. This work also pointed out the need for plum ripening at the production site prior to shipment as it has been recommended for peaches (Crisosto et al., 2004) or at the warehouse before retail display (Crisosto, 1999). Our ongoing sensory work on plum, peach and nectarine cultivars suggested that the relationship between consumer acceptance and quality attributes will be cultivar dependent, thus, the establishment of a minimum quality index based on SSC or SSC:TA needs to be evaluated for each cultivar. Also, plums should be marketed and consumed within their potential market life. This information provides guidance for growers, packers, shippers, handlers and retailers in designing their postharvest strategy to increase plum consumption.

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