Using Amaranth as a Model Plant for Evaluating Imperfect Storages: Assessment of Solar-refrigerated and Evaporatively-cooled Structures in India

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Abstract. Some storages have limited control over their internal environment and undergo daily and seasonal fluctuations in both temperature and humidity, which cause variation in the metabolic activity of stored products. As a result, it is difficult to assess and compare the performance of these imperfect storages using measures of environmental control. We propose using measures of plant senescence as a proxy for estimating storage performance of these “imperfect” storages based on the premise that physiological processes integrate changes of temperature and/or humidity in a predictable, mathematically describable manner. We evaluated amaranth (*Amaranthus tricolor* L.) as a model plant for evaluating imperfect storages using a red-leaf cultivar Pusa lal chaulai and a green-leaf cultivar Pusa kiran. Amaranth is a leafy vegetable grown worldwide and is a highly nutritious and versatile food. Cumulative respiration, a measure of integrated metabolic activity, was regressed against leaf abscission, chlorophyll loss, and leaf yellowing of amaranth stems for four storages having different, variable, temperature profiles. Storages included 1) an evaporatively cooled (EC) structure; 2) a solar-refrigerated and evaporatively cooled (SREC) structure; 3) an uncooled laboratory (UL); and 4) a household refrigerator (REF). We found that the rate of abscission, chlorophyll loss, and leaf yellowing differed markedly for the four storages; however, these measures of senescence were linearly related to estimates of cumulative respiration. The ease of measuring leaf abscission, chlorophyll loss, and leaf yellowing permits data collection even with minimal resources. We propose that amaranth would make an effective model plant for comparing the performance of storages differing dramatically in temperature control. A 10% leaf abscission in amaranth is proposed as a target for comparing storages.

Smallholder farmers in developing countries do not have easy access to cold storage for several reasons. Cold storages with good control of temperature and humidity are energy intensive and expensive, involve a large initial capital investment, and require an uninterrupted electrical grid supply, which is not readily available in many farm communities. The publication of the National Institute for Transforming India noted that the lack of cold chain infrastructure was linked to an estimated INR 92,561 crore (US\$12.1 billion) annually and that many of the existing resources are inefficiently used

by being dedicated to single commodities (NITI Aayog, 2018). Food losses of more than 40% occur at postharvest and processing levels in developing countries (FAO, 2011). Rais and Sheoran (2015) reported that postharvest losses in India were 25% to 30% due to lack of cold storage facilities and cold supply chain, and that these losses have lowered the per capita availability of fruits and vegetables in India and commented that only 10% to 11% of Indian fruits and vegetables are provided cold storage and that capacity needs to be increased by 40%. In India alone, there are $\approx$ 136.8 million small

and family operated farms that have the potential to benefit from on-farm or community coolers (Lowder et al., 2016).

Lacking the capital for investment and the infrastructure to sustain typical cold storage facilities, low-cost, low-energy, EC chambers can serve as a useful alternative to cold stores for short-term, on-farm storage by smallholder farmers (Ambuko et al., 2017; Chopra et al., 2004b; Mogaji and Fapetu, 2011). These storages are affordable, environment-friendly, and can be made from locally available materials. A number of EC chamber designs exist, including a clay pot within a pot, separated by wet sand (e.g., pot-in-pot or Zeer pot), a chamber covered with wet cloth (e.g., Coolgardie Safe), chambers with wet pads and fan (e.g., “swamp cooler”), storages with wettable (often sand) packing in between wetted exterior walls (e.g., Zero Energy Brick Cooler or ZEBC) (Ambuko et al., 2017; Chopra et al., 2004a, 2004b; Habibunnisa et al., 1988; Jha and Chopra, 2006; Longmone, 2003; MAAS, 2012), and hybrid refrigeration and EC storage (Chopra and Beaudry, 2018a). All are better suited to use in hot and dry conditions, where evaporation and temperature suppression are maximized (Basediya et al., 2013). At best, the internal temperature reduction in traditional brick-sand-brick (BSB) EC storages is $\approx$ 10 to 15 °C and relative humidity is reported to be 85% to 90% (Chopra et al., 2004a, 2004b; Jahun et al., 2013; Roy and Khurdiya, 1986). The temperatures and humidity in these storages fluctuate daily and seasonally in accordance with ambient temperatures and humidities and are not very precisely controlled. Chopra and Beaudry (2018b) described how walls composed of pervious-concrete and mesh-fabric provided improved cooling compared to the conventional wall because of their lower thermal mass and higher thermal transmittance.

EC structures are inherently “imperfect” in that they have hourly, daily, and seasonal fluctuations in both temperature and humidity (Chopra and Beaudry, 2018a; Chopra et al., 2004b). For these and other structures or chambers having fluctuating conditions, it is difficult to evaluate and compare performance and efficacy for predicting the storage of perishables. We propose that a “model” plant material might prove an efficacious way to compare imperfect storage technologies. A model plant material would have to be available worldwide, be easy to produce, and undergo simple-to-measure changes in appearance and quality. In poorer, developing regions, agricultural research laboratories are not always outfitted with sophisticated equipment, so the use of simple and inexpensive parameters for evaluating storage performance can have some advantages.

Amaranth (*Amaranthus* spp.) is a perishable agricultural commodity, grown worldwide by farmers, and available throughout the year in tropical and subtropical climates. In India, it is popularly known as “Chaulai” and is an important and popular leafy crop. The species grown for vegetables are represented

mainly by *A. tricolor*, *Amaranthus dubius*, *Amaranthus lividus*, and *Amaranthus hybridus* (Ebert et al., 2011; Onyango, 2010). Amaranthus is a rich source of nutrients and serves as an alternative source of nutrition for people in developing countries. Tender stems and leaves of green and red morph genotypes of amaranth are a good source of protein, vitamins, and dietary fiber. On a fresh weight (FW) basis, they contain moisture (84%, wet basis), protein (32 g·kg⁻¹), fat (3 g·kg⁻¹), carbohydrates (70 g·kg⁻¹), and vitamin C (0.85 mg·g⁻¹); and on a dry weight basis, potassium (27 mg·g⁻¹), calcium (20 mg·g⁻¹), magnesium (27 mg·g⁻¹), and iron (0.7 g·kg⁻¹) (Prakash and Pal, 1991; Sarker and Oba, 2019; Sarker et al., 2020; Shukla et al., 2006; Singh et al., 2001), and possess abundant antioxidants (Ebert et al., 2011; Khanam and Oba, 2013; Mampholo et al., 2015; Nyaura et al., 2014).

Temperature is one of the most crucial factors influencing the rate of metabolism of perishables, including metabolic activities associated with senescence and ripening (Kays and Paull, 2004; Liberty et al., 2013; Platenius, 1942). Respiration rate is a direct indicator of the level of total sum of metabolic activity and a high rate of respiration is associated with short shelf life (Agudelo et al., 2016; Onyango, 2010; Tano et al., 2005). There is a 2- to 3-fold increase in the deterioration rate for every 10 °C rise in temperature above optimum temperature (Fonseca et al., 2002; Kays and Paull, 2004; Mangaraj and Goswami, 2011). More specifically, the rate of senescence in stored amaranth has been shown to be highly dependent on storage temperature (Nyaura et al., 2014).

Our objective was to evaluate amaranth as a possible model plant material for the evaluation of the performance of imperfect storages. We studied parameters of senescence (leaf abscission, leaf yellowing, and chlorophyll loss) as they related to an estimate of the total metabolic activity experienced by amaranth stems for four storages differing in their degree of temperature control. These

storages included UL, REF, EC storage, and SREC storage.

Materials and Methods

The rate of senescence of amaranth was determined using three “imperfect” storages and a household REF, the latter achieving the lowest and most consistent temperatures (see descriptions that follow). The respiratory activity of amaranth was estimated based on previous studies by calculating the respiratory response of amaranth to temperature and integration over time to obtain an estimate of the total sum of metabolic activity. The change in senescence parameters was tracked over time and related to cumulative respiratory activity.

Experimental site and raw materials. The study was conducted at the Division of Agricultural Engineering, ICAR-IARI, New Delhi. Two cultivars of amaranth (*A. tricolor* L.) were used: 1) red amaranth ‘Pusa lal chaulai’, also called ‘Lal Sag’ (Ebert et al., 2011) and 2) green amaranth ‘Pusa kiran’. Amaranth stems ≈0.3 m in length were harvested early in the morning from the farm of the Division of Vegetable Science at ICAR-IARI. Stems with healthy and unbroken leaves, of uniform color, were selected for use. For the evaluation of senescence parameters, each sample consisted of an amaranth stem wrapped in a damp cloth and put inside a low-density polyethylene (0.35 × 0.25 m) zip-lock packaging bag to minimize moisture loss. For the evaluation of moisture loss, three 500-g bundles of amaranth were kept in crates in each storage structure and weights taken at several timepoints during storage using a digital weighing balance. Cumulative weight loss was determined and expressed as weight loss as percentage of the initial weight. The experiments were carried out from June to September in 2018 and 2019; more than 1230 samples were evaluated. The length of the storage duration was either 8 or 26 d, with the longer durations used for the lowest temperature environment in the household refrigerator. Sample numbers per treatment combination varied from 3 to 10. Each cultivar/storage type combination was replicated three times, with the exception of EC in combination with red amaranth and REF in combination with green amaranth, both of which had only two replications.

Storage structures. There were four storages: 1) SREC, 2) EC, 3) UL, and 4) REF used in this study, the latter of which was considered as a control. Two of the storage structures were specially built. One was an EC structure made of mesh-fabric walls of capacity 2 tons as previously described (Chopra and Beaudry, 2018b). The SREC storage (Fig. 1) was similar in construction to the EC storage, being identical in size (3 m × 3 m × 3 m) and construction to the EC structure and having a storage capacity for up to 2 t of fruits and vegetables. The SREC was insulated with 5-cm-thick panels of styrofoam and refrigerated by an air conditioner

modified (with split evaporator coil with thermal storage) to generate air temperatures as low as 5 °C. The refrigeration system was run from a photovoltaic array of fourteen 330-W panels (CS6U-330P; Canadian Solar Inc., Guelph, Ontario, Canada) whose power was inverted to AC using a 5-kW inverter (MPP 5048; MPP Solar Inc., Taipei, Taiwan). The evaporative cooling was coupled with the solar-powered refrigeration system to reduce heat load, enabling the use of a smaller solar panel array and smaller capacity refrigeration system (Chopra and Beaudry, 2018a). The UL storage was an unshaded, metal-roofed, brick research barn at the IARI campus. The REF storage was located in an adjacent air-conditioned laboratory.

The air temperature in these four storages was measured by T-type (copper-constantan) thermocouples and logged every 15 min in a datalogger (CR10X; Campbell Scientific, Logan, UT). In addition, a thermocouple was placed in a 1-cm-wide, 10-cm-long water-soaked cotton sock over which air could pass, to measure wet bulb temperature. The relative humidity (%) was calculated by the empirical relationship between wet and dry bulb temperatures (Vaisala, 2013). Temperature data were downloaded from the datalogger onto a computer with PC400W software (Campbell Scientific).

Mathematical model for respiration of whole amaranth stems. To relate the rate of senescence processes to the varying temperatures in the storage structures, a model was developed to relate temperature to the rate metabolic activity using the rate of respiration as a proxy for the rate of metabolism. Dark respiration rate was used as a measure of global metabolic activity because respiratory activity provides the needed energy and carbon skeletons for all metabolic reactions (Kays and Paull, 2004). The assumption that the temperature sensitivity of global metabolic activity accurately reflects senescent processes is tentative; however, the temperature sensitivities of individual processes of senescence are not published to our knowledge. It was assumed that the rate of metabolism was instantaneously responsive to temperature and that senescence-related metabolic activity was unidirectional in the direction of greater and more complete senescence, thus permitting integration of metabolic activity over time.

The linearized Arrhenius equation (Eq. [1]) was used to estimate respiration rate (r_{CO_2}) for amaranth on a FW basis for different temperatures, where apparent energy of activation (E_a , kJ·mol⁻¹) characterizes the temperature dependence of r_{CO_2} and A (g·kg⁻¹·h⁻¹) is the Arrhenius factor (Eriko et al., 2001; Fonseca et al., 2002).

$$\ln(r_{CO_2}) = \frac{-E_a}{R} \frac{1}{T} + \ln A, \quad [1]$$

where R = universal gas constant (0.0083144 kJ·mol⁻¹·K⁻¹) and T = temperature (K).

Published literature on the rate of respiration (r_{CO_2}) of amaranth (whole plant and leaves) consisted of three studies that reported respiration at storage temperatures ranging from 5 to 42 °C (Bunce, 2007; Byrd

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et al., 1992; Thammawong et al., 2019). To convert published values to similar units ($\text{g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$) on a FW basis, leaf area, weight, and moisture content of amaranth (Jangde et al., 2018; Mujaffar and Loy, 2016; Singh et al., 2014) were used.

An Arrhenius plot of previously published data (Fig. 2, inset) indicated that the natural log of r_{CO_2} depended linearly on the reciprocal of temperature. The values of apparent E_a and A for amaranth from the fitted line were $55.8 \text{ kJ}\cdot\text{mol}^{-1}$ and $2.16 \text{ E}9 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$, respectively. The coefficient of determination (r^2) value was 0.90. The exponential equation for predicting respiration rate (Eq. [2]) had a temperature coefficient of 6707.64 K.

$$r_{\text{CO}_2} = 2.16 \times 9 e^{(-6707.64/T)}, \quad [2]$$

where T = temperature (K).

The r_{CO_2} ($\text{g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$) of amaranth was calculated from the temperature profile of the four storage structures (SREC, EC, UL, and REF) from Eq. [2] as depicted (Fig. 2). The integrated respiratory activity over time ($\text{g}\cdot\text{kg}^{-1}$) was used to estimate cumulative CO_2 respired.

Measures of senescence and their assessment. Leaf abscission (%) was calculated as the ratio of number of detached leaves from each sample/branch and total number of initial leaves. Abscised leaves were measured after stems were removed from the

storage bags and agitated slightly. Only leaves longer than 1 cm were considered. Yellowing (%) was assessed for both attached and detached leaves and was calculated as the ratio of leaves exhibiting any yellow areas to total number of leaves. Both yellowing and leaf abscission were observed on day 0 and every 1 or 2 d subsequently. Chlorophyll was extracted from fully expanded leaves by a non-maceration method (Hiscox and Israelstam, 1979). Randomly selected leaves were cut into small pieces and a subsample (25 mg) was added to 5 mL dimethyl sulfoxide. The test tubes were kept in an oven at 65°C for 4 h to facilitate the extraction of chlorophyll into the solution. The absorbance of solution was measured at 645 and 663 nm using double-beam ultraviolet-Visible spectrophotometer (Model No. LMSP-UV1900; Labman Scientific Instruments Pvt. Ltd., Chennai, India). The total chlorophyll was calculated according to Arnon (1949) (Eq. [3]).

$$\begin{aligned} \text{Total chlorophyll (mg}\cdot\text{L}^{-1}) \\ = 20.2 D_{645} + 8.02 D_{663}, \end{aligned} \quad [3]$$

where D is absorbance for a 1-cm path. The total chlorophyll was expressed as $\text{mg}\cdot\text{g}^{-1}$ FW, after considering extraction volume (0.005 L) and FW (0.025 g) of amaranth sample used for chlorophyll estimation.

Senescence parameters were observed on day 0 and every 1 to 2 d during storage. The measures of senescence [i.e., leaf abscission (%), chlorophyll ($\text{mg}\cdot\text{g}^{-1}$) and yellowing (%)] were regressed against estimated cumulative CO_2 respired for pooled data from all trial runs for all storage structure/cultivar combinations (Eq. [4]).

$$\begin{aligned} \text{Measure of senescence} &= b_1 * \\ &(\text{estimated cumulative } \text{CO}_2) + b_0 \end{aligned} \quad [4]$$

Threshold and storability. Leaf abscission (%) was used to determine the storability of amaranth for each storage structure, as it was less variable and subjective than yellowing assessment and simpler to measure than chlorophyll content. Leaf abscission was plotted against estimated cumulative CO_2 respired for all trial runs for all storages. The data were then subjected to linear regression analysis. The upper 99% confidence limits (UCLs) were used to generate a conservative estimate of cumulative CO_2 respired for 10%, 20%, 30%, and 40% threshold levels of leaf abscission. Adopting the 99% UCL would reduce risk of excessive leaf loss compared with the fitted line. Then, for each storage structure/cultivar/leaf abscission threshold combination, the number of days required to reach the cumulative CO_2 respired was determined and was taken to represent the end-of-storability. In addition, for each of the four leaf abscission thresholds, the actual (observed) leaf loss, degree of yellowing, chlorophyll content, and moisture loss was determined when the end of end-of-storability was reached. The point of time when end-of-storability was reached was

typically between assessment dates, so values for leaf loss, degree of yellowing, chlorophyll content and moisture loss were obtained by linear interpolation between successive assessment dates.

Statistical analysis. The data collected were subjected to univariate analysis, including analysis of variance and separation of means by the least significant difference method followed by Tukey's honestly significant difference test for observed means at $\alpha = 0.05$, using a statistical package IBM SPSS Statistics V25 (IBM Corp., Armonk, NY). The impact of storage type and cultivar on experimental values of temperature, estimated CO_2 respired, senescence parameters, and water loss was evaluated after 8.4 d. Further, a one-sample t -test was done to determine if the four target thresholds of leaf abscission (10%, 20%, 30%, and 40%) generated from the model regression using all data differed from observed values of leaf abscission at end-of-storability for the four storage types.

Results and Discussion

Temperature and relative humidity profile of storages. The temperature and relative humidity (RH) profile in the four storage types, SREC, EC, UL, and REF, was tracked over the course of each experiment. For a typical experimental run, the temperature in UL varied between 22.5°C , the lowest nighttime temperature, and 40.4°C , the highest daytime temperature (Fig. 3). During this period, the temperature in EC varied from 25.0 to 36.0°C and that in SREC ranged from 6 to 20°C . REF storage varied between 2.2 and 13.5°C . Relative to 0°C , the maximum temperatures in UL and EC were almost 2.0 and 2.5 times that in SREC and REF, respectively, whereas the minimum temperatures in UL and EC were 4 and 10 times higher than the minimum in SREC and REF, respectively. The range of RH in the SREC was between 80% and 100% and the RH in the EC room was between 88% and 100%. The RH in the UL varied between 53% and 100%, whereas the RH in REF was lowest and varied between 10% and 88%. The temperatures for our EC room were significantly higher than those obtained by Ambuko et al. (2017) for the zero energy brick cooler (18.0 to 20°C) and the evaporative charcoal cooler (15.5 to 20.5°C). This was likely because the ambient temperatures (15.3 to 29°C) and RH (46% to 97%) in Kenya were lower than those in India.

Elevated humidity in the interior of EC storages is well established (Basediya et al., 2013; Liberty et al., 2014); however, the humidity ($>85\%$ RH) of SREC storages has not been documented. Unlike the EC room, the SREC room does not have wetted interior walls and yet achieved similar high humidities. Since the temperatures achieved in the SREC were considerably lower than ambient, they were near or below the dew point for the air (10 to 27°C) (<https://www.wunderground.com/history/monthly/in/new-delhi/VIDD/>

Fig. 1. Standalone, batteryless, off-grid, solar-refrigerated evaporatively-cooled (SREC) structure at village Picholiya (lat. $26^\circ24'27.6''\text{N}$, long. $74^\circ28'09.9''\text{E}$), Ajmer, Rajasthan, 2020.

Fig. 2. Respiration rate (CO_2 production; r_{CO_2}) of amaranth leaves and stems as a function of temperature. Data are from previously published studies (Bunce, 2007; Byrd et al., 1992; Thammawong et al., 2019) and fitted using the linearized Arrhenius equation (inset) to obtain the energy of activation and Arrhenius constant.

date/2019-6), which would have ensured an elevated humidity.

Estimated CO₂ respired (cumulative respiration). The apparent energy of activation (E_a) for r_{CO_2} based on previously published studies was 55.8 kJ·mol⁻¹. This is the first report of an apparent E_a for amaranth respiration, but the value is similar to those for other plant materials. Apparent E_a values are reported to range from 20 to 100 kJ·mol⁻¹ for common fruits and vegetables in air, with the most frequent E_a values being between 50 and 80 kJ·mol⁻¹ (Beaudry, 2007; Eriko et al., 2001; Tano et al., 2005).

Cumulative respiration from the initiation of the storage experiment, used to assess the cumulative amount of metabolic activity at any point in the storage period, rose more quickly in storages operating at elevated temperatures (Fig. 3). The cumulative respiration was responsive to daily and long-term

variation in the structure temperatures as evidenced by changing slope of the curve, but overall tended to increase linearly with time for all storages. The cumulative respiration for amaranth rose most rapidly in UL, followed by EC, then SREC, and was lowest in REF.

Effects of structure type and cultivar for a specific storage duration. After 202 h (8.4 d), the cumulative CO₂ respired in UL and EC was ≈123 g·kg⁻¹ and 102 g·kg⁻¹, which was several-fold higher than that respired in SREC and REF, which was 32 and 18 g·kg⁻¹, respectively (Table 1). This resulted from the fact that the temperatures in EC and UL were ≈15 °C higher than those in the SREC and REF structures. This is consistent with the findings of Thammawong et al. (2019), who found 4.3-fold increase in r_{CO_2} for amaranth with a temperature increase of 15 °C. In fact, for most fruits and vegetables, the respiratory rate increases by 2- to 6-fold from 0 to 15 °C (Beaudry et al., 1992; Becker and Fricke, 1996; Cameron et al., 1994; Lakakul et al., 1999).

Leaf abscission was extensive, especially in the warmer storages; interestingly, however, leaf abscission in amaranth has not been discussed in the literature to our knowledge. Leaf abscission was lowest for REF (6.3%), higher for SREC (22.3%), and highest for EC and UL (67.1 and 71.2%, respectively) following a 202-h storage period (Table 1).

The yellowing was negligible in refrigerated and SREC storages and was higher, 49.5% and 70.1%, respectively, in the warmer (EC and UL) storages. Ambuko et al. (2017) reported a change in hue angle in amaranth leaves from initial value of 138 °H (darker shade of green) to 115 to 121 °H (lighter shade of green) in 8 d of storage in EC structures.

The average initial amount of chlorophyll in green and red amaranth was 3.19 ± 0.19 mg·g⁻¹ FW, which is lower than chlorophyll content (6.5–7.5 mg·g⁻¹ leaf tissue) of amaranth reported by Jomo et al. (2016). However, the chlorophyll content was much higher than that reported by Sarker et al. (2020) for green amaranth (0.56 mg·g⁻¹ FW) and by Sarker and Oba (2019) for red amaranth (0.48 mg·g⁻¹ FW) and more in keeping with that published by Khanam and Oba (2013, 2014). The chlorophyll content and chlorophyll loss at the end of 202 h were affected by storage type and cultivar, with the

greatest loss experienced in the UL storage and the least in the REF and SREC storages (Table 1). Yellowing was higher in EC and UL than in REF and SREC storages and chlorophyll loss was positively correlated ($P = 0.02$) with yellowing, having a coefficient of determination (r^2) of 0.66.

Moisture loss was lowest in REF (21%) and SREC (15%) structures as compared with EC (37%) and UL (69%) storages (Table 1). Ambuko et al. (2017) reported that amaranth stored in EC storage had lost 16% moisture after 8 d, whereas storage at ambient room conditions led to 47.6% moisture loss after 5 d. The moisture loss in our EC room was higher than that in EC storage used by Ambuko et al. (2017), likely because the temperatures for our EC room (25.0 to 36.0 °C) were significantly higher than those obtained by Ambuko et al. (2017), for the zero energy brick cooler (18.0 to 20 °C) and the evaporative charcoal cooler (15.5 to 20.5 °C). The data suggest that, for a 202-h storage period, the household refrigerator limited senescence parameters and moisture loss to the greatest extent and that SREC provided slightly less protection. EC and UL were similar and poorly protected amaranth against senescence and moisture loss.

Relationship between senescence and cumulative CO₂ respired. Leaf abscission, yellowing, and chlorophyll content were dependent on the amount of CO₂ respired in a linear fashion, having coefficients of determination (r^2) of 0.89, 0.82, and 0.66, respectively (Fig. 4, Table 2). Variation in the predicted curve was described by the 99% confidence intervals (dashed lines) and the 99% prediction intervals for the data distribution (dotted lines). The relatively high correlation for the relationship between leaf abscission and the estimate of cumulative CO₂ respired, suggests a temperature-sensitive metabolic model can be used to describe the data for structures differing substantially in their temperature control and for different cultivars of amaranth. The linearity of the relationship permits a simple means of linking the amount of CO₂ respired to specific thresholds for quality or quality loss. A leaf abscission rate of 40%, for instance, was, on average, predicted to occur after the amaranth had respired 68.25 g·kg⁻¹ CO₂, independent of the structure or the cultivar (Table 3).

Fig. 3. Temperature profile and estimated cumulative CO₂ respired on a fresh weight basis in UL (uncooled laboratory), SREC (solar-refrigerated evaporatively cooled) structure, EC (evaporatively cooled) structure, and REF (refrigerator) over a representative 8.4-d period in June-July of 2019 in Delhi, India.

Table 1. Comparison of average temperatures throughout storage, and cumulative CO₂ respired, moisture loss, leaf abscission, and yellowing of amaranth in SREC, REF, UL, and EC storages after 8.4 d (202 h) storage. ANOVA shows P values for structure type and cultivar and their interaction.

Structure type	Avg temp (°C)	CO ₂ respired (g·kg ⁻¹)	Moisture loss (%)	Leaf abscission (%)	Chlorophyll (mg·g ⁻¹)	Chlorophyll loss (mg·g ⁻¹)	Yellowing (%)
REF	7.24 a	18.44 a	21.15 ab	6.29 a	2.71 c	0.43 a	0.01 a
SREC	12.08 a	31.94 a	14.80 a	22.30 b	2.52 bc	0.70 ab	1.26 a
EC	29.33 b	102.4 b	36.86 b	67.07 c	2.10 ab	1.16 bc	49.56 b
UL	31.76 b	122.9 c	69.37 c	71.21 c	1.85 a	1.39 c	70.10 c
ANOVA							
Structure type	<0.001	<0.001	<0.001	<0.001	0.005	0.003	<0.001
Cultivar	0.600	0.406	0.797	0.311	0.028	0.024	ND
Structure × cultivar	0.976	0.342	0.315	0.392	0.797	0.549	ND

ND = not determined. Means within each column followed by different lowercase letters differ significantly at $P < 0.05$.

Effects of structure type and cultivar on storability of amaranth. Because of the high correlation between cumulative CO₂ respired and leaf abscission and its ease of measurement, this parameter was used for determining the storability of amaranth. Use of the 99% upper confidence limit established a target for cumulative CO₂ respired that was lower (more conservative) than the fitted line. The conservative estimate of the targets for CO₂ respired for 10%, 20%, 30%, and 40% threshold levels of leaf abscission was taken to be ≈ 17.8 , 32.0, 46.2, and 60.4 g·kg⁻¹ CO₂,

respectively (Table 3). Each is $\approx 13\%$ lower than for the fitted line.

The time taken for the stored amaranth to reach target levels of CO₂ respired, associated with specific thresholds for leaf abscission, was determined. Because cultivar did not affect leaf abscission (Table 1), the data for the second cultivar were treated as additional replicates. The time required to reach the target levels of CO₂ respired differed between storages (Table 4). At 10% leaf abscission, the number of days until the end-of-storability differed more than 5-fold among storage types; storability was 1.3 d in UL, 1.5 d in EC, 4.7 d in SREC, and 8.1 d in REF. The experimental (observed) values of leaf abscission on these dates were less than those predicted for the 10% threshold and similar to the predicted abscission rates for the 20%, 30%, and 40% abscission thresholds, respectively (Table 5). Thus, the observed value of leaf abscission was conservative for 10% threshold and accurate for 20%, 30%, and 40% thresholds.

At the end-of-storability for a 10% leaf abscission threshold (17.8 g·kg⁻¹ CO₂ respired), the actual leaf abscission did not differ between storage types (Table 4), which was as per the experimental design. However, storage type did affect yellowing, which was negligible (0.01%) in SREC and REF, whereas it was $\approx 1.5\%$ and 7.2% in EC and UL, respectively. Storage type also affected chlorophyll content, which was lowest in REF. Yellowing was evident for UL and EC, but not for SREC and REF, however the degree of yellowing was not associated with differences in chlorophyll, in apparent contrast to the results in Table 1. This is likely because yellowing was rated on all leaves in a sample, whereas chlorophyll was from a tissue subsample. Further, leaves having only a small degree of yellowing were categorized as yellow. Moisture loss was also affected by storage type when the end-of-storability was reached; it was at its maximum (21.6%) in REF followed by 12.5% in UL, 8.8% in SREC, and 5.6% in EC storage. This is consistent with the low humidity found in REF and UL storages and the high humidity found in SREC and EC storages.

For the 20% leaf abscission threshold (32.0 g·kg⁻¹ CO₂ respired), the days to end-of-storability was almost 1.7 times that at 10% leaf abscission in all the storages. Actual leaf drop did not differ between structures and was consistent with their classification level of having 20% leaf abscission (Table 5). Chlorophyll content did not differ between storages when the end-of-storability was reached and moisture loss was lowest for the EC room and highest for the REF storage. The excessive amount of moisture loss for the REF storage is indicative of the low humidity recorded in this environment. In this case, even if quality loss due to abscission was acceptable in REF, the moisture loss would have limited acceptability.

The end-of-storability for leaf abscission thresholds of 30% (CO₂ respired = 46.2 g·kg⁻¹) and 40% (CO₂ respired = 60.4 g·kg⁻¹) was not reached in 8 d of the experiment for SREC, so no data are available for comparison; however, these targets were reached in EC and UL storages within the experimental timeframe. In EC and UL, the end-of-storability was 3.8 and 3.1 d, respectively, for 30% leaf abscission and 4.9 and 4.1 d, respectively, for 40% leaf abscission. REF storage, which was for a longer time (27 d), took 21.5 and 24.8 d to reach the target levels of CO₂ respired for the 30% and 40% thresholds; however, moisture loss was at or above 40%. Yellowing and moisture loss were affected by storage type (only EC and UL evaluated), but because of the limited sample number, mean separation could not be performed. The chlorophyll content was unaffected by storage type at 30% and 40% leaf abscission thresholds.

Nyaura et al. (2014) concluded that green amaranth maintained acceptable visual appeal for 4, 8, 12, and 18 d for the vegetables stored at 25, 15, 10, and 5 °C, respectively. They considered decay as a sign of end-of-storability and did not mention leaf loss, but the timeframe roughly matches that in this study. The timeframe for storability found in this study is also consistent with Ambuko et al. (2017), although the criteria for determining quality differed as they considered physiological weight loss and vitamin C; however, they found that EC storage improved the quality of leafy amaranth, providing an additional 2 d storability relative to ambient room conditions.

The amaranth has potential to serve as a model plant for evaluating imperfect structures that cannot generate controlled temperature and humidity conditions. The functionality of storages can be expressed as the time to reach end-of-storability for amaranth when a storability threshold is clearly defined. For practical purposes, 10% leaf loss may be a threshold that is easily and objectively measured, but other options exist, including thresholds for chlorophyll content and leaf yellowing. We were unable to find prior reference for the use of cumulative CO₂ respired as a means for linearizing physiological responses to storage, but the linkage between time and temperature on storability

Fig. 4. Senescence parameters of amaranth in UL (uncooled laboratory), SREC (solar-refrigerated evaporatively cooled) structure, EC (evaporatively cooled) structure and REF (refrigerator). The solid line is the regression line, dashed lines are 99% confidence limits, and dotted line 99% prediction limits. Closed symbols are for green amaranth ('Pusa kiran') and open symbols are for red amaranth ('Pusa lal chaulai').

Table 2. Values for model variables (Eq. [4]) and their standard error (SE) and 99% confidence interval (CI) for the linear regression describing senescence parameters of amaranth in SREC, REF, UL, and EC storages as a function of cumulative respired CO₂.

Senescence parameter	b ₀ (SE, CI)	b ₁ (SE, CI)	r ²
Leaf abscission (%)	-5.00 (0.93, 2.42)	0.66 (0.02, 0.05)	0.89
Yellowing (%)	-6.35 (1.59, 4.22)	0.52 (0.03, 0.08)	0.82
Chlorophyll content (mg·g ⁻¹)	1.91 (0.03, 0.07)	-0.01 (0.00051, 0.001)	0.66

Table 3. Estimated cumulative CO₂ respired for 10%, 20%, 30%, and 40% threshold levels of amaranth leaf abscission from regression model values (Eq. [4]).

	Threshold leaf abscission (%)			
	10.00	20.00	30.00	40.00
Regression line	Estimated cumulative CO ₂ respired (g·kg ⁻¹)			
Upper confidence limits (99%)	17.84	32.01	46.19	60.37
Fitted line	22.75	37.92	53.09	68.25

Table 4. Leaf abscission (%) and time (d) of storage for amaranth in SREC (solar-refrigerated evaporatively cooled), REF (refrigerator), UL (uncooled laboratory), and EC (evaporatively cooled) storages after reaching a target level of cumulative CO₂ respired using the 99% upper confidence interval for the regression in Fig. 3 for 10%, 20%, 30%, and 40% leaf abscission.

Structure	Avg time (d)	Leaf abscission (%)	Chlorophyll (mg·g ⁻¹)	Yellowing (%)	Moisture loss (%)
10% threshold, estimated CO ₂ respired = 17.8 g·kg ⁻¹					
SREC	4.7 b	5.9 a	2.8 ab	0.01 a	8.8 a
EC	1.5 a	1.2 a	2.9 b	1.5 b	5.6 a
UL	1.3 a	4.1 a	2.8 ab	7.2 c	12.5 a
REF	8.1 c	6.2 a	2.7 a	0.01 a	21.6 b
P value	<0.001	0.427	0.015	<0.001	0.001
20% threshold, estimated CO ₂ respired = 32.0 g·kg ⁻¹					
SREC	8.2 b	23.4 a	2.5 a	2.9	14.1 ab
EC	2.6 a	12.2 a	2.8 a	11.5 ± 4.6	9.5 a
UL	2.2 a	20.0 a	2.6 a	25.2 ± 5.6	26.4 b
REF	14.9 c	4.4 a	2.3 a	0.01	40.0 c
P value	<0.001	0.078	0.254	0.123*	<0.001
30% threshold, estimated CO ₂ respired = 46.2 g·kg ⁻¹					
SREC	ND	ND	ND	ND	ND
EC	3.8 a	21.9 ab	2.6 a	22.8 ± 4.0	14.3 a
UL	3.1 a	41.4 b	2.5 a	28.8 ± 0.4	36.7 b
REF	21.6 b	10.8 a	2.6 a	3.60	48.8 c
P value	<0.001	0.022	0.782	0.035*	<0.001
40% threshold, estimated CO ₂ respired = 60.4 g·kg ⁻¹					
SREC	ND	ND	ND	ND	ND
EC	4.9 ± 0.37	40.1 ± 13.3	2.5 ± 0.20	35.5 ± 2.7	22.5 ± 5.6
UL	4.1 ± 0.81	47.4 ± 10.0	2.4 ± 0.11	31.3 ± 3.3	44.0 ± 7.0
REF	24.8	ND	ND	ND	ND
P value	<0.001*	0.328*	0.300*	0.292*	<0.001*

*Insufficient data to perform mean separation. ND = not determined. Means within each column followed by different lowercase letters differ significantly at *P* < 0.05.

Table 5. Comparison of leaf abscission threshold with observed leaf abscission for amaranth stored in SREC (solar-refrigerated evaporatively cooled), REF (refrigerator), UL (uncooled laboratory), and EC (evaporatively cooled) storages. *P* values represent the probability that the values are the same.

Leaf abscission threshold (%)	Observed leaf abscission (%) (mean ± SE)	<i>P</i> value
10.00	4.34 ± 1.14	<0.001
20.00	16.6 ± 2.45	0.19
30.00	29.2 ± 4.71	0.87
40.00	44.0 ± 3.51	0.27

is well established (Kays and Paull, 2004). Indeed, many forms of time-temperature indicators exist for integrating the impact of temperature effects across time and identifying end-of-storability for perishable items (Arens et al., 1997; Galagan and Su, 2008; Hu and Loconti, 1973; Rani and Abraham, 2006). The linear relationships for abscission, chlorophyll loss, and yellowing to the cumulative CO₂ respired for amaranth in this study support the utility of this idea. It is important to note that respiratory activity can markedly increase or decrease for harvested plant organs (Fonseca et al., 2018; Verlinden et al., 2014). Therefore, it is anticipated that not all plant responses may be as well behaved as for amaranth in the current study.

In this study, we determined that, during June and July in Delhi (early monsoon season), an EC room is not an effective means of cooling produce and, using 10% abscission as a quality threshold, was essentially equivalent to an uncooled room, yielding 1.3 and 1.5 d of storability, respectively. An SREC room, using both solar-powered refrigeration and evaporation for cooling, was a 4.7-d storage, whereas a more highly controlled household refrigerator could be classified as an 8.1-d storage. Because the storage structures are imperfect (i.e., the temperature and RH are highly variable), it is difficult to compare them

suitably. Leaf abscission (%) in amaranth affords an inexpensive and easy measurement method for comparing these structures.

Literature Cited

- Agudelo, C., C. Restrepo, and J.E. Zapata. 2016. Respiration kinetic of mango (*Mangifera indica* L.) as function of storage temperature. *Rev. Fac. Nac. Agron.* 69(2):7985–7995.
- Ambuko, J., F. Wanjiru, G.N. Chemining'wa, W.O. Owino, and E. Mwachoni. 2017. Preservation of postharvest quality of leafy amaranth (*Amaranthus* spp.) vegetables using evaporative cooling. *J. Food Qual.* 2017, doi: 10.1155/2017/5303156.
- Arens, R.P., R.D. Birkholz, D.L. Johnson, T.P. Labuza, C.L. Larson, and D.J. Yarusso. 1997. Time-temperature integrating indicator device. US Patent 5,667,303.
- Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol.* 24:1–15.
- Basediya, A.L., D.V.K. Samuel, and B. Vimala. 2013. Evaporative cooling system for storage of fruits and vegetables - a review. *J. Food Sci. Technol.* 50(3):429–442.
- Beaudry, R.M. 2007. MAP as a basis for active packaging, p. 31–55. In: C.L. Wilson (ed.). *Frontiers of 'intelligent' and 'active' packaging for fruits and vegetables*. CRC Press, Boca Raton, FL.
- Beaudry, R.M., A.C. Cameron, A. Shirazi, and D.L. Dostal-Lange. 1992. Modified-atmosphere packaging of blueberry fruit: Effect of temperature on package O₂ and CO₂. *J. Amer. Soc. Hort. Sci.* 117:436–441.
- Becker, B.R. and B.A. Fricke. 1996. Transpiration and respiration of fruits and vegetables, p. 110–121. In: *New Developments in Refrigeration for Food Safety and Quality*. International Institute of Refrigeration, Paris, France, and American Society of Agricultural Engineers, St. Joseph, MI.
- Bunce, J.A. 2007. Direct and acclimatory responses of dark respiration and translocation to temperature. *Ann. Bot.* 100(1):67–73.
- Byrd, G.T., R.F. Sage, and R.H. Brown. 1992. A comparison of dark respiration between C3 and C4 plants. *Plant Physiol.* 100(1):191–198.
- Cameron, A.C., R.M. Beaudry, N.H. Banks, and M.V. Yelanchi. 1994. Modified atmosphere packaging of blueberry fruit: Modeling respiration and package oxygen partial pressures as a function of temperature. *J. Amer. Soc. Hort. Sci.* 119:534–539.
- Chopra, S. and R. Beaudry. 2018a. Redesigning evaporatively cooled rooms to incorporate solar powered refrigeration in India. *Acta Hort.* 1194:609–616.
- Chopra, S. and R. Beaudry. 2018b. Innovative composite wall designs for evaporative cooled structures for storage of perishable. *Indian J. Agr. Sci.* 88(11):1692–1695.
- Chopra, S., B. Baboo, S.K.A. Kudos, and H.S. Oberoi. 2004a. An effective on-farm short term storage structure for tomatoes. *J. Rural Technol.* 1(5):221–226.
- Chopra, S., S.K.A. Kudos, H.S. Oberoi, B. Baboo, K.U. Mahmood Ahmad, and J. Kaur. 2004b. Performance evaluation of evaporative cooled room for storage of kinnow. *J. Food Sci. Technol.* 41(5):573–577.
- Ebert, A.W., T. Wu, and S. Wang. 2011. Vegetable amaranth (*Amaranthus* L.). *Intl. Cooperators' guide*. AVRDC – The World Vegetable Center. Publication Number: 11-754.
- Eriko, Y., T. Keiko, H. Daisuke, H. Wenzhong, and U. Toshitaka. 2001. Effect of temperature on the respiration rate of some vegetables. *Control*

- applications in post-harvest and processing technology. 3rd IFAC/CIGR Wkshp., 3–5 Oct. Tokyo, Japan.
- FAO. 2011. Global food losses and food waste – extent, causes and prevention. FAO, Rome, Italy.
- Fonseca, S.C., F.A. Oliveira, and J.K. Brecht. 2002. Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: A review. *J. Food Eng.* 52(2):99–119.
- Fonseca, S.C., L. Gil, M.C. Manso, and L.M. Cunha. 2018. Modelling the influence of storage temperature and time after cutting on respiration rate of diced red onions (*Allium cepa* L. cv. Vermelha da Póvoa). *Postharvest Biol. Technol.* 140:27–33.
- Galagan, Y. and W.-F. Su. 2008. Fadable ink for time–temperature control of food freshness: Novel new time–temperature indicator. *Food Res. Intl.* 41:653–657.
- Habibunnisa, E.A., E. Aror, and P. Narasimham. 1988. Extension of storage life of the fungicidal waxol dip treated apples and orange under evaporative cooling storage conditions. *J. Food Sci. Technol.* 25(2):75–77.
- Hiscox, J.D. and G.F. Israelstam. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. *Can. J. Bot.* 57:1332–1334.
- Hu, K.H. and J.D. Loconti. 1973. Temperature–time integrating indicator. US Patent 3,768,976.
- Jahun, B.G. S.A. Abdulkadir, S.M. Musa, and H. Umar. 2013. Assessment of evaporative cooling system for storage of vegetables. *Intl. J. Sci. Res. (IJSR)* 5:1197–1203.
- Jangde, B., B.S. Asati, B. Tripathy, P. L. Bairwa, and L. Kumar. 2018. Genetic variability for quantitative characters in vegetable Amaranthus (*Amaranthus tricolor* L.). *Intl. J. Bioresource Stress Mgt.* 9(1):093–097.
- Jha, S.N. and S. Chopra. 2006. Selection of bricks and cooling pad for construction of evaporatively cooled storage structure. *J. Inst. Eng. (India): Agr. Eng. Div.* 87:25–28.
- Jomo, O.M., G.W. Netondo, and D.M. Musyimi. 2016. Drought inhibition of chlorophyll content among seven Amaranthus species. *Intl. J. Adv. Res. Sci. Eng. Technol.* 3(2):1362–1371.
- Kays, S.J. and R. Paull. 2004. *Postharvest biology*. Exon Press, Athens, GA.
- Khanam, U.K.S. and S. Oba. 2013. Bioactive substances in leaves of two amaranth species, *Amaranthus tricolor* and *A. hypochondriacus*. *Can. J. Plant Sci.* 93:47–58.
- Khanam, U.K.S. and S. Oba. 2014. Phenotypic plasticity of vegetable amaranth, *Amaranthus tricolor* L. under a natural climate. *Plant Prod. Sci.* 17:166–172.
- Lakakul, R., R.M. Beaudry, and R.J. Hernandez. 1999. Modeling respiration of apple slices in modified atmosphere packages. *J. Food Sci.* 64:105–110.
- Liberty, J.T., G. Agidi, and W.I. Okonkwo. 2014. Predicting storability of fruits and vegetables in passive evaporative cooling structures. *Intl. J. Sci. Eng. Technol.* 3(5):518–523.
- Liberty, J.T., W.I. Okonkwo, and E.A. Echiegu. 2013. Evaporative cooling: A postharvest technology for fruits and vegetables preservation. *Intl. J. Sci. Eng. Res.* 4(8):2257–2266.
- Longmone, A.P. 2003. Evaporative cooling of good products by vacuum. *Food Trade Rev. (Pennwalt Ltd).* 47:13–16.
- Lowder, S.K., J. Skoet, and T. Raney. 2016. The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Dev.* 87:16–29.
- MAAS. 2012. Australian Coolgardie Safe 1900–1910. Australian Museum of Applied Arts and Sciences. 22 June 2020. <<https://collection.maas.museum/object/260620>>.
- Mampholo, M.B., D. Sivakumar, and J. Van Rensburg. 2015. Variation in bioactive compounds and quality parameters in different modified atmosphere packaging during post-harvest storage of traditional leafy vegetables (*Amaranthus cruentus* L. and *Solanum Retroflexum*). *J. Food Qual.* 38(1):1–12.
- Mangaraj, S. and T.K. Goswami. 2011. Measurement and modeling of respiration rate of guava (cv. *Baruipur*) for modified atmosphere packaging. *Intl. J. Food Prop.* 14(3):609–628.
- Mogaji, T.S. and O.P. Fapetu. 2011. Development of an evaporative cooling system for the preservation of fresh vegetables. *Afr. J. Food Sci.* 5(4):255–266.
- Mujaffar, S. and A.L. Loy. 2016. The rehydration behavior of microwave-dried amaranth (*Amaranthus dubius*) leaves. *Food Sci. Nutr.* 5(3):399–406.
- NITI Aayog. 2018. *Strategy for New India@ 75*. National Institution for Transforming India, New Delhi.
- Nyaura, J.A., D.N. Sila, and W.O. Owino. 2014. Postharvest stability of vegetable amaranth (*Amaranthus dubius*) combined low temperature and modified atmospheric packaging. *Food Sci. Qual. Mgt.* 30:66–72.
- Onyango, C. 2010. Preharvest and postharvest factors affecting yield and nutrient contents of vegetable amaranth (var. *Amaranthus hypochondriacus*). C. T. de Wit Graduate School of Production Ecology and Resource Conservation, Leeuwen, Netherlands, PhD Diss.
- Platenius, H. 1942. Effect of temperature on the respiration rate and the respiratory quotient of some vegetables. *Plant Physiol.* 17:179–197.
- Prakash, D. and M. Pal. 1991. Nutritional and antinutritional composition of vegetable and grain amaranth leaves. *J. Sci. Food Agr.* 57:573–583.
- Rais, M. and A. Sheoran. 2015. Scope of supply chain management in fruits and vegetables in India. *J. Food Process. Technol.* 6:427.
- Rani, D.N. and T.E. Abraham. 2006. Kinetic study of a purified anionic peroxidase isolated from *Eupatorium odoratum* and its novel application as time temperature indicator for food materials. *J. Food Eng.* 77:594–600.
- Roy, S.K. and D.S. Khurdiya. 1986. Studies on evaporatively cooled zero energy input cool chamber for storage of horticultural produce. *Indian Food Pack.* 40:26–31.
- Sarker, U. and S. Oba. 2019. Protein, dietary fiber, minerals, antioxidant pigments and phytochemicals, and antioxidant activity in selected red morph *Amaranthus* leafy vegetable. *PLoS One* 14(12):E0222517.
- Sarker, U., M. Hossain, and S. Oba. 2020. Nutritional and antioxidant components and antioxidant capacity in green morph *Amaranthus* leafy vegetable. *Sci. Rep.* 10:1336.
- Shukla, S., A. Bhargava, A. Chatterjee, J. Srivastava, N. Singh, and S.P. Singh. 2006. Mineral profile and variability in vegetable amaranth (*Amaranthus tricolor*). *Plant Foods Hum. Nutr.* 61:23–28.
- Singh, G., A. Kawatra, and S. Sehgal. 2001. Nutritional composition of selected green leafy vegetables, herbs and carrots. *Plant Foods Hum. Nutr.* 56:359–364.
- Singh, P., S. Singh, B.R. Singh, J. Singh, and S.K. Singh. 2014. The drying characteristics of amaranth leaves under greenhouse type solar dryer and open sun. *Greener J. Agr. Sci.* 4(6):281–287.
- Tano, K., A. Kamenan, and J. Arul. 2005. Respiration and transpiration characteristics of selected fresh fruits and vegetables. *Agronomie Africaine* 17(2):103–115.
- Thammawong, M., E. Kasai, D. Syukri, and K. Nakano. 2019. Effect of a low oxygen storage condition on betacyanin and vitamin C retention in red amaranth leaves. *Scientia Hort.* 246:765–768.
- Vaisala. 2013. Humidity conversion formulas. Vaisala Oyj Inc., Helsinki, Finland.
- Verlinden, S., S.M. Silva, R.C. Herner, and R.M. Beaudry. 2014. Time-dependent changes in the longitudinal sugar and respiratory profiles of asparagus spears during storage at 0 °C. *J. Amer. Soc. Hort. Sci.* 139:339–348.