Morphological Changes Associated with Postharvest Fruit Deterioration and Physical Parameters for Early Determination of Shelf Life in *Capsicum chinense* Jacq.

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Abstract. Thirty four pepper accessions (*Capsicum chinense* Jacq.) from the Caribbean were evaluated under controlled environmental conditions viz. darkness, 21.8 °C, and 90% relative humidity (RH) to determine the genetic variation and morphophysiological changes associated with loss of shelf life. The experiment was arranged in a randomized complete block design with three replications and 10 fruits per replication. The following parameters were recorded over a period of 20 days: fruit weight, shrivelling score, and proportion of fruits showing incipient pedicel necrosis, up to 20% pedicel necrosis, total pedicel/calix necrosis (but with no pericarp necrosis), incipient pericarp necrosis. Water loss overtime, water loss slope and intercept, and days to incipient pedicel necrosis, 20% pedicel necrosis, total pedicel/calix necrosis, and incipient pericarp necrosis were derived from the data. There were significant differences ($P < 0.05$) among accessions with respect to all parameters measured. Deterioration under storage initiated as incipient necrosis of the pedicel tip, which proceeded along the entire pedicel and calyx and subsequently into the pericarp. Shelf life varied from 6.6 to 16.9 days based on days to 20% pedicel necrosis and up to 19.5 days based on days to incipient pericarp necrosis. Shelf life based on days to 20% pedicel necrosis, total pedicel/calix necrosis, and incipient pericarp necrosis were highly autocorrelated ($r = 0.94$ to 0.99 , $P < 0.01$) and paralleled water loss from fruits. Pepper accessions with heavier fresh fruit weights had lower water loss rates and longer shelf lives than those with lighter fruits. Days to 20% pedicel necrosis and incipient pericarp necrosis were the best measures of shelf life as they best predicted marketability and usability of fruits as early as 8 days after harvest (DAH) ($R^2 = 0.94$) and 9 DAH ($R^2 = 0.82$), respectively, thus reducing the time of shelf life studies by half. Based on days to 20% pedicel necrosis, five accessions with shelf lives over 15 days were identified.

Pepper (*C. chinense* Jacq.) is a short lived, herbaceous perennial (Basu and De, 2003) belonging to the plant family, *Solanaceae* (Bosland et al., 1996; Eshbaugh, 1993). It is indigenous to Central and South America and

the Caribbean (Heiser, 1976), with its center of diversity in the Amazon basin. A study by Moses and Umaharan (2012) revealed three distinct phylogenetic groups in pepper with the Caribbean accessions from the Lesser Antilles clustering separately from those of the Greater Antilles. Pepper is an important source of essential vitamins including vitamin C (Eshbaugh, 1976), minerals (DeWitt and Bosland, 1996), and is known for its pungency (D'Arcy and Eshbaugh, 1974). It is consumed mostly as a fresh vegetable to enhance the taste of foods, but sometimes processed into sauces (Sinha and Petersen,

2011), pharmaceuticals (Stewart et al., 2005), and cosmetics or used in the defense industry.

In the Caribbean, pepper is grown as an annual crop and is subjected to multiple harvests during the growing season at the mature green stage (when the pericarp is green but feels firm to the touch) and when the berry reaches its maximum size (Sinha and Petersen, 2011). A recent unpublished market survey conducted in 2014 by the University of the West Indies showed that the majority of fruits with no defects in color, size, shape, and possessing up to 20% necrosis of the pedicel can be marketed as fresh produce, whereas a smaller proportion of fruits with necrotic pedicels and calyces but showing no pericarp necrosis can be used to make sauces and flakes but are not salable as fresh produce. Pepper begins deterioration following harvest due to desiccation, microbial growth, or due to biochemical senescence (Nipersos-Carriedo et al., 1991). Being nonclimacteric, pepper fruits produce very little endogenous ethylene and hence are not capable of continuing their ripening process once detached from the parent plant (Gamage and Rehman, 1999; Sinha and Petersen, 2011).

In *C. annuum* L., a closely allied species, postharvest deterioration (shrivelling and softening) has been mainly ascribed to water loss (Maalekuu et al., 2005) with cultivar differences with respect to the time taken to loss of shelf life (Lownds et al., 1993, 1994). Very little work has been done to date on shelf life of *C. chinense*. The aim of this study was to determine the genetic variation and physical changes associated with fruit deterioration toward developing an early prediction method for determining shelf life in *C. chinense*.

Materials and Methods

Germination and care of seedlings. Nine seeds each from 34 pure lines of *C. chinense* (Bharath, 2012) were washed in 0.25% bleach solution for 1 min and rinsed three times with sterile distilled water. The seeds were kept overnight on damp filter paper in covered petri dishes to facilitate imbibition. The seeds were sown in seedling trays containing a moist, peat-based medium (Premier® Promix (BX); Premier Horticulture Ltd., Quebec, Canada) and carefully labeled. The seedling trays were then placed in black plastic bags and placed on a bench top away from direct sunlight. Following germination, the trays were removed from the bags and placed in a shaded greenhouse. During the first 6 weeks of growth, the young seedlings were fertilized once a week using Nutrex 20–20–20 (Marman USA Inc., FL) and biweekly with Newfol calcium (Marketing Arm International, FL) following manufacturers' specifications. The seedlings were also supplied once with Phyton 27 Plus (Marketing Arm International) following manufacturer's specifications to prevent fungal diseases.

Cultural conditions in the field. The experimental field was ploughed, rotovated,

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lined, and staked. Hardened 8-week-old seedlings were transplanted onto cambered beds at the University Field Station, Mount Hope, Trinidad in a randomized complete block design with three replications. Each replication consisted of three plants spaced at 0.91 m × 0.61 m. The mean temperature, rainfall, and RH at the field station were 31.5 °C, 1231 mm, and 72.8%, respectively. The soil type at the station is a well-drained river estate loam (Brown and Bally, 1967). Five grams of each of the fertilizers Blaukorn 12:12:17:2Mg (Compo Expert GmbH, Münster, Germany) and Osmocote 15:9:12 (Scotts-Sierra Horticulture Products Company, OH) were applied to the planting hole and incorporated into the soil before planting. Immediately following field planting, Diazinon (Insecticidas Internacionales, Aragua, Venezuela) and Batchac Bait (Fibrokil, Carsen Chemicals Ltd., Chaguanas, Trinidad) were applied as per manufacturers' specifications to control mole crickets and leaf cutter ants, respectively. The seedlings were then fertilized weekly with a foliar application of Nutrex, monthly with Newfol calcium, and at 4 and 6 months after planting with Blaukorn 12:12:17:2Mg following manufacturers' specifications. Fastac (Chemcontrol Ltd., San Fernando, Trinidad) was applied once a month to control insects up to 4 months after field planting. Bioneem (Sumitomo Chemical Corporation, Japan) was applied during the 5th month to control insects, whereas the miticide/insecticide, Newmectin (Marketing Arm Panama, Colon, Panama) was applied once a month following manufacturer's specifications from month 6 onwards.

Weeds were controlled in the experiment using monthly applications of Fusilade (Syngenta, Wilmington, DE) between rows as per manufacturer's specifications during the first 3 months. Thereafter, the weeds were controlled using a brush cutter (Stihl, Waiblingen, Germany). The plants were watered using a sprinkler irrigation system as necessary.

Experimentation. Fruits were harvested at the mature green stage, between 0600 and 0800 hr. Ten unblemished, uniform fruits from each of the three replicate plots per accession were selected from the fifth harvest for the study. The harvested fruits were placed in labeled perforated, clear plastic bags and transported immediately on ice to the postharvest laboratory of the University of the West Indies. Fruits from each bag (replicate) were weighed (PGW 753e; Adam Equipment Inc, CT) and the mean weight per fruit calculated. For the shelf life experiment, the replicated fruits of the 34 accessions were arranged on a bench top in a completely randomized design at a temperature of 21.8 ± 1.0 °C (González et al., 2005) and 90% ± 2% RH. The fruits were placed 2 cm apart on dry paper towels and covered with an aluminum foil hood to maintain a uniform environment and were monitored for a period of 20 d. At 2, 4, 6, 8, 10, 12, and 14 DAH, each replicate was weighed individually and the

mean weight per fruit was calculated to give an estimation of water loss per fruit. At 4, 6, 8, 10, and 14 DAH each fruit was assessed by five experts for degree of shrivelling using a hedonic scale (0-absence of wrinkles, 1-slight shrivelling, 2-mild shrivelling, 3-severe shrivelling, 4-very severe shrivelling) and the mean shrivelling score per replicate was calculated. The symptoms of deterioration under storage first appear as incipient pedicel necrosis, then necrosis progresses rapidly along the pedicel and then the calyx and finally manifests as necrosis of the pericarp. At 2, 4, 6, 8, 10, and 12 DAH each fruit across all accessions and replicates was assessed for incipient pedicel necrosis and at 4, 6, 8, 10, 11, 13, 15, and 17 DAH each fruit was assessed for up to 20% pedicel necrosis, total pedicel/calyx necrosis (with no pericarp necrosis), and incipient pericarp necrosis. Days to incipient pedicel necrosis, up to 20% pedicel necrosis, total pedicel/calyx necrosis, and incipient pericarp necrosis were calculated.

Data analysis. All proportional data were subjected to an arcsin transformation before data analysis. Regression analysis was conducted to determine the relationship between fresh weight and weight loss over time for each accession and the slope and intercept were recorded. One-way analysis of variance (NCSS, 2007) was used to determine whether there were significant differences ($P < 0.05$) among accessions for the following variables: fresh weight; arcsin percentage weight loss, slope and intercept of weight loss over time; arcsin proportion of fruits showing incipient pedicel necrosis, up to 20% pedicel necrosis, total pedicel/calyx necrosis over time; days to incipient pedicel necrosis, 20% pedicel necrosis, total pedicel/calyx necrosis, incipient pericarp necrosis; and shrivelling score. Where significant, least significant difference ($P < 0.05$), within accession coefficient of variation (cv within), between accession cv (SD between the mean of the accessions divided by the general mean), and an index of discrimination (ID = cv between/cv within) were calculated for each parameter.

Pearson's product moment correlation (NCSS, 2007) was used to measure the association between the variables. Where the correlations were large and significant, linear regression analysis (NCSS, 2007) was performed to determine the nature of the relationship between the variables of interest.

Results

Fruit fresh weight. There were significant differences ($P < 0.001$) among the pepper accessions with regard to fresh weight, with fresh weight varying from 5.2 (accessions S21 and SC5) to 15.4 g (L26) (Table 1).

Incipient pedicel necrosis. Pepper deterioration during storage always began with pedicel necrosis and ended with pericarp necrosis. There were significant differences among accessions with respect to the proportion of fruits showing incipient pedicel

necrosis at 6, 8 ($P < 0.001$), and 10 ($P < 0.05$) DAH but not at 2, 4, and 12 DAH (data not shown). There were also significant differences among accessions in the number of DAH to incipient pedicel necrosis ($P < 0.001$) (Table 1). On average, the proportion of fruits showing incipient pedicel necrosis varied from 62.3% at 6 DAH, 88.9% at 8 DAH, and 93.8% at 10 DAH. Accessions L60 (5.3 DAH) and L54 (9.0 DAH) had the shortest and longest time to incipient pedicel necrosis, respectively, the general mean being 7.1 DAH.

Pearson's product moment correlation values were large and significant between arcsin proportion of fruits showing incipient pedicel necrosis at 8 DAH with 10, 12 DAH ($r = 0.86, 0.72, P < 0.01$) and 10 DAH with 12 DAH ($r = 0.90, P < 0.01$). The correlations between arcsin proportion of fruits with incipient pedicel necrosis at 4, 6, 8, 10, and 12 DAH showed significant ($P < 0.05$ to 0.01) negative correlations with days to incipient pedicel necrosis ($r = -0.41$ to -0.86), with the correlation coefficients increasing with time.

Fruits with up to 20% pedicel necrosis. There were significant differences ($P < 0.001$) among accessions with respect to proportion of fruits with ≤20% pedicel necrosis from 6 DAH onwards as well as days to 20% pedicel necrosis (Table 1). The proportion of fruits across all accessions with ≤20% pedicel necrosis varied from 70.2% at 8 DAH to 6.1% at 17 DAH. At 17 DAH, 27 accessions had no fruits with ≤20% pedicel necrosis and only three accessions, viz. S21, MB17, and MB18 had greater than 40.0% of fruits showing ≤20% pedicel necrosis. Overall, fruits of MB16 had the shortest number of days to 20% pedicel necrosis (6.6 DAH) while S21 and MB17 had the longest (16.9 DAH), with the general mean being 12.0 DAH.

There were significant positive correlations ($r = 0.44$ to $0.97, P < 0.01$) between days to 20% pedicel necrosis with proportion of fruits with ≤20% pedicel necrosis at 4, 6, 8, 10, 11, 13, 15, and 17 DAH, with the correlation coefficients increasing with time up to 13 DAH. As early as 8 DAH, number of days to 20% pedicel necrosis per accession at the end of the study period can be predicted with the following linear equation: number of days to 20% pedicel necrosis = 7.1 (arcsin proportion of fruits with ≤20% pedicel necrosis at 8 DAH) + 6.1, $R^2 = 0.94$.

Fruits with total pedicel and calyx necrosis. There were significant differences ($P < 0.001$) among accessions with respect to proportion of fruits with total pedicel/calyx necrosis from 8 DAH onwards (Table 1). At 8 DAH, 18.6% of the fruits showed total pedicel/calyx necrosis on average across all accessions, and the proportions increased to 38.4%, 44.9%, 52.8%, 63.7%, and 87.9% at 10, 11, 13, 15, and 17 DAH, respectively. Overall, MB16 had the smallest number of days to total pedicel/calyx necrosis (6.7 DAH), whereas MB17 had the largest value (18.2 DAH), with the general mean being 13.0 DAH.

Table 1. Fruit fresh weight (grams); mean days after harvest (DAH) to incipient pedicel necrosis, 20% pedicel necrosis, total pedicel/calyc necrosis, and incipient pericarp necrosis; mean weight loss slope, intercept, and coefficient of determination for 34 pepper (*Capsicum chinense* Jacq.) accessions under controlled storage conditions.

Accession	Fruit fresh wt (g)	Days to necrosis (DAH)				Wt loss		
		Pedicel			Pericarp	Slope	Intercept	R ²
		Incipient	≤20%	100%				
MB14	11.8	6.2	14.2	15.3	17.3	-0.23	11.91	0.85
MB16	12.8	6.3	6.6	6.7	7.3	-0.55	13.62	0.92
MB17	13.5	6.3	16.9	18.2	19.5	-0.14	13.39	0.97
MB18	13.7	6.7	16.3	17.8	18.2	-0.18	13.61	0.78
S20	14.6	8.1	14.9	16.2	16.6	-0.19	14.32	0.98
S21	5.2	6.8	16.9	17.3	18.1	-0.08	5.17	0.99
F10	9.4	8.7	12.6	13.7	14.5	-0.23	9.15	0.98
F11	9.4	7.7	12.0	13.2	16.8	-0.23	9.20	0.99
F12	9.9	7.0	13.6	14.7	16.5	-0.19	9.88	0.99
F13	10.1	6.6	12.2	13.5	15.1	-0.16	10.12	0.91
F22	10.5	7.5	12.2	13.6	14.3	-0.16	10.29	0.98
F9	7.9	8.7	13.2	14.4	16.2	-0.17	7.75	0.99
H1	10.0	7.7	15.3	16.1	16.3	-0.16	10.03	0.97
L26	15.4	7.5	9.5	9.7	10.5	-0.44	16.14	0.80
L27	12.6	7.1	13.2	15.2	16.5	-0.26	12.76	0.91
L29	9.2	5.9	11.3	11.9	12.9	-0.21	9.09	0.92
L30	13.5	7.8	11.8	13.4	15.9	-0.34	13.84	0.81
L31	10.7	8.6	9.8	10.1	10.4	-0.29	10.94	0.80
L33	9.2	7.2	10.6	11.0	11.1	-0.22	9.00	0.97
L52	6.5	6.1	8.5	8.7	9.1	-0.19	6.42	0.81
L53	6.6	6.9	10.5	11.3	11.6	-0.22	6.42	0.99
L54	8.7	9.0	12.4	13.3	14.4	-0.21	8.44	0.98
L55	7.4	6.9	11.1	12.7	14.7	-0.15	7.18	0.94
L561	9.9	7.7	12.6	13.8	14.4	-0.15	8.24	0.45
L562	9.9	7.1	13.7	14.9	16.3	-0.21	9.82	0.99
L58	12.6	8.3	10.8	11.4	12.4	-0.37	13.25	0.86
L59	12.7	6.4	12.7	13.6	14.2	-0.27	12.76	0.93
L60	7.5	5.3	10.0	10.7	10.9	-0.18	7.27	0.98
L62	7.4	5.8	12.4	14.3	14.7	-0.12	7.25	0.98
L64	8.8	6.4	12.0	13.8	14.1	-0.20	8.85	0.98
L66	10.1	7.4	11.5	12.1	14.0	-0.24	10.12	0.95
SC5	5.2	7.7	9.3	9.8	10.3	-0.16	5.38	0.86
SP6	9.3	6.3	8.2	8.3	8.8	-0.34	9.29	0.99
SP7	6.1	6.5	10.2	10.5	11.0	-0.18	6.37	0.83
Significance (<i>P</i> <)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	—
Mean	9.9	7.1	12.0	13.0	14.0	-0.22	9.92	—
SEM	0.78	0.45	0.50	0.63	0.73	0.042	0.773	—
LSD	1.82	1.05	1.17	1.48	1.72	0.099	1.815	—
cv within	0.32	0.11	0.07	0.08	0.09	-0.081	0.135	—
cv between	0.27	0.13	0.20	0.21	0.21	-0.414	0.284	—
ID	0.9	1.2	2.9	2.6	2.4	5.1	2.1	—

LSD = least significant difference; ID = index of discrimination.

The correlations between number of days to total pedicel/calyc necrosis with arcsin proportion of fruits with total pedicel/calyc necrosis at 4, 6, 8, 10, 11, 13, 15, and 17 DAH were highly significant ($r = 0.47$ to 0.97 , $P < 0.01$), with the correlation coefficients increasing with time up to 13 DAH. The results show that the number of days to total pedicel/calyc necrosis at the end of study period can be predicted reasonably well at 10 DAH using the equation: number of days to total pedicel/calyc necrosis = 8.7 (arcsin proportion of fruits with total pedicel/calyc necrosis at 10 DAH) + 6.9 ; $R^2 = 0.94$.

Incipient pericarp necrosis. There were significant differences ($P < 0.001$) among accessions with respect to days to incipient pericarp necrosis (Table 1). The average proportion of fruits overall accessions with incipient pericarp necrosis increased gradually from 10.8% to 89.3% over the period 7 to 17 DAH. At 17 DAH, 17 accessions showed 100% incipient pericarp necrosis, whereas

MB17 (10.1%) had the smallest proportion. Overall, MB16 had the fewest days to incipient pericarp necrosis (7.3 DAH) whereas MB17 had the largest value (19.5 DAH), the general mean being 14.0 DAH. The results show that days to incipient pericarp necrosis at the end of the study can be predicted as early as 9 DAH using the following linear equation: days to incipient pericarp necrosis = -8.8 (arcsin proportion of fruits with incipient pericarp necrosis at 9 DAH) + 16.7 ; $R^2 = 0.82$.

Fruit fresh weight at harvest did not show significant correlations ($r = 0.18$ to 0.27 , $P > 0.05$) with days to incipient pedicel necrosis, 20% pedicel necrosis, total pedicel/calyc necrosis, or incipient pericarp necrosis. Days to incipient pedicel necrosis did not show significant correlations with either days to 20% pedicel necrosis, total pedicel/calyc necrosis, or incipient pericarp necrosis (data not shown). However, days to 20% pedicel necrosis showed strong significant correlations

($P < 0.001$) with days to total pedicel/calyc necrosis ($r = 0.99$) and days to incipient pericarp necrosis ($r = 0.94$). Similarly, the correlation between days to total pedicel/calyc necrosis and days to incipient pericarp necrosis was large ($r = 0.97$) and significant ($P < 0.001$).

Among the various measures of shelf life in pepper, days to 20% pedicel necrosis had the largest ID (2.9) followed by days to total pedicel/calyc necrosis (2.6), days to incipient pericarp necrosis (2.4), and days to incipient pedicel necrosis (1.2) (Table 1).

Shrivelling score. There were significant differences ($P < 0.05$) among the pepper accessions with regard to the shrivelling score from 6 to 14 DAH (data not shown). The mean shrivelling scores overall accessions increased gradually from 0.4 at 6 DAH, to 0.7 at 8 DAH, to 1.8 at 10 DAH, and to 2.1 at 14 DAH. Shrivelling scores at 6, 8, 10, and 14 DAH correlated ($r = 0.44$ to 0.91 , $P < 0.01$) among themselves (Table 2). However, shrivelling score did not show significant correlations ($P > 0.05$) with fruit fresh weight, days to incipient pedicel necrosis, or proportion of fruits with incipient pedicel necrosis over time (data not shown). Shrivelling scores did not show significant correlations ($P > 0.05$) with arcsin proportion of fruits with ≤20% pedicel necrosis, total pedicel/calyc necrosis, or incipient pericarp necrosis (data not shown).

Weight loss for the 34 pepper accessions. Weight loss for each of the 34 pepper accessions from 2 to 14 DAH showed linear decreases (R^2 of 0.45 to 0.99, mean = 0.91) over time albeit at different rates (Table 1). Weight loss slope ranged from -0.08 in S21 to -0.55 in MB16, with a mean of -0.22 . S21 also had the smallest intercept (5.17) whereas L26 had the largest (16.14), the general mean was 9.92. Weight loss slope showed a 5-fold variation among the pepper accessions, whereas weight loss intercept showed a 2-fold variation.

Arcsin percentage weight loss over time showed small but significant ($r = 0.35$ to 0.45 ; $P < 0.05$) correlations with shrivelling scores over time (data not shown). Fruit fresh weight did not show significant correlations with arcsin percentage weight loss over time (data not shown), but fruit fresh weight showed a significant negative correlation ($r = -0.55$, $P < 0.01$) with weight loss slope. Weight loss intercept showed small but significant correlations ($r = -0.34$ to -0.37 , $P < 0.05$) with shrivelling score from 8 to 14 DAH but weight loss slope did not correlate with shrivelling score (Table 2).

Neither arcsin percentage weight loss over time, weight loss slope, nor intercept showed a significant correlation with days to incipient pedicel necrosis or proportion of fruits with incipient pedicel necrosis over time (data not shown). However, arcsin percentage weight loss at 8, 10, 12, and 14 DAH showed significant correlations ($P < 0.05$ to 0.01) with arcsin proportion of fruits with ≤20% pedicel necrosis ($r = -0.37$ to -0.89), total pedicel/calyc necrosis from 8 to

17 DAH ($r = -0.40$ to -0.90), and incipient pericarp necrosis from 9 to 17 DAH ($r = 0.39$ to 0.83) (Table 3), with the correlation coefficients getting larger over time. Arcsin percentage weight loss at 8, 10, 12, and 14 DAH also showed significant negative correlations ($P < 0.01$) with days to 20% pedicel necrosis ($r = -0.55$ to -0.87), total pedicel/calyx necrosis ($r = -0.55$ to -0.89), and incipient pericarp necrosis ($r = -0.53$ to -0.83), with the correlation coefficients improving over time (Table 3).

Weight loss slope showed significant correlations with proportion of fruits with $\leq 20\%$ pedicel necrosis from 6 to 15 DAH, days to 20% pedicel necrosis, proportion of fruits with total pedicel/calyx necrosis at 4 DAH and from 8 to 15 DAH, days to total pedicel/calyx necrosis, days to incipient pericarp necrosis ($r = 0.39$ to 0.60 , $P < 0.05$ to 0.01), and proportion of fruits with incipient

pericarp necrosis at 5 DAH and from 9 to 15 DAH and ($r = -0.34$ to -0.59 , $P < 0.05$ to 0.01) (Table 3).

Discussion

This study showed that there exists a wide variation in cultivated pepper (*C. chinense* Jacq.) accessions with respect to fruit fresh weight (from 5.2 to 15.4 g). These results support the findings of a recent study that showed a high degree of genetic variability among *C. chinense* cultivated in the Caribbean using molecular markers (Moses and Umaharan, 2012; Moses et al., 2014).

In chile pepper (*C. annuum* L.), water loss, shrivelling, pericarp color changes, and pericarp necrosis indicate the progression of postharvest deterioration (Walker, 2010). Under controlled storage conditions, the *C. chinense* accessions showed progressive deterioration albeit at different rates. The deterioration was first evident as incipient pedicel necrosis, which progressed gradually and covered the entire pedicel and calyx. The fruit deterioration then progressed into the pericarp. Fruits also showed shrivelling, which progressed over time as a result of moisture loss.

Although incipient pedicel necrosis was the first physiological parameter of fruit degradation that was observed during pepper storage in this study, it did not correlate very well with other parameters that monitored progression of deterioration. This may suggest that incipient pedicel necrosis is governed by a different mechanism. Although

days to 20% pedicel necrosis, total pedicel/calyx necrosis, incipient pericarp necrosis, as well as weight loss slope showed significant ($P \leq 0.05$) correlations among themselves, Maalekuu et al. (2005) working with *C. annuum* showed that water loss occurs mainly via the pericarp with insignificant amounts occurring via the pedicel. Hence, the strong correlation between water loss and pedicel necrosis in this study suggests that the two processes although independent, occur simultaneously. Several previous studies (Lownds et al., 1994; Ryan and Lipton, 1972; Showalter, 1973; Smith et al., 2006; Watada et al., 1987) have shown that postharvest water loss is the primary factor limiting shelf life in *C. annuum*.

Although shrivelling score showed small but significant correlations with weight loss and hence water loss, it did not show significant correlations with arcsin proportion of fruits showing pedicel necrosis ($\leq 20\%$ or total pedicel/calyx), incipient pericarp necrosis, days to pedicel necrosis ($\leq 20\%$ or total pedicel/calyx), or days to incipient pericarp necrosis. Further, the fact that fruits achieved a shrivelling score of 2.1 at 14 DAH suggested that shrivelling became a factor when fruits were already not marketable (mean of 12 DAH) or processable (mean of 13 DAH).

Fruit fresh weight showed a significant negative correlation with fruit weight loss slope in this study, suggesting that fruits that are heavier at harvest have lower water loss rates. This observation is very similar to that noted in *C. annuum* by Lownds et al. (1993) and Maalekuu et al. (2004, 2005). Weight loss slope was negatively correlated ($P < 0.05$) with arcsin percentage weight loss only from 8 to 14 DAH. This result suggests that pepper accessions with smaller fruit sizes and larger water loss rates lose less water during the latter periods of storage. This may also point to the fact that pedicel necrosis, which accounts for varietal differences as early as 6 DAH is independent of water loss.

This study showed that shelf life based on a 20 d storage experiment can be predicted reliably as early as 8 or 10 DAH based on pedicel necrosis ($R^2 = 0.94$) or incipient pericarp necrosis (9 DAH; $R^2 = 0.82$). Prediction equations developed in this study have also been shown to accurately predict the shelf life of a variable set of pepper accessions grown in the Caribbean. The results show that these measures can reduce the time of shelf life experiments by half.

Days to 20% pedicel necrosis and days to total pedicel/calyx necrosis showed an almost 3-fold variation while days to incipient pericarp necrosis showed a 2-fold variation among the 34 pepper accessions. Based on days to 20% necrosis of the pedicel, five accessions, viz. H1, MB17, MB18, S20, and S21 have a shelf life of 15 d or more. As reported by Sinha and Petersen (2011) and observed in this study, incipient fruit necrosis quickly followed total pedicel/calyx necrosis (mean of one day between the two). The study showed that of the measures of shelf life, days to 20% necrosis of the pedicel had

Table 2. Pearson's product moment correlations between shrivelling scores over time, weight loss slope, and intercept for 34 pepper accessions (*Capsicum chinense* Jacq.) under controlled storage conditions.

	Shrivelling score at DAH				Wt loss	
	6	8	10	14	Slope	Intercept
4	0.20	0.17	0.27	0.24	-0.02	-0.04
6		0.81	0.44	0.44	0.00	-0.26
8			0.67	0.63	0.03	-0.34
10				0.91	0.18	-0.36
14					0.27	-0.37

Correlation coefficient is significant for 32 df at $P < 0.05$ and $P < 0.01$ when $r = 0.34$ and 0.44 , respectively.

Table 3. Pearson's product moment correlations between arcsin percentage weight loss, and weight loss slope with arcsin proportion of fruits with $\leq 20\%$ pedicel necrosis, total pedicel/calyx necrosis, incipient pericarp necrosis over time; and days after harvest (DAH) to 20% pedicel necrosis, total pedicel/calyx necrosis, incipient pericarp necrosis for 34 pepper accessions (*Capsicum chinense* Jacq.) evaluated under controlled storage conditions.

	DAH	Arcsin percentage wt loss at DAH					Wt loss slope
		6	8	10	12	14	
Arcsin proportion of fruits with $\leq 20\%$ pedicel necrosis	4	-0.36	-0.34	-0.40	-0.30	-0.51	0.23
	6	-0.24	-0.30	-0.32	-0.28	-0.72	0.40
	8	-0.28	-0.52	-0.57	-0.62	-0.86	0.60
	10	-0.32	-0.51	-0.56	-0.63	-0.89	0.57
	11	-0.32	-0.48	-0.53	-0.61	-0.86	0.54
	13	-0.27	-0.47	-0.51	-0.58	-0.79	0.48
	15	-0.20	-0.37	-0.41	-0.48	-0.65	0.37
	17	-0.23	-0.37	-0.39	-0.47	-0.43	0.32
Days to 20% necrosis of the pedicel		-0.32	-0.55	-0.59	-0.65	-0.87	0.57
Arcsin proportion of fruits with total pedicel/calyx necrosis	4	-0.04	-0.08	-0.20	-0.17	-0.56	0.39
	6	-0.11	-0.09	-0.22	-0.14	-0.56	0.32
	8	-0.26	-0.46	-0.52	-0.51	-0.79	0.53
	10	-0.31	-0.51	-0.55	-0.63	-0.90	0.58
	11	-0.34	-0.53	-0.56	-0.64	-0.88	0.55
	13	-0.31	-0.49	-0.52	-0.58	-0.82	0.51
	15	-0.25	-0.45	-0.48	-0.56	-0.75	0.44
	17	-0.25	-0.40	-0.44	-0.49	-0.46	0.33
Days to total pedicel/calyx necrosis		-0.31	-0.55	-0.59	-0.66	-0.89	0.58
Arcsin proportion of fruits with incipient pericarp necrosis	5	0.29	0.47	0.51	0.53	0.74	-0.47
	7	0.21	0.20	0.30	0.25	0.64	-0.24
	9	0.25	0.55	0.59	0.65	0.83	-0.59
	11	0.30	0.56	0.58	0.63	0.80	-0.53
	13	0.29	0.52	0.54	0.57	0.77	-0.49
	15	0.31	0.51	0.52	0.59	0.75	-0.46
	17	0.26	0.39	0.44	0.48	0.46	-0.34
DAH to incipient pericarp necrosis		-0.32	-0.53	-0.58	-0.62	-0.83	0.52

Correlation coefficient is significant for 32 df at $P < 0.05$ and $P < 0.01$ when $r = 0.34$ and 0.44 , respectively.

the largest ID followed by days to total pedicel/calyx necrosis. These two measures therefore would be the best measures to discriminate between pepper accessions.

Based on these evaluations, it is suggested that $\leq 20\%$ pedicel necrosis be used as the measure for determining shelf life for various reasons. Firstly, this is the first occurring symptom in storage in all pepper accessions. Secondly, it can be used to predict shelf life as early as 8 DAH. Thirdly, it is also the measure that shows the largest variation among peppers (almost 3-fold variation) and finally it is the most reliable as a measure with the largest index of differentiation. It is proposed that this would be a fairly quick method to phenotypically characterize shelf life in breeding trials.

According to a recent unpublished market survey carried out in 2014 by the University of the West Indies, a vast majority of pepper fruits with no defects in color, size, shape, and possessing $\leq 20\%$ necrosis of the pedicel are marketable as fresh produce, while those with $>20\%$ pedicel necrosis but no pericarp necrosis can also be used in the processing industry to produce pepper flakes and sauces. This market survey suggested that the best parameters for evaluating shelf life in pepper were days to 20% necrosis of the pedicel, which determines the number of days that peppers can be marketed as fresh produce and days to incipient pericarp necrosis, which determines the number of days that peppers can remain in storage and still be processed into sauces and flakes. Hence these two measures have practical relevance to the marketability of pepper in the Caribbean.

For this study, pepper fruits were picked early in the day when the temperatures were cool, stored and transported quickly to the laboratory under optimum conditions (low temperature and high relative humidity) as this is best practice (Samira et al., 2013). High temperatures increase the vapour pressure difference between the fruit and the surrounding, which is the driving potential for faster moisture transfer from the fruit to the surrounding air (Hardenburg et al., 1986). Also, high temperatures cause the pericarps and pedicels to lose turgidity or firmness, making detachment of the fruits from the plants more difficult (Sinha and Petersen, 2011). It is therefore recommended that pepper be harvested during the cooler parts of the day such as early morning or late evening (Sinha and Petersen, 2011) and taken immediately to storage to ensure maximum shelf life.

In conclusion, the study showed a large variation for shelf life among pepper accessions grown in the Caribbean. Shelf life based on days to 20% necrosis of the pedicel as well as days to total pedicel/calyx necrosis and days to incipient pericarp necrosis were

found to be highly correlated and showed parallels with moisture loss rates. Pepper accessions with larger fresh weights had lower rates of water loss and therefore longer shelf lives. The results, however, show that pedicel deterioration may precede the direct effects of moisture loss observed as loss of gloss, flaccidity, and shrivelling, which are also difficult to measure quantitatively. Days to 20% necrosis of the pedicel, total pedicel/calyx necrosis, and incipient pericarp necrosis had the largest indices of discrimination of all the shelf life parameters measured. Days to 20% pedicel necrosis taken at 8 DAH is suggested as the best measure of shelf life due to its early predictability, large variation, and reliability as a measure. Based on days to 20% pedicel necrosis, the study identifies five accessions viz. H1, MB17, MB18, S20, and S21 as having the best shelf lives of 15 or more days.

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