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EFFECT OF STORAGE TEMPERATURE ON RIPENING AND POSTHARVEST QUALITY OF GRAPE AND MINI-PEAR TOMATOES

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Abstract. **Specialty tomatoes have become a staple item in the produce section of many markets. There is little literature available, however, regarding postharvest handling. Field-grown mini-pear ('Red Pear') and grape ('Santa') tomatoes were harvested at breaker/turning stage (10% to 30% red), sorted for uniformity, placed in loosely capped glass vials (n = 4), and stored the same day at 5, 10, 13 or 20 °C. After 7 days tomatoes stored at 5 or 10 °C were transferred to 20 °C for ripening. Pear tomatoes stored at 5 °C/20 °C reached the red-ripe stage (light-red + 6 days) in 18 days, while those stored at 10 °C/20 °C in 17 days, those stored at 13 °C in 16 days, and those stored at 20 °C in 12 days. Grape tomatoes ripened similarly for respective storage temperatures. At red-ripe stage there were no temperature effects on external or internal color for either type. External hue angles ranged from 40 to 45° (red-orange); internal color of grape tomatoes was more yellow than pear (83 to 87° and 67 to 75°, respectively). However, both pear and grape tomatoes stored at 13 °C lost about 50% less weight during ripening to red-ripe stage (3.5% and 2.6%, respectively) and were firmer (2.1 and 3.0 N at 2 mm deformation, respectively) than at the other temperatures. Grape tomatoes had a higher respiration rate (RR) at 20 °C than pear tomatoes, initially at 58 mg·kg-hr^{-1} and decreasing to 24 mg·kg-hr^{-1} by day 11. In contrast, RR for pear tomatoes decreased from 30 to 14 mg·kg-hr^{-1} by day 8. At 13 °C RR for grape tomatoes decreased from 25 to 18 mg·kg-hr^{-1} during ripening; that for pear tomatoes was about 5 mg·kg-hr^{-1} lower on respective days. Initial soluble solids contents (SSC) were higher for both tomato types harvested at red-ripe stage than at breaker/turning stage (pear: 4.9 vs. 3.7 °Brix; grape: 5.1 vs. 4.2 °Brix, respectively); SSC remained lower for virtually all tomatoes ripened to red-ripe stage, suggesting that these grape and pear tomatoes should be harvested near red-ripe stage for best flavor. Storage at 5 °C resulted in about 30% reduction in total titratable acidity (0.41%-pear and 0.34%-grape), whereas those from other treatments maintained similar levels (0.53 to 0.67%).**

Tomato (*Lycopersicon esculentum* Mill.) is the highest volume vegetable crop sold for fresh consumption in the Caribbean Region. Total tomato production in the Caribbean/North American region in 1998 was almost 14 million Mt; more than one tenth of this amount was imported by the U.S. and Canada (FAOSTAT, 2000). Tomato is widely grown throughout the U.S. by both local market growers and large-scale producers. Florida is the largest U.S. producer of fresh-market tomatoes during the fall, winter and spring seasons with annual sales of $580 million for the 2000-2001 season, a 26% increase over the previous season (Anonymous, 2002).

The adoption of marketing orders and USDA grade standards for round tomatoes results in the arrival of tomatoes at retail markets with acceptable appearance. However, flavor is determined by consumers when the tomato is eaten, and flavor perception affects future purchases. In the mid-1990s, a consumer-driven demand for 'field-fresh' flavor caused dramatic changes in tomato marketing. This demand led to very successful introductions of specialty tomato types, including roma, cherry, cluster, and most recently, grape and mini-pear types, often selling two-to-three times the price of round tomatoes. These specialty types are grown both in the field and under protected culture and are often picked at breaker (10% red color) or riper stages. In the 2000-2001 production season, shipments of Florida-grown cherry tomatoes doubled over the previous year (Anonymous, 2002).

Specialty tomatoes have become popular because consumers perceive them to have better flavor than field-grown tomatoes harvested at green stage, even though studies have shown that properly harvested and handled green tomatoes ripen with excellent flavor (Maul et al., 2000). To succeed in today's highly competitive markets, shippers must be capable of consistently supplying tomatoes that consumers recognize as having good flavor. However, tomatoes harvested with high quality have been shown to rapidly lose that quality through improper handling and shipping. For example, at times tomatoes are stored and shipped below 12.5 °C to slow ripening and decay, however they will not develop their full flavor potential (Maul et al., 2000). Internal bruising, caused by impacts during handling, also causes off-flavor in upon ripening (Moretti et al., 2001).

Currently, little postharvest information is available for growers and shippers to market high-flavor, specialty tomatoes. Handlers of specialty tomatoes rely on recommendations that were developed for standard, round tomatoes, even though optimal handling conditions for tomatoes may vary with the type or variety. This restricts the ability of growers and shippers to compete in new and potentially lucrative markets.

The research described here is the outgrowth of the Premium-Quality Tomato Program, a multi-disciplinary effort that has focused on improving the final quality of standard, green-harvested tomatoes by a team of scientists from the University of Florida and the U.S. Dept. of Agriculture (Sargent et al., 1998). This program confirmed that tomato genetics affects flavor. Trained taste panelists (Baldwin et al., 1998) found that widely grown, round tomato cultivars bred for high firmness lacked flavor compared to high-flavor cultivars developed by J. W. Scott at the University of Florida's Gulf Coast Research & Education Center in Bradenton.

Production of specialty tomatoes in protected culture is also on the rise in Florida, Canada, Mexico and Europe. We recently studied flavor and postharvest life of seven varieties of

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cluster tomatoes and 'Trust', the most widely grown round-type tomato in protected culture (Sargent et al., 1999). Sensory panelists rated all of these varieties as average in ripe aroma, sweetness and tomato flavor and lower in off-odor, sourness, green/grassy, off-flavor. 'Campari' was rated significantly higher in tomato flavor, while 'Aranca' was consistently perceived to have stronger off-odor, sourness and off-flavor. 'Trust' was rated somewhat lower in sweetness and higher in sourness and green/grassy notes, but intermediate in other notes. 'Aranca', 'Campari' and 'E20-3000090' tended to soften faster than the other varieties during simulated shipping, while 'Durasol' and 'Aranca' maintained better calyx appearance.

Grape tomatoes have become a common sight in restaurants and a staple of the produce section of most supermarkets. Mini-pear type tomatoes are also available, but on a smaller scale. Data is lacking concerning handling practices for maintaining postharvest quality of specialty tomatoes and it is likely that optimal conditions may vary quite differently from those used for larger tomatoes. During typical commercial handling, commodities are often shipped in mixed loads, meaning that shipping temperatures may be 5 °C or lower, well below recommended temperatures for many crops including tomatoes. Since standard, round tomatoes are sensitive below 12.5 °C, specialty tomato quality may also be affected when held at lower temperatures.

This study was conducted to determine ripening and postharvest quality attributes of grape and mini-pear tomatoes during simulated commercial handling conditions.

Materials and Methods

Plant material. Field-grown mini-pear ('Red Pear') and grape ('Santa') tomatoes were grown using standard production practices at the North Florida Research and Education Center-Suwannee Valley. On Dec. 5, 2001, tomatoes were harvested and brought to the Postharvest Horticulture Laboratory at the University of Florida, Gainesville. The fruit was sorted for breaker/turning stage (10% to 30% red; U.S.D.A., 1976), placed in loosely capped glass vials (n = 4), and stored the same day at 5, 10, 13 or 20 °C. After 7 d storage, fruit stored at 5 or 10 °C were transferred to 20 °C for ripening. Additional pear and grape tomatoes were held continuously at 13 °C or 20 °C and respiration rate was measured daily for 11 d (6 d beyond light-red stage). Standard tomato color ratings were modified to represent ripening patterns observed for grape and mini-pear tomatoes, which differ from ripening patterns observed of standard round fruit. The modified color ratings for these tomatoes were: Breaker = <10% color, Turning = 10-30%, Pink = 30-60%, Light-orange = 60-90%, Orange = >90%, Light-red = >90% + no translucence through pericarp wall, Red-ripe = total red coloration.

The following data was collected on sub-samples (n = 4) when individual tomatoes reached light-red stage, light-red + 3 d and light-red + 6 d.

Weight loss. Weight loss was determined at the red-ripe stage.

Firmness. Firmness was evaluated using an Instron Universal Testing Instrument (Model 4411, Canton, MA) fitted with an 8.0-mm diameter probe, using a crosshead speed of 50 mm/min and a 5 kg load cell. Force at 2 mm deformation was recorded in kg-force and converted to Newtons (N).

Color. Color was evaluated using a Minolta CR-200 Chroma Meter. Two readings/fruit equator were made and averaged for external color, then the fruit was sliced equatorially for one reading for internal color. Color is reported only for hue angle, where 0° = red, 90° = yellow and 180° = green.

Respiration measurements. Individual tomatoes (breaker/turning stage) were weighed and placed in 50 ml glass Wheaton vials (one fruit per vial), loosely capped with plastic lids fitted with a rubber septum and stored at either 13 °C or 20 °C. Every 24 h, containers were sealed for approximately 1 hr, followed by removal of a 0.5 mL sample of the head space from each container. CO_2 concentration was measured using a gas chromatograph fitted with a thermal conductivity detector and a ¼ inch Carbopack column (GOW MAC Instruments Co., series 580 TCD, Bridgewater, NJ). Respiration rates were calculated by the following equation:

$$\text{ml } CO_2 \text{ /kg-hr} = \% \ CO_2 \times K$$

where K = (ml/min × 60 min/hr)/kg × 100.

Frozen sample preparation. Immediately after the above measurements were taken at each evaluation stage, individual tomatoes were frozen at -20 °C. Later, the samples were thawed, homogenized using a polytron, and the homogenate centrifuged at 15000 RPM for 20 min. The resulting supernatant was filtered using cheesecloth and then frozen for later analysis of the following parameters.

Total soluble solids content. A drop of the supernatant as prepared above was placed on the prism of a digital refractometer (Reichert-Jung, Mark Abbe II Refractometer, Model 10480, Depew, NY) and the soluble solids content (SSC) was read in °Brix.

pH. The pH was determined from the same supernatant with a pH meter (Corning Scientific Instruments, pH meter 140, Medfield, MA) standardized with pH 4.0 and 7.0 buffers.

Total titratable acidity. 0.5 g of each sample supernatant was weighed out and diluted in 50 ml of distilled water. The samples were analyzed by an automatic titrimeter (Fisher Titrimeter II, No. 9-313-10, Pittsburg, PA), titrated with 0.01 N NaOH to an endpoint of ph 8.2 and mL of NaOH required to reach the endpoint was recorded. Total titratable acidity (TTA) was calculated by using the following equation:

$$\% \text{ acid} = [(\text{vol. of NaOH (ml)} * \text{Normality (NaOH)} * 0.064) / 0.5 \text{ g of juice}] * 100,$$

where 0.064 = milliequivalent factor for citric acid.

Statistical analyses. All data was subjected to analysis of variance and treatment means were compared using Duncan's Multiple Range Test (P < 0.05% level).

Results and Discussion

Days to red-ripe stage. Tomatoes of both types ripened at similar rates for the respective storage temperatures; they also ripened faster with increased storage temperature. Those stored at 5 or 10 °C for 7 d and transferred to 20 °C ripened after 19 and 17 d, respectively, while those stored at 13 and 20 °C continuously reached red-ripe stage after 16 and 12 d, respectively (Table 1). There was no visible evidence of chilling injury due (non-uniform external color) for tomatoes stored under the low-temperature storage treatments. Results are reported for grape and pear tomatoes at the red-ripe stage only (light-red + 6 d) unless otherwise noted. Regardless of storage treatment, once the tomatoes reached light-red stage, they uniformly reached red-ripe stage in six days.

Table 1. Days from breaker/turning stage to red-ripe stage as affected by storage temperature.[z]

Treatment	Grape tomatoes	Pear tomatoes
5 °C/20 °C	19	18
10 °C/20 °C	17	17
13 °C	16	16
20 °C	13	12

[z]Red-ripe stage = Days to light-red stage + 6 days.

Weight-loss. The grape and pear tomatoes stored continuously at 13 °C lost significantly less weight at red-ripe stage (2.6% and 3.5%, respectively) than tomatoes stored at the other temperatures (from 4.1% to 7.6%) (Tables 2a, b). Mature-green, round tomatoes typically lose about 5% weight during ripening at 20 °C (Chomchalow, 1990). The higher weight losses for cucumbers stored at 5 °C or 10 °C may have been the result of stress response from these low temperatures, whereas tomatoes stored continuously at 20 °C lost more moisture due to a higher respiration rate.

Firmness. Grape and pear tomatoes ripened at 13 °C were 0.3 to 0.7 N firmer than those ripened under the other temperature regimes (Tables 2a and b). Grape tomatoes tended to be firmer than pear tomatoes at respective treatments. As with weight loss discussed above, storage at 5 or 10 °C followed by transfer to 20 °C (19 and 17 d, respectively; Table 1) was sufficient to induce chilling injury, characterized by disruption of normal cell-wall functions. Tomatoes stored for 13 d at 20 °C ripened and senesced faster than those stored at the lower temperatures.

Hue angle. There were no significant differences in external or internal color for tomatoes due to treatment for either tomato type. External color for grape and pear tomatoes at breaker/turning stage was initially 94.1° and 88.7°, respectively, and tomatoes from all treatments eventually ripened to typical red-orange color at red-ripe stage (40.4° to 44.2°) (Tables 3a, b). Initial internal color was greener than initial external color for both types (108.1°, grape; 93.3°, pear), however at red-ripe stage the internal color of grape tomatoes was noticeably more yellow (82.8° to 86.5°) than that for pear tomatoes (67.0° to 74.7°). In both of these tomato types, locular gel did not ripen to red color typical of other tomato types, such as roma or round.

Table 2a. Weight loss and firmness of grape tomatoes at red-ripe stage.

Treatment	Weight loss (%)	Firmness (N)
5 °C/20 °C	4.9 a[z]	2.6 ab
10 °C/20 °C	4.1 a	2.6 ab
13 °C	2.6 b	3.0 a
20 °C	4.4 a	2.3 b

[z]Columns with different letters are significantly different at $P < 0.05$, according to Duncan's Multiple Range Test.

Table 2b. Weight loss and firmness of pear tomatoes at red-ripe stage.

Treatment	Weight loss (%)	Firmness (N)
5 °C/20 °C	5.5 ab[z]	1.7 b
10 °C/20 °C	7.6 a	1.7 b
13 °C	3.5 b	2.1 a
20 °C	5.7 ab	1.8 b

[z]Columns with different letters are significantly different at $P < 0.05$, according to Duncan's Multiple Range Test.

Table 3a. External and internal color (hue angle) at red-ripe stage for grape tomatoes.

Treatment	External color	Internal color
Initial (breaker-turning stage)	94.1 a[z]	108.1 a
5 °C/20 °C	44.2 b	86.5 b
10 °C/20 °C	43.0 b	82.8 b
13 °C	43.0 b	83.7 b
20 °C	42.1 b	84.8 b

[z]Columns with different letters are significantly different at $P < 0.05$, according to Duncan's Multiple Range Test.

Table 3b. External and internal color (hue angle) at red-ripe stage for pear tomatoes.

Treatment	External color	Internal color
Initial (breaker-turning stage)	88.7 a[z]	93.3 a
5 °C/20 °C	44.2 b	74.0 b
10 °C/20 °C	44.5 b	70.2 b
13 °C	44.3 b	67.0 b
20 °C	40.4 b	74.7 b

[z]Columns with different letters are significantly different at $P < 0.05$, according to Duncan's Multiple Range Test.

Appearance. No decay occurred in tomatoes from any treatments during ripening and storage for several days beyond the red-ripe stage. After 11 d grape and pear tomatoes stored constantly at 20 °C reached red-ripe stage while those from the other temperatures were less ripe (data not shown). Pear tomatoes reached red-ripe stage in the pericarp region containing the locule tissue, but in a few fruits the neck region remained a mottled yellow-orange color; grape tomatoes were uniform in external color.

Respiration rate. CO_2 evolution constantly decreased during the ripening period, indicating the climacteric peaks for both tomato types occurred prior to the initial measurements made at the breaker/turning stage (Fig. 1a, b). The respiration rates (RR) were fairly constant by 11 d storage, at which time all readings were discontinued. RR were higher for both tomato types stored at 20 °C than at 13 °C. At 20 °C grape tomatoes had initial RR of 58 $mg \cdot kg\text{-}hr^{-1}$ decreasing to 40 to 45 $mg \cdot kg\text{-}hr^{-1}$ through Day 6, then to 24 $mg \cdot kg\text{-}hr^{-1}$ by Day 11 (Fig. 1a). In contrast, the initial RR for pear tomatoes at 20°C was about half (30 $mg \cdot kg\text{-}hr^{-1}$) that for grape tomatoes and remained significantly lower throughout ripening (Fig. 1b).

The same trend continued for both tomato types stored at 13 °C. Grape tomato RR decreased from 25 to 18 $mg \cdot kg\text{-}hr^{-1}$ during ripening, while that for pear tomatoes was somewhat lower on respective days. These RR values are similar to those reported by Hardenburg et al. (1986) for round-type tomatoes ripened at 15-16 °C, in which the RR ranged from 16 to 28 $mg \cdot kg\text{-}hr^{-1}$, and at 20 to 21 °C from 28 to 41 $mg \cdot kg\text{-}hr^{-1}$.

Chemical analyses. Tomato flavor, as estimated by soluble solids content (SSC), total titratable acidity (TTA), pH and

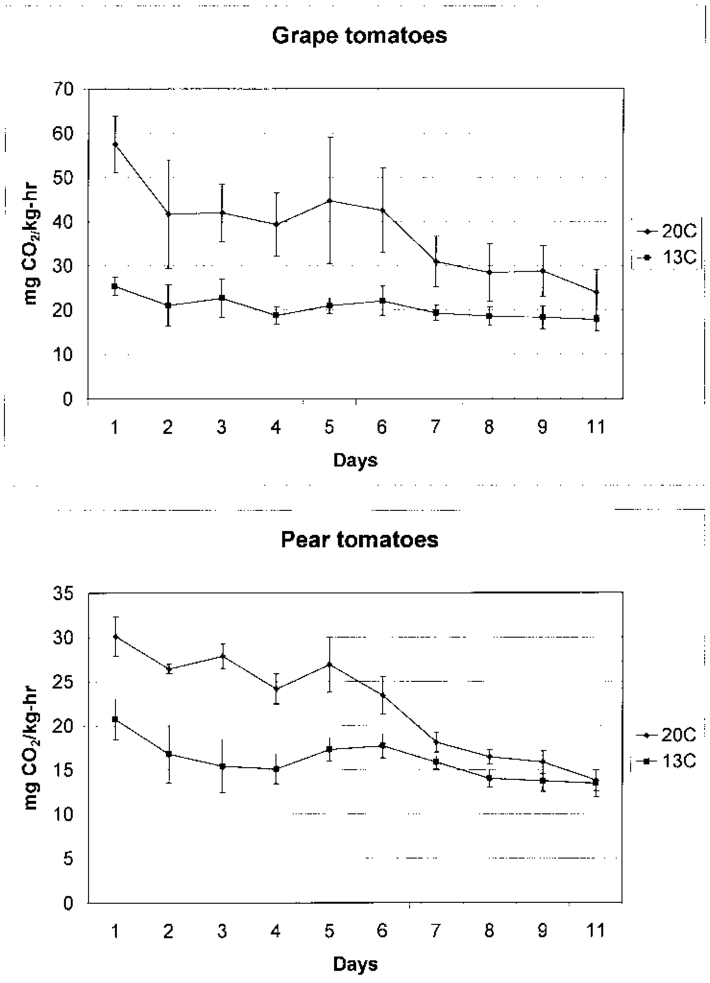

Fig. 1. Respiration rates during ripening at 13 or 20 °C. (Day 1 = breaker/turning stage; Day 11 = red-ripe stage.) (a) grape tomatoes; (b) pear tomatoes.

sugar/acid ratio was affected by harvest maturity. SSC values were similar for grape and pear tomatoes harvested at full-red stage (5.1 and 4.9 °Brix, respectively; Tables 4a, b) and were significantly higher than those harvested at breaker/turning stage (4.2 and 3.7 °Brix, respectively). SSC of those harvested at breaker/turning stage remained constant or slightly lower after ripening to red-ripe stage.

Grape tomato pH was slightly higher for those harvested red-ripe (4.1) than those at breaker/turning stage (3,8), however it remained fairly constant, regardless of harvest maturity or storage temperature (Tables 4a, b). Harvest maturity did not affect TTA for grape tomatoes (0.70%) and remained fairly constant during ripening at 13 °C or 20 °C; grape tomatoes stored at 5 °C which were significantly less acidic (0.34%). Pear tomatoes were most acidic when harvested at breaker/turning stage (0.85%) and become less acidic during ripening (Table 4b).As with grape tomatoes, pear tomatoes stored at 5 °C had less TTA at red-ripe stage than those from other treatments (Table 4b). Sugar/Acid ratios were highest for tomatoes harvested at red-ripe stage (grape = 7.3; pear = 7.5). The ratios for those stored at 5 °C were actually higher due to the significant decrease in acidity during storage. Maul (1999) reported that round-type tomatoes harvested at red stage had lower SSC/TTA ratios ('CPT-5' = 4.5, 'Agriset-761' = 4.4).

Although there were few differences in SSC and TTA due to storage temperature, aroma volatiles have been reported to contribute more to the overall taste quality ("tomato-like" flavor) of tomato fruit (Kader et al., 1977). Studies by Malundo et al. (1995) indicate that simply increasing sugar and acid levels does not improve tomato flavor. Maul et al. (2000) reported higher SSC with ripe 'Solimar' (a round type), after storage at 5 °C for 8 d; however trained panelists gave these same tomatoes higher notes for sourness and lower notes for ripe tomato aroma and flavor as compared to tomatoes stored at higher temperatures. Moretti et al. (1998) reported somewhat lower SSC values (3.98) for whole 'Solar Set' tomatoes and that pericarp and locule tissue were equivalent in SSC. However, pericarp tissue had blander flavor than locule tissue since it contained only about 60% of TTA contained in locule tissue. They also noted that sensory panelists were able to distinguish ripe 'Solar Set' tomatoes with internal bruising (a stressed locule disorder) from unbruised tomatoes (Moretti et al., 1997). In this present study personal observations noted that pear tomatoes tasted blander than grape tomatoes. Most likely, overall flavor perception of pear tomatoes was less favorable because the low-acid pericarp tissue of the "neck" region lacks locular tissue.

Grape and pear tomatoes are carving a special niche in the salad and snack markets at food-service and retail levels. To maintain consistently high flavor, these specialty tomatoes should be picked at red-ripe stage, washed and rinsed, quickly cooled and held at 13 °C with 90 to 95% relative humidity during handling and shipping. Under these conditions, the tomatoes should remain firm, have minimal weight loss and maintain excellent flavor and quality for at least 14 d.

Table 4a. Chemical analyses at red-ripe stage for grape tomatoes.

Treatment	SSC[z] (°Brix)	pH	TTA (%)	Sugar/acid ratio
Initial (harvested at turning-breaker stage	4.2 b[y]	3.8 b	0.69 ab	6.1 bc
Initial (harvested at red stage	5.1 a	4.1 a	0.70 ab	7.3 b
5 °C/20 °C	4.0 b	3.9 ab	0.34 c	11.8 a
10 °C/20 °C	4.1 b	4.0 a	0.66 ab	6.3 bc
13 °C	4.8 b	3.8 b	0.74 a	5.5 c
20 °C	3.9 b	4.0 a	0.61 b	6.4 bc

[z]SSC = Soluble Solids Content; TTA = Total Titratable Acidity (citric acid equivalent).
[y]Columns with different letters are significantly different at $P < 0.5$, according to Duncan's Multiple Range Test.

Table 4b. Chemical analyses at red-ripe stage for pear tomatoes.

Treatment	SSC[z] (°Brix)	pH	TTA (%)	Sugar/acid ratio
Initial (harvested at turning-breaker stage	3.7 c[y]	4.1 a	0.85 a	4.4 c
Initial (harvested at red stage	4.9 a	4.2 a	0.65 b	7.5 b
5 °C/20 °C	4.4 ab	4.3 a	0.41 c	10.7 a
10 °C/20 °C	4.2 bc	4.1 a	0.67 b	6.4 bc
13 °C	3.8 c	4.1 a	0.53 bc	7.1 bc
20 °C	3.7 c	4.1 a	0.68 b	5.5 bc

[z]SSC = Soluble Solids Content; TTA = Total Titratable Acidity (citric acid equivalent).
[y]Columns with different letters are significantly different at $P < 0.5$, according to Duncan's Multiple Range Test.

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