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THE POTENTIAL FOR BELL PEPPER HARVEST PRIOR TO FULL COLOR DEVELOPMENT

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Abstract. **'Triple 4' (red cultivar) and 'Kelvin' (yellow cultivar) bell peppers (*Capsicum annuum* L.) were greenhouse-grown and harvested during two distinct seasons. Harvest 1 (February, 1999) occurred during short photoperiods and cooler daytime temperatures, and Harvest 2 (May) during longer photoperiods and warmer days. Peppers were picked with 10 to 30% color (Stage 3) and 100% color (fully ripe). Fruits of each variety at Stage 3 were also tagged and left to ripen on the plants. Harvested peppers were stored at 20°C and 90% relative humidity (RH) +/- continuous exposure to ethylene gas (100 ppm) using a flow-through system. Both cultivars of peppers ripened off the plant had similar appearance and compositional quality to those ripened on the plant. Red peppers harvested at the onset of color change developed full color faster in storage (4.7 to 5.2 days) than yellow bell peppers left on the plant (10.7 days). Constant exposure to ethylene and harvest season had no effect on ripening for either variety. At full-ripe stage red and yellow peppers averaged 29.9 and 87.5 for hue angle, respectively. No decay or noticeable stem-end shriveling developed during the ripening period in storage. Total titratable acidity (TTA) for peppers ripened on the plant was generally significantly higher than those harvested at color-break. Pulp pH of yellow peppers harvested at full-ripe stage decreased from the early (winter) harvest to the late (spring) harvest. Pulp pH of red peppers did not vary significantly. Total soluble solids (TSS) content increased between early and late harvests for red peppers ripened on the plant (6.07 and 7.55 °Brix, respectively). Red and yellow peppers had similar flesh firmness with respect to harvest season and harvest maturity (26.6 to 31.8 N for red and 22.6 to 28.3 for yellow). Red and yellow pepper varieties could be harvested commercially at the onset of color change and ripened at 20°C and 90% RH while maintaining high quality.**

With 19,000 acres of land planted during the 1996-97 season, bell pepper is one of the most important vegetable crops in Florida (Anonymous, 1998). Bell peppers ripen to various colors depending on the cultivar. Most are harvested and commercialized at immature stage or green color, after the fruit pericarp walls have thickened. Being a hollow fruit, the walls are quite sensitive to bruising and must be handled carefully (Brecht and Sargent, 1995).

Sales of fully ripened fruits have increased in recent years. Several factors have stimulated the market in this direction, notably, fruit quality characteristics (thicker and firmer wall, higher nutritional value and sweeter flavor) and higher prices. Sugar contents have been associated with flavor for a number of fruits and vegetables. Total sugar contents of 1/3 and fully ripe 'Enterprise' bell peppers were approximately 30 and 50% higher, respectively, than those for mature-green peppers (J. K. Brecht, unpublished data). Ascorbic acid contents for raw green and red peppers were reported to be 128 and 190 mg/100 g fresh wt., respectively (USDA, 1984). Other flavor and aroma compounds may also play a part in the flavor differences noted between green and fully ripe bell peppers.

The majority of ripe-harvested peppers are greenhouse grown and imported from Europe, although U.S., Canadian and Mexican production is increasing, and a number of Florida field growers pack ripe peppers on a small scale. Field-grown bell peppers in Florida may have higher returns when harvested green, since the extra time required to develop full color increases production costs due to additional decay and insect damage. A single application of ethephon at 1.12 kg/ha resulted in an almost three-fold increase in ripe 'Yolo Wonder' peppers at harvest (Locascio and Smith, 1977). Care must be

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taken to avoid defoliation of the plants. Hoyer (1996) exposed pepper plants ('Janne') to 0.05 to 5 ppm ethylene, determining that the leaves were more sensitive to abscission than the developing fruits. Saltveit (1977) reported that bell pepper ('Yolo Wonder') harvested at immature green stage had non-climacteric respiratory and ethylene production patterns and did not ripen after harvest. However, partially ripe bell peppers ('Maor') stored in polyethylene bags at 7-8°C for 12 days ripened upon transfer to 25°C for 2 days (Meir et al., 1995).

Ethylene gas is used commercially to promote ripening of a number of fruits, permitting harvest at the preclimacteric stage of maturation (Gull, 1981). Although bell pepper is considered a non-climacteric fruit, exposure to ethylene gas may promote chlorophyll breakdown, accelerating the development of the desired color as in its use to degreen citrus fruit (Grierson et al., 1986). If ethylene were found to promote accelerated ripening in bell pepper, a potential commercial scenario would be to harvest at the first sign of color change, grade/pack and apply ethylene during subsequent storage until full ripeness was achieved, followed by shipping.

Little is known about the effects of ethylene exposure on bell pepper quality or postharvest life. Application of propylene did not stimulate ripening of immature harvested 'Yolo Wonder' bell peppers (Saltveit, 1977). Preliminary tests that we conducted in 1998 showed that 'Robusta' bell pepper (a red, greenhouse variety) harvested at the colorbreak stage ripened significantly faster when stored under continuous ethylene (100 ppm) at 20°C than ungassed control peppers (unpublished data).

We report here on a study designed to determine whether red and yellow bell pepper varieties could be harvested prior to full color and allowed to develop color in storage, and if continuous exposure to ethylene gas could hasten color development.

Material and Methods

Red and yellow bell peppers, 'Triple 4' and 'Kelvin' cultivars, respectively, were harvested from a greenhouse in Fort Pierce, FL. The experiments were carried out for two harvests from the same block in winter (February) and spring (May) seasons of 1999. Ten fruits at Stage 3 (10-30% coloration) and ten fruits at full color stage (100% coloration) were harvested with clippers, put in plastic lugs with bottom pads and transported the same day to the Postharvest Horticulture Laboratory in Gainesville. Tagged fruits at Stage 3 were left attached to the plants and monitored until full color stage to be compared with color development of the detached peppers. Half of the fruits harvested at Stage 3 were stored in continuous-flow air at 20°C and 90% relative humidity (RH), and the other half was stored in continuous-flow ethylene (100 ppm) at 20°C and 90% RH. The following quality parameters were measured for the peppers harvested at full color, those harvested at Stage 3 and ripened to full color during storage, and those tagged at Stage 3 and allowed to ripen on the plant.

Color measurement. A Minolta Chroma Meter CR 2000 (Minolta Camera Co Ltd., Japan) was used to measure external color (L, a and b values). Two determinations were taken at the equator of each fruit. From a* and b* values, hue angles ($\tan^{-1}(b^*/a^*)$) and chroma values $(a^{*2}+b^{*2})^{1/2}$ were calculated according to Shewfelt et al. (1988).

Firmness. Firmness was measured on the shoulder (stem end) hemisphere of each pepper (cut transversely through the equator). Deformation force was determined by an Instron Universal Testing Instrument (Model 4411, Canton, MA) at 2 depths (2 mm and 3 mm) using a convex probe (10 mm diameter) and 50 kg load cell with a crosshead speed of 5 cm/min.

Sample preparation. The excised wall of full color peppers was used to prepare the samples. They were homogenized with a blender and centrifuged at 15000 rpm for 20 min. The supernatant was filtered and frozen in vials at -20°C for later measurements.

Total soluble solids. Total soluble solids were determined using a digital Abbe Mark II Refractometer (model 10480, Depew, NY).

Total titratable acidity. Samples were prepared with 6 g of supernatant diluted in 50 ml of distilled water. With an automatic titrimeter (Fisher Titrimeter II, no. 9-313-10, Pittsburgh, PA), the samples were titrated with 0.1 N NaOH to an endpoint of pH 8.2. The percent total titratable acidity was calculated by the equation:

$$\% \text{ acid} = \frac{(\text{vol NaOH (ml)} * \text{normality (NaOH)} * 0.067}{6 \text{ g of sample}} * 100$$

where: 0.067 = milliequivalent factor for malic acid.

Statistical analysis. For both early and late harvest seasons, fruits harvested at Stage 3 were randomized into two groups (+/- ethylene). Peppers that were tagged at Stage 3 were later harvested at full color. Also at each harvest, fully ripe peppers were harvested for comparative purposes. Standard deviation was calculated from pepper means for each of these four treatments (n = 10 fruits).

Results and Discussion

Red peppers ('Triple 4') harvested at the onset of color change (Stage 3) developed full color faster in storage at 20°C/90% RH (4.7 to 5.2 days) than yellow bell peppers ('Kelvin') left on the plant (10.7 days) (Table 1). There were no significant differences within cultivars. And, constant exposure to ethylene did not accelerate ripening in either variety. Neither were there significant differences in ripening rates with respect to early or late season harvest.

Late-season peppers harvested at Stage 3 ripened to visual quality that was equivalent to peppers that were ripened on the plant. For example, peel color quality at full-ripe stage was similar for both ripening methods, regardless of variety. Red peppers averaged 29.9° for hue angle and 31.5 for chroma value (Table 2) and yellow peppers averaged 87.5° and 41.1

Table 1. Ripening time (days) to reach full color for red and yellow peppers harvested at colorbreak and stored at 20°C/90% RH, +/- ethylene or ripened on the plant.

Color at full-ripe stage	Harvest season	Days to full color		
		Harvested at colorbreak		Tagged and ripened on plant
		Air control	Ethylene	
Yellow	Early	6.7 ± 0.52[z]	7.0 ± 1.41	10.7 ± 3.83
	Late	6.5 ± 1.28	5.8 ± 1.14	8.2 ± 1.69
Red	Early	5.7 ± 1.21	4.7 ± 1.21	7.0 ± 1.67
	Late	5.1 ± 1.00	5.2 ± 1.03	5.7 ± 1.89

[z]Means ± standard deviation (n = 10).

Table 2. L*, hue angle and chroma values of red bell peppers harvested at colorbreak and stored at 20°C/90% RH, +/- ethylene or ripened on the plant.

Color values	Treatment			
	Harvested ripe	Harvested at colorbreak		Tagged and ripened on plant
		Air control	Ethylene	
L*	34.23[z]	38.89	38.14	33.95
s.d.	±1.17	±1.05	±1.85	±1.38
Hue angle	25.52	30.98	30.05	28.65
s.d.	±2.09	±3.46	±5.91	±2.31
Chroma	30.06	32.54	30.33	21.55
s.d.	±3.45	±3.83	±2.38	±2.24

[z]Means ± standard deviation (n = 10).

Table 3. L*, hue and chroma values of yellow bell peppers at harvest and at full color from winter and spring seasons. (Storage at 20°C/90% RH, +/- ethylene.)

Color values	Treatment			
	Harvested ripe	Harvested at colorbreak		Tagged and ripened on plant
		Air control	Ethylene	
L*	52.96	54.26	51.98	54.23
s.d.	±2.34[z]	±2.97	±2.38	±2.01
Hue angle	86.09	86.98	89.10	86.29
s.d.	±1.78	±4.50	±2.22	±2.83
Chroma	40.82	40.82	36.26	46.38
s.d.	±4.41	±5.58	±4.46	±3.33

[z]Means ± standard deviation (n = 10).

for these respective values (Table 3). Peppers ripened in storage had no decay and stem-end shriveling was negligible (data not shown).

There were slight differences in flavor components due to maturity stage at harvest maturity and to harvest season. Total titratable acidity (TTA) for peppers ripened on the plant was generally significantly higher than those ripened in storage (Tables 4 and 5). Pulp pH of yellow peppers harvested at full-ripe stage decreased from the early (winter) harvest to the late (spring) harvest (Table 5). For instance, peppers harvested ripe had a pH of 5.24 and 5.07 for early and late seasons, respectively. Pulp pH of red peppers did not vary significantly (Table 4).

Total soluble solids (TSS) content increased between early and late harvests for red peppers (6.07 and 7.55 °Brix, respectively). However, for yellow peppers, TSS increased between early and late harvests for those harvested at Stage 3 (4.32/6.26 and 4.45/5.86 °Brix) for Air Control and Ethylene treatments, respectively (Table 5). The increases in TTA and TSS resulted in similar TSS/TTA ratios for red and yellow peppers harvested in early season. The only significant difference occurred at the initial harvest of ripe peppers in which the value for red pepper was 24.7 and that for yellow pepper was 35.4, due to higher TSS for the latter (Table 4).

Red and yellow peppers had similar flesh firmness with respect to harvest season and harvest maturity (26.6 to 31.8 N for red and 22.6 to 28.3 N for yellow) (Tables 4 and 5). However, ambient temperatures have been reported to affect firmness. Kaaya (1995) observed that field-grown 'Jupiter' peppers harvested green during the warmer spring season had firmness similar to those harvested in this experiment (28.8 N). However, those grown under the cooler fall field temperatures were significantly firmer (37.8 N).

The use of film overwraps may further extend the postharvest quality of bell peppers. Meir et al. (1995) found that partially ripe 'Maor' bell peppers packed in perforated, polyethylene bags could be stored at 3°C for 12 days without visible symptoms of chilling injury and normal subsequent ripening. Rodov et al. (1995) stored bell pepper in sealed film bags containing a sachet consisting of 10 g NaCl with the result of lower incidence of decay. These and other innovations may serve to further extend the postharvest quality of ripe bell peppers.

Table 4. Physical-chemical parameters of red bell peppers harvested at colorbreak and stored at 20°C/90% RH, +/- ethylene or ripened on the plant.

	Treatment							
	Harvested ripe		Harvested at colorbreak				Tagged and ripened on plant	
			Air control		Ethylene			
	Early	Late	Early	Late	Early	Late	Early	Late
TTA (%)[z]	0.24	0.26	0.20	0.23	0.19	0.22	0.24	0.27
s.d.	±0.02[y]	±0.02	±0.04	±0.03	±0.03	±0.02	±0.04	±0.02
pH	5.07	5.02	5.13	5.08	5.14	5.12	5.18	5.17
s.d.	±0.03	±0.02	±0.08	±0.03	±0.09	±0.05	±0.05	±0.04
TSS (°Brix)[x]	5.94	7.52	5.93	6.45	5.82	6.57	6.07	7.55
s.d.	±0.79	±0.59	±0.89	±0.67	±0.84	±0.4	±1.08	±0.39
Firmness (N)	31.80	28.40	26.20	—	28.40	—	27.70	—
s.d.	±2.48	±4.22	±2.35		±1.97		±1.14	
TSS/TTA								
Red	24.7	28.9	29.6	—	30.6	—	25.3	—
Yellow	35.4	29	28.7	—	26.2	—	23.4	—

[z]Total Titratable Acidity (n = 10).
[y]Means ± standard deviation.
[x]Total Soluble Solids.

Table 5. Physical-chemical parameters of yellow bell peppers harvested at colorbreak and stored at 20°C/90% RH, +/- ethylene or ripened on the plant.

	Treatment							
	Harvested ripe		Harvested at colorbreak				Tagged and ripened on plant	
			Air control		Ethylene			
	Early	Late	Early	Late	Early	Late	Early	Late
TTA (%)[z]	0.19	0.23	0.15	0.23	0.17	0.21	0.26	0.24
s.d.	±0.03[y]	±0.02	±0.03	±0.02	±0.02	±0.02	±0.05	±0.02
pH	5.24	5.07	5.13	5.08	5.17	5.06	5.43	5.28
s.d.	±0.07	±0.02	±0.07	±0.06	±0.09	±0.02	±0.09	±0.08
TSS (°Brix)[x]	6.73	6.68	4.32	6.26	4.45	5.86	6.15	7.06
s.d.	±1.42	±0.34	±1.33	±0.46	±0.48	±0.37	±0.67	±0.72
Firmness (N)	28.3	25.19	25.10	—	22.60	—	23.05	—
s.d.	±3.32	±3.91	±3.03		±4.10		±4.99	

[z]Total Titratable Acidity (n = 10).
[y]Means ± standard deviation.
[x]Total Soluble Solids.

Conclusions

Bell peppers harvested at the onset of color change and ripened at 20°C/90% RH had similar appearance and compositional quality (total soluble solids, total titratable acidity, and pH) to those ripened on the plant. Postharvest exposure to ethylene gas did not affect the rate of color development of red or yellow bell peppers. Incidence of decay or shriveling did not increase noticeably during ripening of harvested fruits.

Red and yellow pepper varieties could be harvested commercially at the onset of color change and ripened at 20°C and 90% relative humidity while maintaining high quality. Lack of ethylene response by the cultivars in this experiment (and the fact that it did work in the earlier preliminary experiment) suggests that the wide range of germplasm used in pepper breeding programs may result in varieties with different sensitivities to ethylene.

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