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Kinetics of Post-harvest Quality Changes and Shelf Life Evaluation of Vegetable Amaranth Stored in Solar Refrigerated and Evaporative Cooled Structure

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ABSTRACT: Solar refrigerated and evaporative cooled (SREC) storage structure was developed to provide on-farm, cold storage facility for smallholder farmers. The study was conducted to study the kinetics of post-harvest quality changes and shelf life evaluation of vegetable amaranth stored in solar refrigerated and evaporative cooled structure. In ambient condition (UL), temperatures varied between 22-42°C, in SREC temperature ranged from 6 to 20°C, with relative humidity of 85-100%. After end of the storage period, weight loss, leaf fall, chlorophyll loss and leaf yellowing of amaranth leaves were higher in EC and UL conditions compared to SREC and refrigerated storage. The kinetics of stored product in an evaporative cooled structure is specific to the particular system and product being studied. It is essential to consider the unique characteristics of each storage system. In this Study, fractional kinetics model was used to predict the shelf life of amaranth stored under SREC, EC, REF and ambient storage condition. The study of kinetics of stored product in an evaporative cooled structure offers valuable insights into shelf life prediction.

Keywords: Post harvest quality, shelf life, degradation kinetics, evaporative cooled, storage.

INTRODUCTION

Fruits and vegetables are considered as one of the main sources of nutrients in human diet. India is one of the largest producer of horticultural crops, and is often referred as the basket of fruit and vegetables. The annual post-harvest food loss is estimated to be around 1.3 billion tons worldwide (Kumari *et al.,* 2022). In India, fruits and vegetables have the highest level of total postharvest losses to the tune of around 16 percent (Jha *et al.,* 2015). The total horticultural production was about 333.25 million tonnes during 2021-22 from an area of 27.56 million hectares in the country (MoAFW estimate of 2021-22). In India only 2 percent of vegetables and fruits are being processed whereas rest are consumed as fresh (MoFPI, Portal2017). Lack of affordable cold storage facilities in our sub-tropical climate conditions and improper post-harvest management practices of agricultural commodities, result in high quantitative and qualitative losses in vegetables.

Storage of agriculture commodities such as fruits and vegetables is major concern in India. The farmers in India face difficulties in storage as options are very limited. The situation is much more alarming for smallholder farmers, as they do not have easy access to cold storage. The high temperature and low relative humidity are the major abiotic factors that affect storability of vegetables (Leberty *et al.,*2013). For each 10°C upsurge in temperature above optimum temperature level the deterioration rate of the product increases two to three fold (Liberty *et al.,* 2014).

India have 37.4 million metric tonnes (mMT) of storage capacity but their distribution is not uniform among various states. The top four states with high cold storage capacity are Uttar Pradesh (14.7mMT), West Bengal (5.94mMT), Gujarat (3.82mMT), Punjab (2.31mMT) contributing to 72% of the storage capacity in the country (Agricultural statistics at glance report 2020). Also 75% of the cold storages are used only for potatoes which indicates dearth of availability of storage facilities for other agricultural commodities (MoFPI, 2017). Backward integration is a process in which company expands its role with supplier or manufacturer. Here manufacturer and raw material supplier is farmer. Because of lack of on-farm cold storage facility farmer not able to store harvested farm produce on farmer's field. Thus, farmer sell its product at distress sale to middlemen who, procure and store material in cold store facility available in major cities and sell agriculture produce at higher price. So, benefits goes to middlemen. Thus if we adopt on-farm cold storage facilities farmer will get involved as a raw material supplier in supply chain which is act as backward integration in this study. Major success on part of efficient cold chain lies in having good backward integration but sadly it has been completely neglected so far in our country.

Among agricultural commodities, leafy vegetables are most vulnerable to damage. They start deteriorating rapidly after harvest. Vegetables are highly perishable and continue to respire even after being harvested, resulting in significant post-harvest losses due to biological and environmental factors (Hegazy, 2013; Ambuko *et al.,* 2017; Shipman *et al*., 2021). Therefore, in order to maintain good quality of the produce, care should be taken right from the time of harvest. Since temperature plays a critical role in maintenance of quality of fresh produce, there is urgent need of suitable postharvest storage facilities to preserve and maintain the quality of the product after harvest. It should also be affordable even by smallholder farmers.

An evaporatively cooled storage structure with solar refrigeration system wasdeveloped in-house at the Indian Agricultural Research Institute (IARI) in New Delhi (Chopra and Beaudry 2018). The SREC structure is a unique, off-grid, and battery less cold storage facility designed for storing perishable agricultural commodities. It can store up to 2 tons of fruits and vegetables on the farmer's field. Mahangade *et al.* (2020), use an amaranth as a model plant for evaluating solar refrigerated and evaporative cooled storage structure.

The objective of this study was to study the degradation kinetics of post-harvest quality changes and shelf life evaluation of vegetable amaranth as per consumer's preference stored in different storage structure. The kinetics of post-harvest quality changes can provide insights into the underlying biochemical and physiological processes occurring in vegetable amaranth during storage. Assessing the quality of vegetables typically involves evaluating multiple parameters, such as color, weight loss, and nutritional composition. Each parameter may have different kinetics and responses to storage conditions. By establishing reference kinetic models, one can compare the actual quality changes during storage with the expected patterns. Degradation kinetics of changes/ degradation in physical quality parameters of stored vegetable amaranth leaves as a function of time in different refrigerated and evaporative cooled storage structure is not published as per our knowledge.

MATERIALS AND METHODS

A. Experimental site

The experiment was conducted at the Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi

B. Raw Material

Two varieties of amaranths (*Amaranthus* sp.). One is red amaranth '*PusaLal Chaulai*', and another green amaranth '*Pusa Kiran*' were used for the study. Amaranth were harvested early in the morning from the field of the Division of Vegetable Science at Indian Agricultural Research Institute, New Delhi. Healthy, uniform colour and intact leaves were selected for the present study.

C. Storage conditions

Four different storage conditions were assessed in this study. (a) SREC: Solar-refrigerated and evaporative-cooled (b) EC: evaporatively-cooled (c) UL: Uncooled laboratory, ambient storage (d) REF: Household refrigerator.

D. Physico-chemical attributes

For green leafy vegetables loss in weight, leaf fall, yellowness of leaves and total chlorophyll content are of prime importance from retailers' commercial point of view. These reflect the quality attributes in fresh leafy vegetables purchase by consumer (Hussin *et al.,* 2010). Therefore, these physico-chemical changes were studied to understand the storage behaviour of amaranth in different storage structures and thus to compare their efficacy for storage of vegetable amaranth leaves.

(i) Weight loss. For weight loss determination, uniform sized bundles of amaranth leaves approximately equal weight of 500 gram were kept in triplicates in each storage structure for storage study. The initial and final weights of amaranth bundles were taken by using digital weighing balance (accuracy 0.1g) at several intervals during storage. Weight loss was calculated using the formula:

$$\text{Weight Loss}(\%) = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \times 100$$

(ii) **Leaf fall.** For determination of leaf fall, samples were prepared by wrapping an amaranth stem in a damp cloth and placing it LDPE packaging bag. Leaf fall of each branch was noted at regular interval during storage period. Leaf fall (%) was calculated by using the following formula

$$\text{Leaf fall}(\%) = \frac{\text{Total number of detached leaves}}{\text{Total number of initial leaves}} \times 100$$

(iii) **Yellowness.** Colour of the leafy vegetable is directly linked to the consumer preference. For evaluation of yellowness parameter, samples prepared for leaf fall were used. Yellowness was evaluated for all detached and attached leaves. Yellowness was calculated by using the following formula and expressed in percentage of the total number of leaves.

$$\text{Yellowness}(\%) = \frac{\text{Leaves exhibiting any yellow area}}{\text{Total number of leaves}} \times 100$$

(iv) **Chlorophyll content.** Chlorophyll content was estimated by a non-maceration method (Hiscox and Israelstam 1979). Using UV-Visible spectrophotometer (Labman Scientific Instruments Pvt. Ltd., Chennai, India). The total chlorophyll was calculated using equation (Arnon, 1949) and expressed as $g.kg^{-1}$ of fresh weight basis.

Total chlorophyll content (mg/L) = (20.2 Abs_{645} + 8.02Abs_{663})

E. Shelf Life as per consumer's preference testing

Determine the acceptable levels for each quality attribute based on consumer preferences and expectations. Conducted consumer preference tests to evaluate consumer acceptance of the leafy vegetables. Analyse the data collected from the quality assessments and consumer preference testing. Identify the point at which the leafy vegetables no longer meet the consumer acceptance criteria for the desired quality attributes. This is considered the end of shelf life, indicating the maximum duration for which the product can maintain consumer acceptance.

F. Degradation kinetic model

The degradation in quality parameters of fruit and vegetables stored in different storage structure has been described by a basic zero order or first order model reaction mechanism. Kinetic models were used to fit the experimental data and estimate the kinetic parameters. The quality parameters as a function of time can be predicted by Fractional kinetic model (Lana *et al.,* 2005).

$$F = F_\infty + (F_o - F_\infty)e^{-kt}$$

where, F is the value of quality parameter at time t,

F_o, the initial value quality parameter at harvest,

F_∞, equilibrium or the non-zero maximum value quality parameter,

k, the reaction rate constant,

t, the time (in days), counting from the time of harvest.

G. Statistical Analysis

The analysis of experimental data was done by using a statistical package SAS version 9.3. The data was subjected to analysis of variance (ANOVA) and separation of means by Least Significant Difference (LSD) method and subsequently Tukey's significant difference test($p<0.05$) was applied for comparisons of means.

RESULTS AND DISCUSSION

A. Temperature Profile of Storage Structures

The temperature in the storage structures fluctuated with the time of the day. In UL (ambient condition) the highest day time temperature was 40.4°C, whereas the lowest night temperature was 22.5°C. During this period, the temperatures in the EC fluctuated between 25.0 to 36.0 °C. In contrast, temperatures in the SREC structure varied from 6 to 20 °C and in REF temperatures ranged from 2.2 to 13.5 °C. The temperature differential from ambient condition in SREC, EC and REF structures during storage was 6 to 10 times (Fig. 1).

B. Relative Humidity Profiles of storage structures

Relative humidity values in UL were between 50 and 100%, the relative humidity values in the EC storage structure ranged between 88 to 100%. At the same time, relative humidity values in SREC structure ranged between 80 to 100%. Relative humidity values in REF storage were lowest as compared to other storage structures

C. Weight loss

Water is a main component of leafy vegetables and it supplements the total weight of vegetable. Loss of water leads to decrease in the weight and turgidity of leafy vegetable. Most of the leafy vegetables contain nearly 90 to 95% water at the time of harvest (Nath *et al.,* 2007). The leafy vegetables lost weight during storage irrespective of the storage conditions. Water loss is responsible for the observed weight loss. By the end of fifth day of storage, the amaranth stored in UL (ambient conditions) had lost more than half of the initial weight 55.35%, whereas weight loss was 29.61% case of amaranth stored in the EC. The corresponding weight loss was 8.94% and 9.85% for the SREC and REF, respectively. At the end of the storage period (day 8), amaranth leaves stored in the REF and SREC had lost 20.87% and 16.93% of their initial weight, respectively while in EC and UL the weight loss was 43.55 % and 73.55%, respectively. The 5% weight loss was achieved after 3 days of storage period in SREC and REF. Weight loss was highest in first few days followed by a declining trend. The weight loss of amaranth leaves stored in the SREC and REF was at slower rate compared to those stored in EC and UL. ANOVA at 1% level of significance showed that there was significant difference in the weight loss of stored leafy vegetable under different storage condition. Analysis of variances showed that interaction of cultivar type (red or green amaranth) and the storage conditions had no significant effect on weight loss on particular storage day. It is also found that effect of storage condition with storage days had significant effect on weight loss of vegetable. Least square means for effect of structure type* days (Table 1) shows significant difference on weight loss of vegetables. Similar trend was observed by Ambuko *et al.* (2017) that storages with higher temperature had more weight loss of amaranth as compared to lower storage temperature. They reported 16.2% moisture loss after 8 days of storage in EC structure when temperature varied between 15.5 to 20.5 °C, and 47.6% of weight loss in ambient condition after 5 days storage period. A similar trend was observed by Mampholo *et al.* (2015) who has stored amaranth in modified atmosphere packaging with different polypropylene packaging material.

D. Leaf fall

Leaf fall is one of the important senescence parameter. In leafy vegetables, leaf fall contributes to loss of overall saleable weight of product and also loss of turgidity and aesthetic value which affects sale ability of the vegetables. Leaf fall was lower in REF (10.55%) and SREC (27.86%) compared to EC (67.16%) and UL (75.12%) in green amaranth (Fig. 2a), while in case of red amaranth it was lower for REF (12.80%) and SREC (20.93%) compared to EC (65.84%) and UL (71.35%) after 8 days of storage (Fig. 2b). Analysis of variance at 1% level of significance showed that there was significant difference in the leaf fall of stored leafy vegetable in different storage structures but no significant effect was recorded with cultivar type (red or green amaranth). Besides it was found that effect of storage structures with storage days had significant effect on leaf fall of vegetable. Least square means for effect of structure type* days of leaf fall shows significant difference in leaf fall of vegetables.

E. Yellowness

Color variations in fresh fruits and vegetables have a direct impact on the price of the produce. The retention of green colour in leafy vegetables during the selling period is regarded as an important quality parameter, indicating chlorophyll pigments that are linked to the product's appealing fresh appearance. Yellowness started appearing in stores leaves after 8 days of storage period. The least yellowness was observed in SREC

(1.54%) and REF (0.70 %) storage condition and was highest in UL (74.17 %) and EC (59.14 %) storage condition (Table 2). The severity of the yellowness in amaranth leaves has increased with storage time but the severity of yellowing was more in EC and UL than SREC and REF storage condition. When compared with the EC and UL storage condition, the SREC and REF retained the green color of the amaranth leaves up to 7th day. However, the leaf yellowing was significantly higher after the 3rd and 5th day respectively in UL and EC storage condition. This can be related to the higher temperature in UL storage conation and lower temperature was maintained in SREC and REF. Statistical analysis shows that there was significant effect on yellowness of leafy amaranth stored in different storage structures and on different storage days. Least square means for effect of structure* days of yellowness (Table 2) shows significant difference in yellowness of vegetables stored in SREC, EC and UL storage condition but no significant effect was observed with SREC and REF storage condition. Ambuko *et al.* (2017) also reported change in hue angle in amaranths, varying from 138 °H to 115 °H for eight days in EC storage condition. Mampholo *et al.* (2015) stored amaranth in modified atmosphere packaging with different polypropylene packaging material at 10 °C and observed from the 6th day, *Amaranth. cruentus* L. leaves packed in biorientated polypropylene packaging BOPP04 and BOPP06 showed yellowing. While unpacked leaves showed yellowing from 3rd day of storage.

F. Chlorophyll content

Chlorophyll gives leaves their green colour, and changes in chlorophyll content can be a good indicator of leaf senescence during storage. Chlorophyll in the amaranths degraded slowly during storage period from the initial value 3 g.kg^{-1} to 2.50 g.kg^{-1} and 2.84 g.kg^{-1} at the end of storage period of 8 days in the SREC and REF structure, respectively (Fig. 3a,b). The degradation was highest in amaranths stored in UL 1.66 g.kg^{-1} (ambient conditions), which was 46.4% of initial value. The chlorophyll content has decreased with storage time in all the storage conditions adopted in this study. However, the SREC and REF resulted in a substantial retention of chlorophyll amaranth leaves. The degradation of chlorophyll is linked to the peroxidation of cell membranes during senescence (Zhuang *et al.,* 1995). ANOVA at 1% level of significance showed that there was significant difference in the chlorophyll content of both red and green variety of stored amaranths in different storage structures. Effect of storage structures with storage days was found to have significant effect on chlorophyll content of amaranth vegetable. However, effect of storage structure with cultivar have no significant effect on chlorophyll content of amaranth vegetable. Least square means for effect of structure type* days of chlorophyll content shows significant difference in chlorophyll content of vegetables. The low temperature in the SREC and REF played a role to lower the degradation of the chlorophyll content more significantly than the EC and UL storage condition tested in this study. Our findings for chlorophyll in green amaranth are in variance with findings of Sarker *et al.* (2020) who reported chlorophyll content for green amaranth to be0.56 g.kg^{-1} while 0.48 g.kg^{-1} chlorophyll content for red amaranths reported Sarker and Oba (2019). Jomo *et al*. (2016) reported chlorophyll in the range of 6.5 to 7.5 g.kg^{-1} on fresh weight basis.

G. Shelf Life as per consumer's preference testing

In this study, the data indicated that the SREC structure lowered the rate of senescence rate of leafy vegetable amaranth and maintained the quality of leafy vegetable amaranth better compared to UL. The leafy amaranths remained farm-fresh and in marketable state for up to 4 days more than amaranth stored in UL. For safe storage period upto 5 % weight loss, leaf fall and yellowing was considered to be safe; and at the same time Shelf Life as per consumer's preference testing is tried to note upto which amaranth remain in marketable form is presented in (Table 3). The safe storage period represents the duration at which the vegetable amaranth can be stored without exceeding a threshold of 5% loss in the respective quality parameter. Shelf Life as per Consumer's Preference Testing represents the shelf life of vegetable amaranth based on consumer preference testing. It indicates the duration until the product is considered acceptable by consumers in terms of quality attributes such as weight loss, leaf fall, and yellowness. For weight loss, the SREC and REF structures have a safe storage period of 3 days, while the EC and UL structures have shorter safe storage periods of 2 and 1 day, respectively. In terms of shelf life based on consumer preference testing, the SREC and REF structures have a longer shelf life of 6 days, while the EC and UL structures have shorter shelf lives of 2 and 1 day, respectively. It is important to note that the shelf life based on consumer preference testing may vary depending on factors such as the market demand, storage conditions, and handling practices. Findings have been reported by Nyaura *et al*. (2014), noted that green amaranth stored in 25, 15, 10, and 5 °C, maintained vegetable in acceptable form for 4, 8, 12, and 18 days respectively. Ambuko *et al*. (2017) has also mentioned storage period time frame for amaranths which is consistent to results obtained in this study. Considerably lower temperatures and higher relative humidity in the SREC structure consequently reduced weight loss, leaf fall, yellowing and chlorophyll content degradation of stored leafy amaranth. This ultimately decreased the rate of postharvest senescence reactions and increased storability of stored vegetable.

H. Kinetic model parameters

The first order irreversible consecutive model was used for modelling the quality parameters degradation such as weight loss and chlorophyll content of green and red amaranth stored in different storage structures. The kinetic degradation of weight loss and chlorophyll content in stored amaranth leaves in SREC, EC, UL and REF storage structure follows a first order reaction mechanism, according to integral fitting of the experimental data. This model provides information about the reaction rate constants, k (Table 4). The first order kinetic model gives a good correlation (R^2-values) for all the quality parameters degradation such as weight loss and chlorophyll content of green and red amaranth stored in different storage structures. For weight loss and chlorophyll content, the rate constants (k) are highest for UL followed by EC, SREC, and REF. And the VE is the variance explained in present by the model also presented in the Table 4. The VE values for weight loss and chlorophyll content in amaranth range from 95.05% to 96.57% and 77.41 to 98.51% respectively, suggesting that the kinetic model can explain a significant portion of the variation in the data. The study indicates that the kinetics rate constant of quality change was smaller for SREC and REF than EC and Ambient storage condition. This model provides a tool to describe the weight loss and chlorophyll content behaviour of amaranth stored in SREC, EC, UL and REF storage structure as a function of time and thus predict the shelf life of amaranth. Understanding the kinetics of post-harvest quality changes allows producers to deliver vegetable amaranth to consumers with better quality attributes. By determining the optimal storage duration, the product can maintain its freshness, nutritional content, and overall appeal, leading to increased consumer satisfaction and marketability. Xie *et al.* (2013) have studied kinetic model for green vegetable *Brassica rapa*. Also Musa *et al,* (2017) have studied kinetic modelling of vitamin C changes in leaves of *Moringa oleifera*, *Hibiscus sabdarifa*, and *Hibiscus esculentus* during blanching. Kinetics provides information about the speed at which quality changes occur in the stored product. It helps determine the rate at which various quality parameters, change over time. By studying the kinetics, one can quantify the extent and timing of quality deterioration, allowing for better prediction and control of product quality during storage. Overall, the kinetics of post-harvest quality changes and shelf life evaluation of vegetable amaranth stored in solar refrigerated and evaporative cooled structures contributes to efficient post-harvest management, reduced food waste, and enhanced market performance.

I. Cost economics

As per the cost economics of SREC storage structure the total cost of SREC structure is around Rs. 5,00,000/-. The annual operating cost was obtained around Rs. 1,50,000/-. Cost of storage of commodities in the SREC structure obtained Rs. 0.40 /kg.day. The average cost of storing agriculture commodity in cold storage service on rent basis was observed to be approximately Rs. 0.38/kg.day. It is slightly lower than the cost of storage of perishables in the newly developed SREC structure. However, in areas where cold storage facilities are not available or are inaccessible, the cost of transportation of agriculture commodity to the cold storages add additional cost to the farmer who want to store his produce and want to sell it after increase in market price. This transportation cost can be reduced if we have on farm cold storage facility. Again, if the product quality lost then market value loss is much higher than the storage cost. If we consider subsidies provided by government to farmers storage cost would reduce further. And if storage structure used for high value products then cost of storage would very much affordable and improves profitability. After considering all this points Thus SREC structure can be recommended for farmers/retailers in rural and semi-urban areas.

Table 1: Least square means of weight loss of green and red amaranths stored in various structures during storage.

Storage condition	Amaranth	Storage Period in Days								
		0	1	2	3	4	5	6	7	8
SREC	Green	0.00^a	1.52^c	3.66^c	5.17^c	6.41^c	8.25^d	12.11^d	13.94^d	16.10^d
EC	Green	0.00^a	3.14^b	7.72^b	11.84^b	20.48^b	29.91^b	34.55^b	37.37^b	42.28^b
UL	Green	0.00^a	6.58^a	27.37^a	39.48^a	47.30^a	54.80^a	64.67^a	69.47^a	73.48^a
REF	Green	0.00^a	2.62^c	4.07^c	4.92^c	7.15^c	10.04^c	14.17^c	17.98^c	20.80^c
SREC	Red	0.00^a	3.80^c	5.29^c	6.62^c	7.86^c	9.63^d	11.47^d	14.29^d	17.76^d
EC	Red	0.00^a	5.11^b	10.73^b	13.42^b	21.86^b	29.32^b	36.58^b	41.69^b	44.83^b
UL	Red	0.00^a	9.56^a	32.26^a	38.22^a	46.86^a	55.89^a	65.12^a	69.96^a	73.63^a
REF	Red	0.00^a	3.01^c	6.02^c	6.41^c	7.66^c	12.43^c	15.58^c	18.65^c	20.94^c
Significance		ns	**	**	**	**	**	**	**	**

Means within each column followed by different letters differ significantly at $p < 0.05$.
***Significantly different at $p < 0.05$.

Table 2: Yellowness of leafy amaranths stored in various structures during storage.

Storage condition	Storage Period in days								
	0	1	2	3	4	5	6	7	8
SREC	0.00^a	0.00^a	0.00^c	0.00^c	0.00^c	0.00^c	0.00^c	0.00^c	1.54^c
EC	0.00^a	0.00^a	2.97^b	16.02^b	26.71^b	39.59^b	40.39^b	54.33^b	59.14^b
UL	0.00^a	0.00^a	25.31^a	29.45^a	32.66 ^{a}	47.85^{cd}	54.35^a	72.73^a	74.17^a
REF	0.00^a	0.00^a	0.00^c	0.00^c	0.00^c	0.00^c	1.48^c	0.00^c	0.70^c
Significance	ns	ns	**	**	**	**	**	**	**

Means within each column followed by different letters differ significantly at $p < 0.05$.
**Significantly different at $p < 0.05$.

Table 3: Safe storage period for amaranth stored in different storage structure with respect to storage parameters.

Sr. No	Storage parameters	Storage Structure	Safe storage period (threshold 5% loss of quality parameter)	Shelf Life as per consumer's preference testing
1.	Weight loss	SREC	3 days	6 days
		REF	3 days	6 days
		EC	2 days	2 days
		UL	1 day	1 days
2.	Leaf fall	SREC	4 Days	6 days
		REF	6 Days	6 days
		EC	2 days	2 days
		UL	1 days	1 days
3.	Yellowness	SREC	8 days	6days
		REF	8 days	6days
		EC	8 days	3days
		UL	2 days	2 days

Table 4: The kinetic model parameters for weight loss and chlorophyll degradation of green and red amaranth stored in different storage structures.

Storage structure	Weight loss						Chlorophyll content					
	Green Amaranth			Red Amaranth			Green Amaranth			Red Amaranth		
	k	R^2	VE	k	R^2	VE	k	R^2	VE	k	R^2	VE
SREC	0.028	0.98	96.92	0.031	0.98	96.57	0.08	0.92	86.18	0.05	0.87	77.41
EC	0.094	0.97	94.51	0.101	0.96	95.61	0.17	0.92	85.58	0.15	0.99	98.10
UL	0.278	0.97	95.05	0.286	0.97	95.92	0.24	0.96	93.51	0.32	0.99	98.11
REF	0.035	0.96	93.30	0.038	0.98	96.37	0.03	0.90	82.57	0.02	0.88	77.77

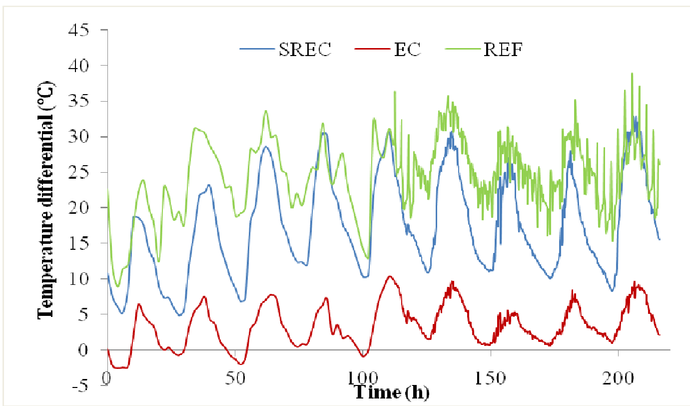
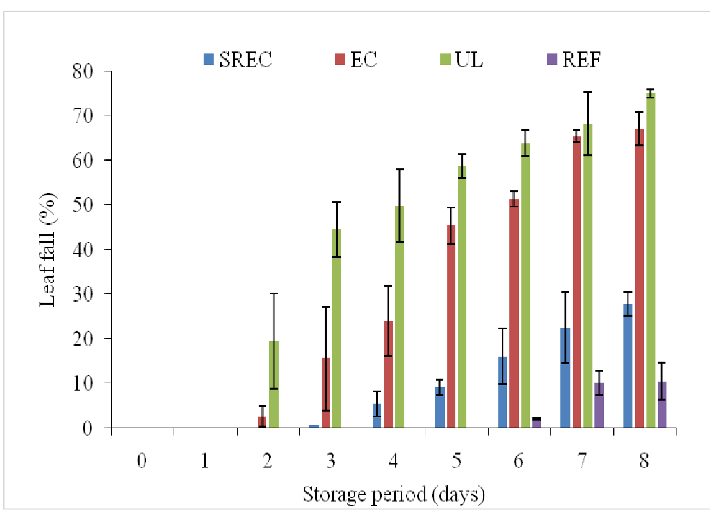
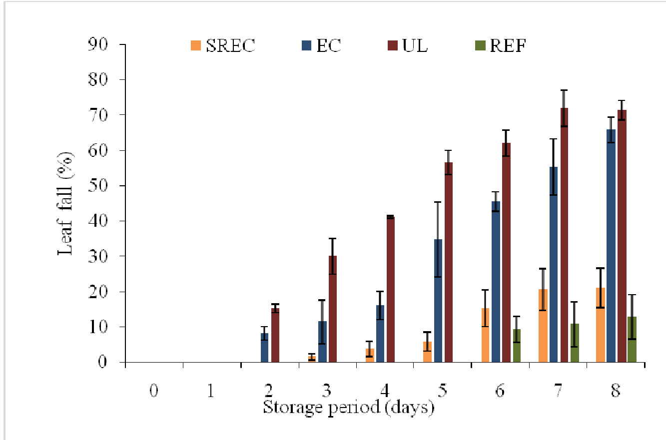


Fig. 1. Temperature differential from ambient condition in solar refrigerated evaporative cooled-, evaporative cooled- and refrigerated structures during storage.

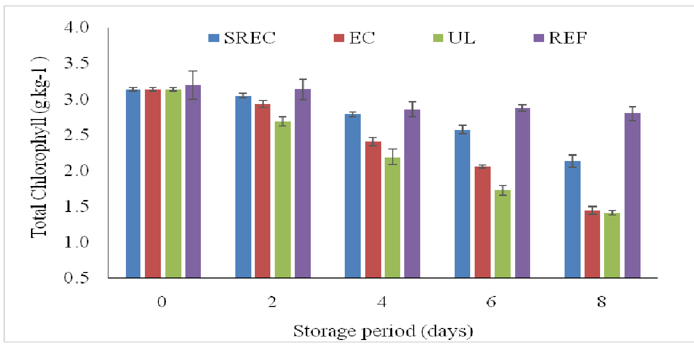


(a)

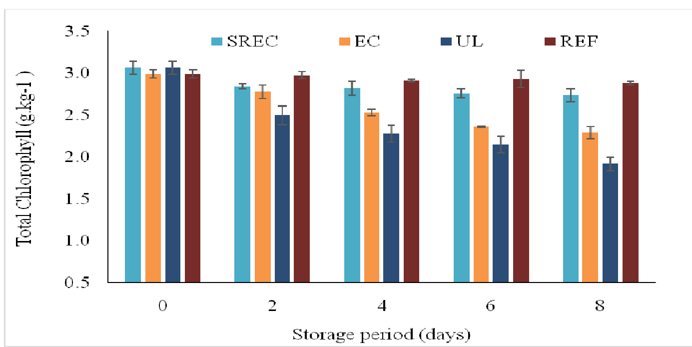


(b)

Fig. 2. Leaf fall of (a) green amaranths and (b) red amaranths in various structures during storage.



(a)



(b)

Fig. 3. Chlorophyll content of (a) green amaranths and (b) red amaranth in various structures during storage.

CONCLUSIONS

This study showed that the rate of senescence was faster in uncooled laboratory (UL) i.e. ambient condition and evaporatively cooled (EC) store as compared to solar refrigerated evaporative cooled (SREC) structure and refrigerator. An innovative off-grid batteryless SREC mesh fabric structure preserved the perishable agricultural commodities in term of quality parameters such visual appearance, weight loss, leaf fall, yellowness and total chlorophyll content comparatively better than EC and UL storage conditions. In comparison to vegetable amaranth stored at ambient condition, the amaranth stored in the SREC and REF remained marketable for an extra 3-5 days. Fractional kinetics model used in this study provides a tool to predict the shelf life of amaranth stored in different storage structures as function of time in days with respect to weight loss and chlorophyll content degradation. These models allow for the prediction of the remaining shelf life of vegetable amaranth stored in SREC, EC, REF and UL storage conditions. Essentially, it will contribute to the main goal of reduction in overall postharvest losses in vegetables by efficient post-harvest management.

FUTURE SCOPE

The future scope of studying the kinetics of stored product in evaporative cooled structures lies in the integration of advanced modelling, IoT and sensor technologies, AI and machine learning, and expansion to different product categories. These advancements will contribute to enhanced storage efficiency, improved quality control, and sustainable post-harvest management practices.

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Conflicts of Interest. None.

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