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Heritability of Fresh-cut Fruit Quality Attributes in *Capsicum*

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Abstract. Fresh pepper (*Capsicum*) fruit that are sliced and/or diced are referred to as fresh-cut products. The current report evaluates the inheritance of postharvest attributes that contribute to pepper fresh-cut quality. Marketable green fruit of large-fruited *Capsicum annuum* accessions with bell and related pod types (Class 1), *C. annuum* accessions with jalapeno and serrano pod types (Class 2), and thin-walled "aji"-like tabasco pod types from *Capsicum baccatum*, *Capsicum frutescens*, and *Capsicum chinense* (Class 3) were processed and stored up to 14 days in selective oxygen transmission rate packaging. Fresh-cut attributes were influenced by genotype as well as year. For all pod types, O_2 and CO_2 partial pressures in storage packages, tissue weight loss, and electrolyte leakage differed among accessions, days of storage, and years of testing. Percent O_2 declined and CO_2 and electrolyte leakage generally increased during storage. Some accessions in Class 1 and Class 2 maintained acceptable product quality during storage. Changes in fruit weight loss were small with greater weight loss observed in Class 1 accessions relative to weight loss for Class 2 and Class 3. Broad-sense heritability for fresh-cut attributes was moderate to low indicating that it will be difficult to breed for fresh-cut quality.

Fresh pepper fruit that are sliced and/or diced are referred to as fresh-cut products. Pepper and other minimally processed fresh-cut vegetables have been used primarily in food service sales and to a lesser extent in retail markets (Lamikanra, 2002). Tissue breakdown and microbial contamination are important problems that shorten product shelf life of pepper and other fresh-cut fruits and vegetables (Barrett et al., 2010). Numerous factors contribute to fresh-cut product shelf life. Preharvest factors that affect raw material and resultant processed product quality include genotypic differences, climatic factors, and cultural practices (Kader, 2002). Multiple postharvest factors also influence fresh-cut product quality (James and Ngarmask, 2010). Physical damage during harvesting and handling, temperature and relative humidity management of harvested product, and supplemental postharvest treatments including modified atmospheres (MAs) can positively or negatively affect the quality of fresh-cut products.

Steps involved in production of fresh-cut pepper products include precooling and washing of freshly harvested fruit followed by trimming, coring, slicing, packaging, and storage at 4 °C. Electrolyte leakage is commonly used as a measure of cell disruption that occurs during cutting of fresh-cut product and tissue breakdown during storage (Allende et al., 2004; Kim et al., 2004; Luo et al., 2004). Tissue softening and progression of fruit ripening that continues after processing, texture loss, desiccation, and decay due to tissue damage and microbial contamination shorten shelf life of fresh-cut product. A number of studies have evaluated pepper for fresh-cut use and focused on fresh-cut product storage temperature and controlled atmosphere storage (Cantwell and Suslow, 2002; Conesa et al., 2007; Gonzalez-Aguilar et al., 2004; Lopez-Galvez et al., 1997; Manolopoulou et al., 2012; Senesi et al., 2000). Low O_2 and high CO_2 concentrations reduce respiration rates and ethylene production. Although pepper is susceptible to chilling injury (CI), potential damage due to CI is offset by the beneficial effects of cold storage on retarding tissue decay. These studies evaluated only one to several cultivars from the sweet bell market class. Howard and Hernandez-Brenes (1998) assessed the suitability of a single jalapeno pepper cultivar for fresh-cut applications. Where more than one cultivar was evaluated,

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longevity of the fresh-cut product was influenced by choice of cultivar and limited by tissue breakdown and/or microbial decay. Stommel et al. (2015) evaluated diverse *Capsicum* germplasm representative of various fruit pod types for fresh-cut suitability. Sweet bell and other large-fruited pod types and jalapeno and serrano accessions varied extensively in suitability for fresh-cut use with some accessions identified within each class that maintained acceptable sensory quality and tissue integrity during storage.

Extensive genetic diversity in *Capsicum* has been characterized (Stommel and Albrecht, 2012). Breeding for tolerance to biotic and abiotic disorders in cultivated pepper has largely focused on improving fruit quality, disease resistance, and varied yield attributes. Genetic diversity, varied production practices, and different maturity stages of harvested product present difficulties in establishing standard selection practices to breed for postharvest quality (Hayes and Luo, 2008). Detailed reports on breeding for postharvest attributes are few. This may be attributed to the expertise and resources often required to conduct postharvest assessment of quality attributes. The current report evaluates the heritability of postharvest attributes that contribute to fresh-cut product quality in diverse pepper pod types.

Materials and Methods

PLANT MATERIALS. Pepper cultivars and *Capsicum* species accessions were selected to represent a range of fresh-cut quality ranging from good to poor (Stommel et al., 2015). Pepper seed of selected accessions was obtained from Enza Zaden (lines denoted with E or caps prefix); Plant Genetic Resources Conservation Unit, U.S. Department of Agriculture, Agricultural Research Service, Griffin, GA (PI441548); and commercial suppliers (named cultivars). Three 12-plant replicates of 6-week-old plants of each accession were transplanted following a randomized complete block design to field plots at the Beltsville Agricultural Research Center, Beltsville, MD, during the 2013 and 2014 summer production seasons. Field-grown plants were spaced at 0.45-m intervals in single rows on polyethylene-covered raised beds positioned on 1.5-m centers with trickle irrigation. Pest control and fertilizer regimes followed standard practices for pepper production in Maryland (University of Maryland, 2016).

The accessions evaluated represented various pepper fruit pod types. Class 1 was composed of 20 large-fruited *C. annuum* accessions with bell, paprika, pimento, and large elongated pod types. Sixteen small-fruited *C. annuum* accessions with jalapeno and serrano pod types plus small-fruited cherry pod types comprised Class 2. Class 3 included seven *C. baccatum*, *C. frutescens*, and *C. chinense* accessions with thin-walled "aji"-like and tabasco pod types. Market maturity for full-size green fruit for respective accessions was assessed via subjective evaluation of fruit color and firmness during development, and marketable green fruit was harvested. Three replicate fruit samples of each accession were obtained by harvest from three groups of four plants each from respective 12 plant replicates and stored at 7 °C overnight before processing.

FRUIT PROCESSING. Pepper fruit were processed as previously described (Stommel et al., 2015). Fruit were washed for 1 min in chlorinated water containing 50 $mg \cdot L^{-1}$ free sodium hypochlorite (NaOCl) adjusted to pH 6.0 to 7.0. Deseeded fruit were sliced transversely in 0.6-cm-thick rings using an industrial slicer (Emura Digisler ECD-302; Emura Food Machine Co., Nagoya, Japan) and washed in 50 $mg \cdot L^{-1}$ NaOCl in water for 0.5 min. Washed fruit slices were centrifuged in a fresh produce centrifuge (Garroutte, Watsonville, CA) for 2 min at 20.5 g_n, and 50.0 ± 1.0 g samples of sliced pepper for evaluation at 0, 7, and 14 d, respectively, for each replicate were transferred to 19 × 28 cm heat-sealed polypropylene bags (CFS Cellpack Packaging, Illfurth, France) with an oxygen transmission rate of 1193 $mL \cdot m^{-2}$ O_2 per 24 h. Samples were stored in the dark at 5 to 7 °C before evaluation (Barth et al., 2016).

FRESH-CUT EVALUATION. Packaged fruit slices were removed from cold storage after 7- and 14-d equivalent test periods for both years and percent O_2 and CO_2 measured in the headspace of sealed bags using a gas analyzer (CheckMate II; PBI Dansensor, Ringsted, Denmark). Weight of the samples in each package was recorded and electrolyte leakage was determined as described by Hong et al. (2000) and Kou et al. (2013) with minor modifications (Stommel et al., 2015). Fruit slices were transferred to 500 mL reverse osmosis (RO) quality water, incubated for 30 min and electrical conductivity (EC_1) was measured. Samples in RO water were frozen slowly to –20 °C for 24 to 48 h to maximize tissue disruption, thawed, and total product EC was recorded (EC_2) over repeat freeze-thaw cycles until total EC was stable. Percent electrolyte leakage was calculated as $(EC_1 - EC_0)/EC_2 - EC_0) \times 100$, where EC_0 = EC of RO water.

STATISTICAL ANALYSIS. The variables O_2, CO_2, weight change, and electrolyte leakage were analyzed as two-factor mixed models using Proc Mixed in SAS (version 12.1; SAS Institute, Cary, NC) with accession and day as the factors and year as the block. For electrolyte leakage, measurements were recorded at 0 d as well as at 7 and 14 d. The assumptions of the models were checked. For Class 2, electrolyte leakage was log transformed to meet the assumptions of the linear model. Values that showed as probable outliers were reviewed in the master data set and omitted from the analyses. The variance grouping technique was used to correct variance heterogeneity present in all three pepper classes. Means comparisons were done with Sidak adjusted probability values so that the experiment-wise error was 0.05.

Variance components estimated from the mixed models procedure were used to calculate broad-sense heritability as

$$H = \frac{\sigma^2_G}{\sigma^2_G + \left(\sigma^2_{GE}/e\right) + \left(\sigma^2_e/re\right)}$$

where σ^2_G is the genetic variance, σ^2_{GE} the genotype × environment variance, σ^2_e the error variance, and re the total number of fruit replicates analyzed per accession. The data were also analyzed by the SAS general linear models procedure, and type III mean squares were used to calculate the upper and lower confidence interval of the estimate of *H* (Knapp et al., 1985) as

$$\text{Upper CI} = 1 - \left[1/\left\{(MS_1/MS_2)F_{(1-\alpha/2;df2,df1)}\right\}\right]$$

$$\text{Lower CI} = 1 - \left[1/\left\{(MS_1/MS_2)F_{(\alpha/2;df2,df1)}\right\}\right]$$

where MS_1 = mean squares for accession, MS_2 = mean squares for accession × year, F = F-distribution value, $\alpha = 0.05$, df2 = df associated with accession × year, and df1 = df associated with accession.

Results

Attributes that contribute to fresh-cut pepper fruit quality were influenced by genotype as well as environment. For accessions comprising Class 1, Class 2, and Class 3, fresh-cut parameters including O_2 and CO_2 partial pressures in storage packages, tissue weight loss, and electrolyte leakage generally differed significantly among accessions and between days of storage as well as between years of testing (Table 1). With the exception of tissue weight loss in Class 1, accession × day interactions were significant in Class 1 and Class 2, but not in Class 3. Year of testing generally had a large effect on these fresh-cut parameters for all fruit classes. For Class 1 and Class 2, days of storage also had a strong influence on percent O_2 and CO_2, weight loss, and electrolyte leakage. For Class 3, accessions had greater influence on percent CO_2 and weight loss relative to days of storage, whereas days of storage had greater effects on percent O_2.

An inverse relationship was evident between percent O_2 and CO_2 in sample storage bags with percent O_2 generally declining and CO_2 increasing over days of storage (Table 2). Percent O_2 declined faster in Class 2 and Class 3 samples after 7 and 14 d of storage relative to that observed for Class 1. Whereas ≈35% of the accessions represented within Class 1 maintained both O_2 and CO_2 partial pressures within recommended ranges for fresh-cut pepper [3% to 5% O_2, 5% to 10% CO_2 (Barth et al., 2016)], only 12.5% of Class 2 small-fruited *C. annuum* accessions maintained optimal package MAs. These included the cherry accession caps5951 and a jalapeno accession 'Goliath'. Percent O_2 was depleted to low levels in the remaining Class 2 samples after 14 d of storage. Overall, percent O_2 declined to suboptimal levels in most Class 3 *C. chinense*, *C. frutescens*, and *C. baccatum* accessions as well after 14 d of storage.

Electrolyte leakage after 14 d of storage for Class 1 accessions was variable. Although electrolyte leakage values increased for many of the accessions, values were relatively unchanged over the evaluation period for accessions including 'Inzell', E20B.24966, E49.10719, 'Healey', and 'Holy Mole'. Electrolyte leakage declined significantly in 'Planet' over days of storage. For Class 2 and Class 3, changes in electrolyte leakage over the 14 d storage period were less varied in comparison with Class 1 accessions and were generally typified by smaller increases in accessions where electrolyte leakage increased during storage. Similar to Class 1, electrolyte leakage was relatively unchanged (e.g., 'Cherry Bomb', and 'Jalapeno') or declined during storage (e.g., 'Mitla', 'Goliath', and 'Ixtapa X3R') for select accessions. In Class 2, one jalapeno accession ('Ixtapa X3R') and all five serrano accessions exhibited electrolyte leakage values at day 0 that were greater than that observed in other Class 1 and Class 2 samples, suggesting that greater tissue damage occurred in these accessions during sampling.

Overall, changes in fruit weight loss were small with greater weight loss in Class 1 accessions after 14 d of storage relative to weight loss observed for Class 2 and Class 3 accessions. Two large-fruited *C. annuum* accessions, 'Pimiento Elite' and 'Alma Paprika', exhibited the greatest weight loss after 14 d of storage, coincident with the greatest electrolyte leakage in this fruit class.

Broad-sense heritability estimated for fresh-cut attributes after 14 d of storage varied from high to low depending on the attribute and fruit class (Table 3). Considerable variation with fresh-cut quality measures reduced the precision of heritability estimates, particularly for O_2 and CO_2 partial pressures and tissue weight loss. Higher heritability estimates were evident for electrolyte leakage in Class 2 and Class 3 ($H = 0.75$ and 0.86, respectively) and weight loss in Class 3 ($H = 0.84$). Broad-sense heritability was moderate for electrolyte leakage in Class 1 ($H = 0.44$) and moderate to low for percent O_2 and CO_2 in all fruit classes (range $H = 0$ to 0.6).

Table 1. Analysis of variance F values for O_2, CO_2, weight loss, and electrolyte leakage of fresh-cut pepper slices from large-fruited *Capsicum annuum* accessions with bell, paprika, pimento, and large elongated pod types (Class 1); small-fruited *C. annuum* accessions with jalapeno, serrano, and cherry pod types (Class 2); and accessions of *Capsicum baccatum*, *Capsicum frutescens*, and *Capsicum chinense* with thin-walled "aji"-like and tabasco pod types (Class 3) stored under passive modified atmosphere packaging conditions for 7 to 14 d.

		O_2	CO_2	Wt loss		Electrolyte leakage
Source	df	F value			df	F value
Class 1						
Year	1	257.37****	17.58****	39.01****	1	92.27****
Accession	19	3.22****	3.16****	3.38****	19	6.68****
Day	1	194.38****	102.97****	31.72****	2	52.46****
Accession × day	19	1.67****	1.98*	1.48	38	4.47****
Class 2						
Year	1	37.26****	7.37**	0.85	1	163.66****
Accession	15	4.04****	6.89****	5.22****	15	82.54****
Day	1	54.97****	16.37****	39.32****	2	66.76****
Accession × day	15	2.24**	2.12*	2.76**	30	10.99****
Class 3						
Year	1	26.51****	0.01	64.10****	1	15.59***
Accession	6	2.28*	3.34**	11.13****	6	23.54****
Day	1	23.45****	0.75	15.49***	2	15.40****
Accession × day	6	1.42	2.09	0.98	12	1.76

****, ***, **, *Significant at $P \leq 0.0001$, $P \leq 0.001$, $P \leq 0.01$, and $P \leq 0.05$, respectively.

Discussion

Variation for O_2 and CO_2 partial pressures, tissue weight loss, and electrolyte leakage was evident among fruit classes as well as among accessions within respective classes. Consistent with prior studies (Stommel et al., 2015), sweet bell and other large-fruited accessions had higher O_2 partial pressures in comparison with jalapeno and serrano fruit types early in the storage period and declined with continued storage. For example, E20L.1012857 was represented in the current and former study and again maintained recommended O_2 partial pressure between 3% and 5% and CO_2 partial pressures less than 10% after extended storage.

Similarly, electrolyte leakage in large-fruited accessions that comprised Class 1 had reduced initial electrolyte

Table 2. Least square means and means comparisons for O_2, CO_2, sample weight loss, and electrolyte leakage of fresh-cut pepper slices from large-fruited *Capsicum annuum* accessions with bell, paprika, pimento, and large elongated pod types (Class 1); small-fruited *C. annuum* accessions with jalapeno, serrano, and cherry pod types (Class 2); and accessions of *Capsicum baccatum*, *Capsicum frutescens*, and *Capsicum chinense* with thin-walled "aji"-like and tabasco pod types (Class 3) stored under passive modified atmosphere packaging conditions for 7 to 14 d. Means comparisons were evaluated using Sidak adjusted probability values so that the experiment-wise error was 0.05.

Class 1										
	O_2 (%)		CO_2 (%)		Electrolyte leakage (%)			Wt loss (g)		
	Day		Day		Day			Day		
Accession	7	14	7	14	0	7	14	Accession	7	14
Sweet bell										
'Inzell'	7.88 ab^z x^y	1.483 ay	5.42 abcy	9.18 abx	6.89 abcx	4.36 abcx	8.01 bcdx	0.608 abcd^x	0.304 b^w	0.776 a
'Spider'	6.71 abcx	0.860 ay	6.13 abcy	11.45 ax	6.81 abx	5.82 abcx	15.25 abcdx	0.608 abcd		
E20B.4555	6.19 abcx	1.147 ay	7.55 abcx	10.43 abx	5.45 abcx	6.09 abcx	16.68 abcdx	0.483 bcd		
E20B.24966	10.33 abcx	3.712 ax	4.33 abcx	7.80 abx	6.10 abcx	3.04 abcx	7.43 cdx	–0.067 bcd		
E20B.4436	9.44 ax	3.513 ay	3.98 cy	9.27 abx	6.04 abcy	2.68 bcz	12.25 abcx	0.658 abcd		
E49.10719	6.95 bcx	2.073 ay	5.90 abcy	9.47 abx	7.57 abx	4.35 abcy	8.27 bcdxy	0.367 bcd		
E20L.1012857	7.17 abcx	3.427 ax	5.67 abcy	10.60 abx	6.08 abcx	5.00 abcx	16.03 abcdx	0.625 abcd		
'Special'	8.19 abx	2.705 ay	5.23 bcy	11.68 abx	4.80 cy	4.52 abcy	11.30 abcx	0.583 bc		
'Tinsena'	8.13 abcx	3.753 ay	5.72 abcx	9.15 abx	6.80 abcx	6.17 abcx	16.00 abcdx	0.708 ab		
'Healey'	7.63 abcx	2.518 ay	5.23 bcx	7.13 abx	7.03 abcx	4.75 abcx	7.20 cdx	0.333 bcd		
'Ferrari'	7.83 abcx	0.688 ay	5.88 abcx	7.73 abx	8.10 ax	6.46 abcx	10.85 abcx	0.600 abcd		
'Seirocco'	9.78 abx	1.642 ay	4.03 cy	9.67 abx	7.36 abcx	4.91 abcx	10.88 abcx	0.430 bcd		
Pimento										
'Pimiento L'	6.74 abcx	2.790 ax	6.28 abcx	9.75 abx	5.39 bcx	6.86 abcx	13.24 abcdx	0.525 abcd		
'Pimiento Elite'	7.11 abcx	2.720 ax	6.83 abcx	11.07 abx	5.92 abcy	8.91 ay	25.07 abx	1.039 abcd		
'Sheepnose Pimento'	9.43 ax	1.258 ay	5.87 abcx	7.03 abx	5.81 abcxy	4.08 abcy	10.51 abcx	0.333 bcd		
Paprika										
'Alma Paprika'	3.29 cx	1.668 ax	8.62 abx	7.75 abx	5.65 abcy	13.39 abcxy	25.34 ax	1.667 a		
Large elongate										
'Laerte'	7.39 abcx	4.630 ax	5.52 abcx	6.25 bx	6.94 abx	4.66 abcx	9.19 abcdx	0.283 cd		
'Pizza'	5.31 abcx	3.217 ax	6.18 abcx	9.78 abx	9.31 abcx	6.04 abx	18.38 abcdx	0.533 abcd		
'Planet'	8.86 abcx	5.303 ax	5.05 abcx	5.95 bx	6.44 abcx	2.35 cy	4.11 dy	0.233 d		
'Holy Mole'	4.17 bcx	0.202 ax	7.70 ax	10.03 abx	7.52 ax	5.23 abcy	9.28 abcdxy	0.250 d		

Continued next page

Table 2. Continued.

Class 2

	O_2 (%)		CO_2 (%)		Electrolyte leakage (%)[v]			Wt loss (g)	
	Day		Day		Day			Day	
Accession	7	14	7	14	0	7	14	7	14
Cherry									
‘Big Bomb’	5.93 a[z] x[y]	0.08 ay	7.13 abx	8.87 bcdx	5.41 fghx	3.02 gy	6.81 cefx	0.20 aby	0.43 abcx
‘Cherry Bomb’	3.80 abx	0.33 ax	7.47 aby	10.27 abcx	5.81 gx	3.89 gy	5.83 efx	0.27 abx	0.25 bcx
caps5951	7.33 abx	3.48 ax	5.08 abx	7.43 cdx	2.98 hx	1.95 gx	4.01 fx	0.17 bx	0.27 abcx
caps7467	4.34 abx	0.11 ay	7.45 abx	9.65 abcdx	4.24 hx	2.79 gy	5.58 efx	0.25 abx	0.35 abcx
Jalapeno									
‘Mitla’	2.75 abx	0.82 ax	8.25 abx	8.93 abcdx	9.70 bcx	5.03 bcdefgx	6.57 cdefx	0.23 abx	0.17 cx
‘Jalapeno Goliath’	4.85 abx	3.84 ax	6.73 bx	6.03 dx	9.19 bcdex	3.43 efgy	3.99 fy	0.18 abx	0.28 bcx
‘Felicity’	4.23 abx	0.28 ay	7.10 abx	7.82 cdx	8.19 cefx	3.52 gy	9.76 bcefx	0.30 aby	0.62 ax
‘Ixtapa X3R’	2.25 abx	0.76 ax	8.67 abx	7.55 cdx	12.02 adx	7.15 cdefy	7.67 cey	0.30 abx	0.35 abcx
‘Jalapeno’	3.49 abx	1.05 ax	7.45 abx	6.58 cdx	8.33 csfx	5.02 fgy	8.10 cex	0.25 abx	0.28 bcx
‘Jalapeno M’	1.77 abx	0.16 ax	8.57 abx	10.90 abcdx	7.59 efgx	6.54 defx	12.95 bcex	0.32 ax	0.47 abcx
caps4711	1.12 bx	0.37 ax	9.97 ax	9.87 abcd	12.74 abcx	10.07 abcdx	18.51 abcx	0.25 abx	0.48 abcx
Serrano									
‘Comisario’	1.10 bx	0.17 ax	9.40 aby	14.27 ax	12.25 abcxy	8.96 bcdey	15.17 bdx	0.52 abx	0.42 abx
‘Devil Serrano’	3.12 abx	0.18 ax	8.18 abx	9.43 abcd	14.48 axy	11.46 aby	20.15 bx	0.23 abx	0.62 abcx
‘Serrano Chili’	1.08 bx	0.62 ax	11.33 abx	15.36 abx	12.56 ay	16.78 ay	35.22 ax	0.22 aby	0.69 abx
‘Serrano Del Sol’	2.53 abx	0.48 ax	8.82 abx	11.47 abcx	15.36 axy	11.93 abcy	22.96 abx	0.33 abx	0.55 abx
‘Serrano Tampiqueno’	1.26 bx	1.28 ax	9.72 abx	9.27 abcdx	14.85 abx	10.87 abx	17.07 abcx	0.28 abx	0.47 abx

Class 3

Accession	O_2 (%)	CO_2 (%)	Electrolyte leakage (%)	Wt loss (g)	Day	O_2 (%)	Electrolyte leakage (%)	Wt loss (g)
Capsicum chinense								
caps1860	2.53 a[u]	7.17 b	3.89 b	0.31 bc	0	—	8.07 a	—
caps2046	1.15 a	8.99 ab	10.73 a	0.60 a	7	3.37 a[t]	5.84 b	0.30 b
caps2043	0.94 a	8.18 ab	8.24 a	0.32 bc	14	1.12 b	9.26 a	0.41 a
Capsicum frutescens								
caps4987	2.84 a	9.81 a	10.17 a	0.28 bc				
Capsicum baccatum								
caps4919	3.62 a	8.10 ab	4.15 b	0.37 bc				
caps3069	2.54 a	7.07 b	7.72 a	0.38 b				
PI441548	2.54 a	8.13 ab	9.18 a	0.22 c				

[z] Accession means within day (i.e., columns) with different a, b, and c letters are different at the 0.05 significance level.

[y] Day means within accession (i.e., rows) with different x, y, and z letters are different at the 0.05 significance level.

[x] Accession means for weight loss with different a, b, and c letters are different at the 0.05 significance level. Only main effects for accessions are presented since the accession × day interaction was nonsignificant.

[w] Day means (days 7 and 14) with different a, b letters are different at the 0.05 significance level. Only main effects for days are presented since the accession × day interaction was nonsignificant for weight loss.

[v] Electrolyte leakage for Class 2 was log transformed to meet the assumptions of the linear model. The means and means comparisons for the variables presented in Table 2 are in their original units.

[u] Accession means within columns with different a, b, and c letters are different at the 0.05 significance level. Only main effects are presented since the accession × day interactions were nonsignificant for all parameters evaluated.

[t] Day means within columns with different a, b letters are different at the 0.05 significance level. Only main effects are presented since the accession × day interactions were nonsignificant for all parameters evaluated.

Table 3. Broad-sense heritability (*H*) and the 95% confidence interval (CI) about *H* for O_2, CO_2, sample weight loss, and electrolyte leakage of fresh-cut pepper slices across large-fruited *Capsicum annuum* accessions with bell, paprika, pimento, and large elongated pod types (Class 1); small-fruited *C. annuum* accessions with jalapeno, serrano, and cherry pod types (Class 2); and accessions of *Capsicum baccatum*, *Capsicum frutescens*, and *Capsicum chinense* with thin-walled "aji"-like and tabasco pod types (Class 3) stored under passive modified atmosphere packaging conditions for 14 d.

Heritability estimate	O_2	CO_2	Wt loss	Electrolyte leakage
Class 1				
H	0.37	0	0.32	0.44
Upper CI	0.75	0.49	0.73	0.78
Lower CI	–0.60	–2.28	–0.71	–0.41
Class 2				
H	0.41	0.60	0.49	0.75
Upper CI	0.80	0.88	0.82	0.92
Lower CI	–0.67	–0.04	–0.54	0.30
Class 3				
H	0	0.11	0.84	0.86
Upper CI	0.80	0.92	0.97	0.98
Lower CI	–5.70	–1.74	0.07	0.44

leakage relative to jalapeno and serrano fruit types, but exhibited large increases in electrolyte leakage during storage relative to jalapeno and serrano fruit classes where these levels remained more constant. Intact pepper fruit that have greater wall thickness, higher dry matter and fruit firmness are generally expected to perform better during commercial harvest and postharvest handling (Gil and Tudela, 2012). We previously observed greater loss in firmness of fresh-cut large-fruited genotypes in comparison with jalapeno as well as serrano genotypes (Stommel et al., 2015). Higher initial electrolyte leakage found in some jalapeno and serrano accessions suggest that these fruit sustained more tissue injury during processing. Accessions represented across studies wherein electrolyte leakage remained relatively constant or declined over the storage period in the current and former study, included Class 1 accessions E20B.24966, E49.10719, 'Planet', and 'Holy Mole' and Class 2 accessions 'Mitla' and 'Ixtapa X3R'. Class 3 *C. chinense*, *C. frutescens*, and *C. baccatum* accessions behaved similarly to small-fruited *C. annuum* Class 2 accessions. As previously proposed, our observations on electrolyte leakage support occurrence of a membrane repair process in fresh-cut pepper where electrolyte leakage is stable or declines during extended storage (Kou et al., 2013; Stommel et al., 2015).

High levels of variance were evident for the fresh-cut attributes evaluated during storage. Despite this variability, trends observed during storage for CO_2 and O_2 partial pressures, tissue electrolyte leakage, and weight loss for the respective fruit classes were consistent with our prior observations. Some of the variability may be attributed to the difficulty of harvesting fruit at the same level of maturity and resultant physiological differences inherent in fruit of different maturity. Variation in maturity will influence softening and other ripening processes that continue in fresh-cut product after pepper fruit are harvested (Kader, 2002). Mimicking commercial harvest practices, harvest of green pepper fruit of different maturity at the same time is common despite efforts to harvest fruit with the same fruit color and firmness (Sanchez et al., 1993; Tadesse et al., 2002).

For most fresh-cut attributes, broad-sense heritability estimates were low to moderate. In general, the variation due to genotype × environment and error for O_2 and CO_2 partial pressures, tissue weight loss, and electrolyte leakage were comparable in Class 1 and Class 2. However, in Class 1, variation due to error for percent O_2 was more than three times greater than that for genotype × environment, and error for percent CO_2 in Class 2 was nearly 2-fold greater than that for genotype × environment. For Class 3, variation due to error was 3- to 10-fold greater than that observed for genotype × environment. Within all fruit classes, the percentage of variation explained by error and genotype × environment was smallest for electrolyte leakage. Electrolyte leakage values from fresh-cut fruit reflects tissue damage sustained during cutting, whereas increases in electrolyte leakage during storage is indicative of cell disruption due to tissue breakdown that occurs as tissue ages and/or decays due to microbial growth. MA packaging is used to help prevent or slow tissue decay. Electrolyte leakage was the most robust quality measure among the attributes evaluated for fresh-cut pepper shelf life and may be considered a reliable selection criterion for breeding. Despite the general reliability of electrolyte leakage to assess tissue damage and trends observed over multiple studies for some pepper genotypes that exhibit acceptable fresh-cut shelf life, the poor precision of broad-sense heritability estimates indicates that breeding for enhanced shelf life will be difficult. We previously identified good agreement between electrolyte leakage and sensory scores for overall fruit quality in fresh-cut sweet bell and other large-fruited *C. annuum* accessions (Stommel et al., 2015). Nonetheless, breeding for enhanced shelf life is daunting due to the large populations typically used in breeding and the laborious nature of analytical measures and/or need for trained panels for reliable sensory characterization.

Although few reports are available that document genetic diversity for fresh-cut quality among cultivated fruits and vegetables and their exotic relatives, recent studies highlight genetic diversity for fresh-cut attributes and, similar to our results, illustrate the challenges as well as the opportunities to breed for fresh-cut performance. In lettuce (*Lactuca sativa*) germplasm, Zhang et al. (2007) identified over 100 quantitative trait loci (QTL) across multiple linkage groups for lettuce shelf life that were environment specific and generally explained less than 30% of the observed variation. In different populations, Hayes et al. (2014) and Atkinson et al. (2013) also found multiple QTL that accounted for variation in fresh-cut lettuce shelf life, but identified a major QTL explaining 40% to 70% of the decay observed in cut lettuce (Hayes et al., 2014). Days of storage was the principal determinant of varied influence of this QTL.

Variation observed among *Capsicum* genotypes for electrolyte leakage and package atmospheric composition during storage of fresh-cut product highlights the opportunity to combine potentially different genetic mechanisms for improving fresh-cut shelf life. Populations developed from select parents will provide estimates of additive effects and utility of those genotypes in breeding for fresh-cut quality.

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