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Research Article

Evaluation of okra (cv. A5) and spinach beet (cv. Pusa Bharati) or enhancing shelf life using different storage conditions for the benefit of marginal farmers

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Abstract
Vegetables sustain huge post-harvest losses owing to their highly perishable nature. Due to complex management challenges, marginal farmers face issues during post-harvest management and cannot get desirable remuneration. The present study assessed the effect of storage conditions on the commonly consumed vegetables, okra (cv. A5) and spinach beet (cv. Pusa Bharati) for prolonging the shelf life and analyzing the cost-benefit ratio. The vegetables were stored at ambient temperature (T_0), Zero Energy Cool Chamber (ZECC) (T_1), and Cold Chamber (T_2), and their physiochemical parameters, overall acceptability and cost-benefit ratio were recorded at regular intervals for two consecutive years. An upward trend in physiological loss in weight (PLW) and spoilage was observed under all settings. However, the rate of PLW and spoilage was rapid in T_0. Among the three conditions, minimum physiological loss in weight of 8.48% and 7.88% was recorded in okra and spinach beet, respectively, in the T_1 during the storage period. Similarly, maximum firmness was observed in T1 with spoilage of 12.9% and 6% on day 3 in okra and spinach beet, respectively. The recorded ascorbic acid content on day 3 in T_1 and T_2 had no notable difference in okra whereas maximum retention of ascorbic acid content was observed in T_1 with values of 76.93 mg/100g on day 3 in spinach beet. The benefit-cost ratio was calculated as >1 in ZECC storage, showing positive results for both vegetables. It was concluded that okra and spinach beet can be stored in ZECC for 5 and 3 days, considering the quality and the PLW.

Keywords: Indian Spinach Beet, Okra, physiological loss in weight, post-harvest management, shelf life, storage, zero energy cool chamber

INTRODUCTION

The majority of the population in the country belongs to the economically poor or middle-class income category, and the food choices for consumption are restricted to fewer options. Okra (*Abelmoschus esculentus L.*) and Spinach beet (*Beta vulgaris*) are some of the most common vegetables grown and consumed in India. The vitamin content in both vegetables is superior to many crops. The addition of okra and spinach beet in diet can offer balanced meal as okra is rich in rich in fiber, vitamin C, thiamine, carotene, folic acid, riboflavin, niacin, oxalic acid, amino acids, phenolics, pectins, and minerals including K, Mg, Ca, and P (Habtemariam, 2019) and leafy vegetable like spinach beet is Vitamins C, A, K, and E, protein, calcium, iron, magnesium, phosphorus, potassium, fiber, and other nutrients (Gibson, 1994).

The metabolic activities such as respiration, transpiration and ripening continue in vegetables even after the harvesting. Therefore, despite having a huge production base, there is a substantial difference between gross production and net availability to the consumer due to high post-harvest losses caused by inadequate crop handling (Singh and Satapathy, 2006). It has been estimated that around 40% of perishable products are wasted in low- and middle-income countries (Kader, 2005; Spang *et al.*, 2019), while it was estimated that 22% of fruits and vegetables are spoiled after harvesting, they are placed on store shelves worldwide (FAO, 2019).

Nearly 90% of India's horticultural produce is offered for sale in fresh form and is mostly produced by small-scale or marginal farmers. Storage plays a crucial role in reducing damages and spoilage after harvesting. To minimize the post-harvest losses of fresh fruits and vegetables, developed high-income nations have developed technologies like enormous refrigerated cold chambers and other types of storage systems, such as a Modified Atmospheric Cold Storage System (MAP) and a Controlled Atmospheric Storage System (CAS). In impoverished countries, the lack of storage techniques following crop harvesting results in significant postharvest losses of 20 to 50% for horticulture items (Majubwa *et al.,* 2022). According to the 2015–16 India Agricultural Census, small and marginal farmers (SMF) account for 86.1% of all Indian farmers. Smallholder farmers are unable to secure a fair price for their produce due to low demand visibility, exploitative intermediation, pricing seasonality and volatility, post-harvest losses, limited quality assurance, limited access to efficient and low-cost storage and logistic issues (Wasudha *et al.,* 2018; Gupta and Li, 2021). The quality and physical attributes of fruits and vegetables, such as look, texture, firmness, and flavor, determine the price of the commodity that one can fetch. The main marketing criterion for vegetables is to preserve the biochemical properties, like ascorbic acid content, and the physical characteristics, like appearance, taste, texture, and moisture content (Ch. Momin *et al*., 2021).

The two most crucial elements in preserving a commodity's post-harvest storage life are temperature control (Majubwa *et al*., 2022) and relative humidity control (Kadar, 1992) during post-harvest storage. Minimal constraints are required to preserve the chemical, biochemical, and physiological alterations required to preserve the product's fresh form through the utilization of temperature and humidity control (Chandra *et al.,* 1999). Low temperature inhibits respiration and microbial incidence. It also prevents the generation of ethylene and reduces sensitivity to ethylene, delaying the process of ripening, which helps in extending the shelf life of the produce. This helps to maintain the crop's quality and freshness, and the produce can be kept longer (Chopra *et al.,* 2003). High relative humidity during storage helps to maintain the nutritional quality, weight, appearance, and flavour of the produce (Arah *et al*. 2015). Small or marginal growers can store vegetables in affordable storage systems for a shorter duration to fetch good remuneration.

In the present study, locally assessable vegetables, okra (*Abelmoschus esculentus L. cv. A5)* and spinach beet (*Beta vulgaris* cv, Pusa Bharati) were stored in three different conditions i.e. ambient temperature, Zero Energy Cool Chamber (ZECC) and Cool Chamber to study their storage behaviour and its effect on the quality and shelf life. Further, the cost-benefit ratio was calculated to evaluate the best storage system for small-scale or marginal farmers.

MATERIALS AND METHODS

The study was conducted using a Zero Energy Cool Chamber built at Amity University Uttar Pradesh, Noida's farm and a Cold Chamber erected on campus. After being harvested early in the morning, the vegetables underwent post-harvest management and were then stored in three different storage conditions—ambient condition (T0) (15±4°C, RH 49-55%), zero energy cool chamber (T1) (10±2 °C, RH 90-95%), and cold storage (T3) (8°C, RH 85-90%)—according to the treatment plan. Physicochemical indicators such as firmness, ascorbic acid (mg/100g), marketability, overall acceptability, and the Benefit-Cost ratio were measured over nine days to determine whether the target was reached. Two years (2021 & 2022) worth of consecutive data were collected for the analysis.

Physiological loss in weight (PLW)

The selected vegetables were weighed regularly to calculate the weight loss during the storage period, and the initial weight was recorded at the initial stage. The estimation was carried out using the standardized method mentioned in Ranganna (2014). The PLW was calculated using the formula below and recorded in percentages.

$$PLW\ (\%) = \frac{(P0 - P1\ or\ P2\ or\ P3)}{P0} * 100 \quad \text{… Eq. (1)}$$

Where, P0 – Initial weight, P1 – Weight after 3 days, P2 – Weight after 6 days and P3 – Weight after 9 days.

Firmness

The firmness of the selected vegetables was measured using a hand penetrometer (Fruit Pressure Tester, FT 327). A 4 mm diameter plunger was fitted into the tester and inserted into the product. The reading on the penetrometer expressed as Kg/cm^2 was observed and recorded.

Ascorbic Acid Content (mg/100g)

Ascorbic acid Content of the selected vegetables was determined using 2, 6-Dichlorophenol- indophenols visual titration method (Johnson, 1948) reported in Ranganna (2014). The samples were freshly prepared in 3% metaphosphoric acid solution and were titrated against the 2, 6 Dichlorophenolindophenol dye solution in the titration tube. The titration was done until the pink colour persisted for 15 sec. The ascorbic acid was calculated using the formula given below, and the value was recorded as mg/100g.

$$AA\ Content\ \left(\frac{mg}{100g}\right) = \frac{Titre * Dye\ Factor * Volume\ Made\ up * 100}{Volume\ of\ Aliqout\ for\ estimation * Volume\ or\ weight\ of\ sample}$$

…..Eq. (2)

Spoilage

The spoilage of the selected vegetables was carried out by eye estimation from the number of leaves or pods in each lot from the initial day and was calculated by the formula given below:

$$Spoliage\ (\%) = \frac{Number\ of\ Spoiled\ Units}{Total\ number\ of\ Units} * 100$$

….Eq. (3)

The number of marketable units was determined by observing the level of decay, surface decay, and shrivelling and was used to calculate the percentage of spoilage during storage as described by Mohammed *et al.* (1999).

Overall acceptability evaluation

The overall acceptability evaluation of the selected vegetables was done based on sensory characters, colour and appearance by the panel of ten semi-trained judges.

The scores were recorded on a scorecard using a 9-point hedonic scale as reported in Ranganna (2014). It is used to measure the consumer's acceptability of selected products ranging from 'like extremely' to 'dislike extremely'.

Statistical Analysis

The experiment was plotted in Complete Randomized Design with three replications for each treatment for two consecutive years. The observations and mean data recorded were subjected to one-factor analysis and ANNOVA using OPSTAT software. A confidence level of 95% ($p<0.05$) was assumed for the data.

Benefit Cost Ratio

Benefit Cost Ratio is directly proportional to the net return. High BCR will result in high net return.

$$BCR = \frac{Net\ Return\ of\ the\ produce}{Total\ Cost\ of\ the\ produce}$$

…..Eq. (4)

RESULT AND DISCUSSION

Effect of storage on physiological loss in weight of okra and spinach beet

The physiological loss in weight of Okra and Spinach beet recorded in three storage conditions is shown in Figures 1 and 2, respectively. A significant difference was observed in physiological weight loss in weight % of the selected vegetables in three storage conditions. T_0 showed the maximum PLW (%) with the highest mean of 32.34 in Okra and 17.80 in Indian Spinach Beet among all treatments. The minimum loss was recorded in Okra stored in T_1 with average means of 4.24%, 8.48%, and 15.93% on day 3, day 6, and day 9, respectively. This was followed by T_2 with an average means of 5.64%, 12.59% and 22.20% on day 3, day 6, and day 9, respectively. The minimum loss in PLW in spinach beet was recorded in T_1 with an average mean of 4.34%, 7.88%, and 9.53% on day 3, day 6, and day 9, respectively. This was followed by T_2 with an average mean of 6.07%, 11.59% and15.56% on day 3, day 6, and day 9, respectively.

The loss in moisture content in living produce is a complex feature that involves the fusion of various morphological, physiological and environmental factors (Lufu et al., 2020). The lower physiological weight loss in ZECC compared to the other condition might be due to high relative humidity and a cool environment inside the system. The result recorded above was as per Dash et al. (2016) for green leafy vegetables and Devi and Singh (2018) for cabbage, broccoli, tomato, passionfruit, pineapple, and banana in ZECC conditions. Also, Mishra *et al.* (2020) stored okra. and pointed gourd in 3 different conditions, i.e. room temperature, freezing condition and ZECC and their findings showed that ZECC has the lowest PLW on 5th day. In contrast, the highest loss in PLW was recorded in room temperature followed by freezing condition.

Evaporative cooling helps extend the shelf life of horticultural commodities in tropical and subtropical environments and helps preserve fruits and vegetables (Basediya *et al.*, 2013).

Effect of storage on firmness of okra and spinach beet

The firmness of okra and spinach beet was recorded at days 0, 3, 6, and 9 in all three storage conditions. In okra, as shown in Figure 3, no significant difference was observed among the treatment T_1 and T_2 on day 3, but a notable difference was recorded on day 6. The highest mean on day 3 and day 6 was recorded in T_1, with the highest mean among all treatments at 2.3 kg/cm^2 and 2.1 kg/cm^2. The minimum mean was recorded in T_0, varying from 2.63 to 0.13 in 9 days storage period. In Spinach beet, as shown in Figure 4, notable differences were observed during the recordings in 9 days. The highest mean was recorded in T_1 with 4 kg/cm^2 values and 3.7 kg/cm^2 on days 3 and 6, respectively. Compared to the other storage conditions, T_0 exhibited the lowest mean among all storage conditions with values of 2.6 kg/cm^2, 1.9 kg/cm^2, and 0.6 kg/cm^2 on days 3, 6, and 9. The results followed Kad *et al.* (2022), where firmness of green capsicum (cv. Indra)

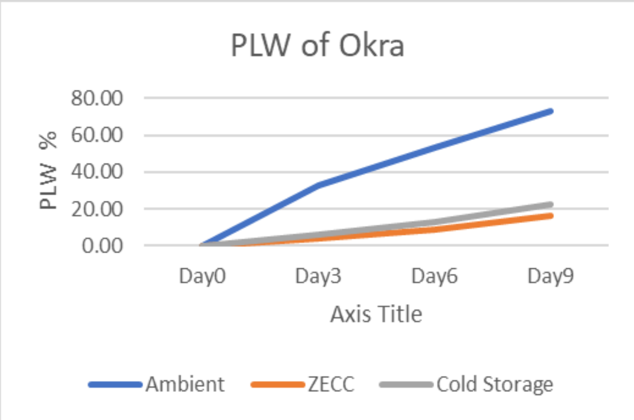

Fig. 1. *Physiological loss in weight (PLW) of okra stored in ambient, zero energy cool chamber (ZECC) and cold storage condition*

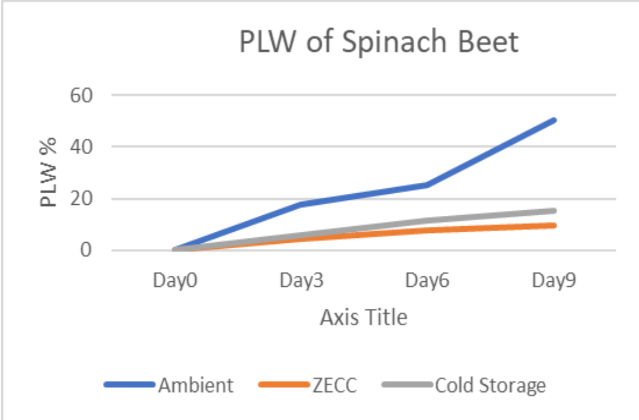

Fig. 2. *Physiological Loss in Weight (PLW) of Indian spinach beet stored in ambient, zero energy cool chamber (ZECC) and cold storage condition*

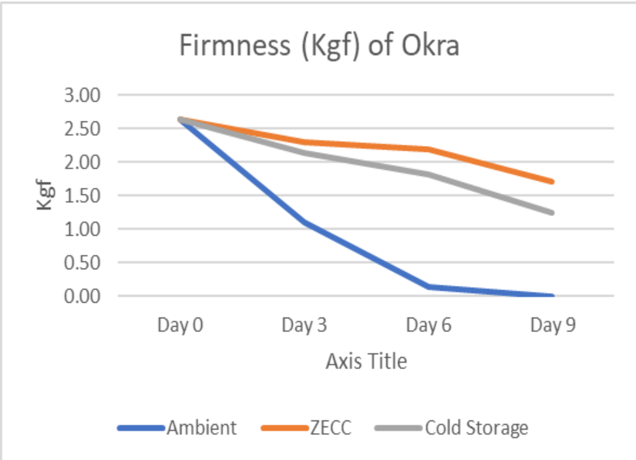

Fig 3. *Firmness of okra stored in ambient, Zzro energy cool chamber (ZECC) and cold storage condition*

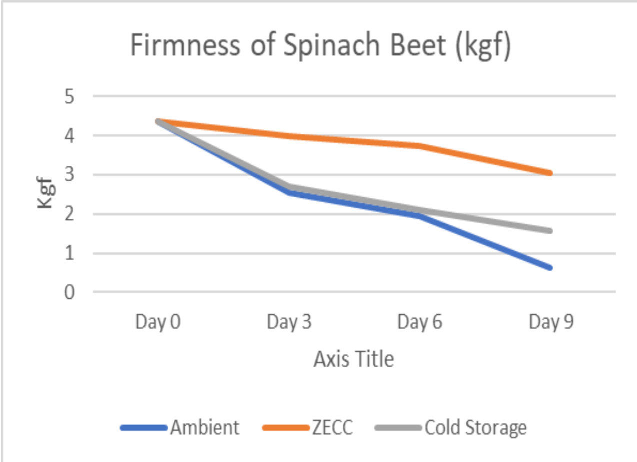

Fig 4. *Firmness of Indian spinach Beet stored in ambient Zero energy cool chamber and cold dtorage condition*

decreased during the storage in ZECC and Cold storage in all the treatment combinations as the storage period increased. The reduction in firmness of the biological produce during storage might result from the breakdown of parenchymal cells, which causes the plant material to soften (Ahmmed *et al.* 2019).

Effect of storage on ascorbic acid content of okra and spinach beet

Analysis of the vegetables revealed that each storage had a distinctive impact on the ascorbic acid content of the vegetable. As can be shown in Figure 5, there were no significant changes between T_1 and T_2 on day 3 in okra. T_2 has the highest mean of 34.6 mg/100g and T_1 has the ascorbic content of 32.98 mg/100g at day 3. At day 6, T_1 had the maximum ascorbic acid retention, exhibiting a value of 17.54 mg/100g. The lowest retention of ascorbic acid content was recorded in T_0 on day 3, day 6, and day 9, ranging from 29.45 to 0.3 mg/100g. In Indian spinach beet, as shown in Figure 6, maximum ascorbic acid retention was exhibited by treatment T_1 on day 3 and day 6, with values ranging from 86.84 to 63.28 mg/100g. T_2 was the second-best treatment, with values ranging from 86.84 to 52.08 mg/100g from initial to day 6. The lowest ascorbic acid retention was recorded in $T_{0,}$ i.e. ambient temperature, ranging from 86.84 to 30.72 mg/100g in Indian spinach beet. The above results are as per Mishra *et al.* (2020) for the okra and pointed gourd, where the highest ascorbic acid content was recorded in ZECC condition on the 5th day of storage compared to the room temperature and freeze condition. Weichmann (1987) indicated that the ascorbic acid concentration of stored produce often diminishes more swiftly at elevated storage temperatures due to its thermolability. The stability of ascorbic acid is often preserved by storing it at low temperatures (Fennema, 1996), and both temperature and loss in moisture content are responsible for decreasing ascorbic content (Kader, 2002). Bello and Fowoyo (2014) concluded that exposure to green leafy vegetables and citrus to high temperatures for a longer duration causes more loss of ascorbic acid content. Garande *et al.* (2019) also reported decreased ascorbic acid content in processed leafy vegetables during storage in ZECC conditions and cold temperatures, significantly less than the room temperature.

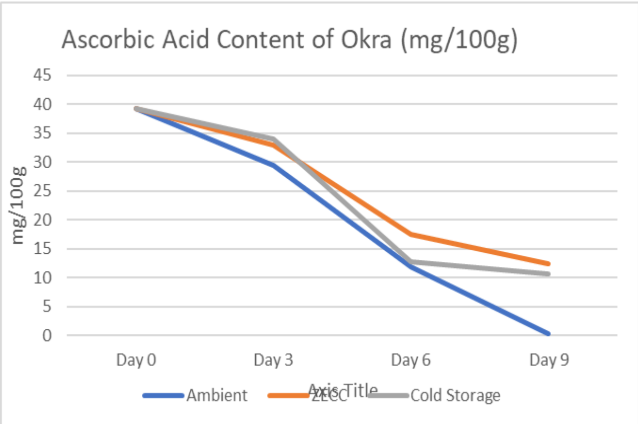

Fig. 5. *Ascorbic Acid Content in okra in ambient, zero energy cool chamber (ZECC) and cold storage condition*

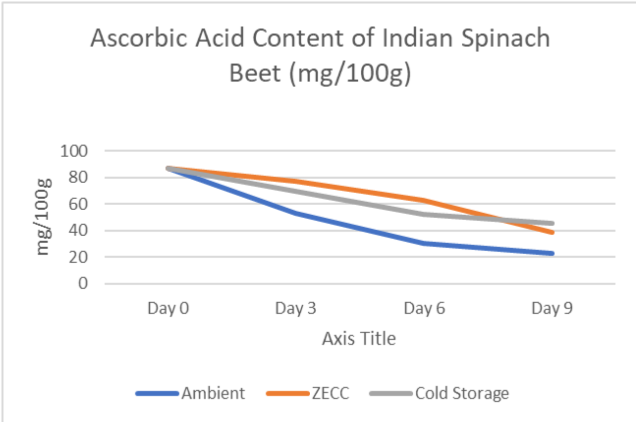

Fig. 6. *Ascorbic Acid Content in Indian spinach beet in ambient, zero energy cool chamber (ZECC) and cold storage condition*

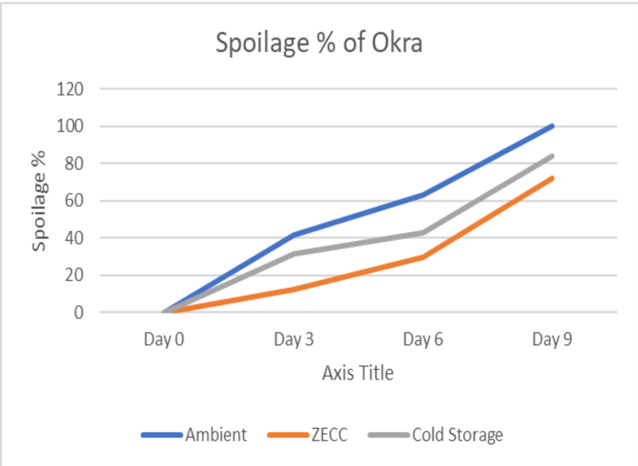

Fig. 7. *Spoilage in okra stored in ambient, zero energy Col Chamber (ZECC) and cold Storage condition*

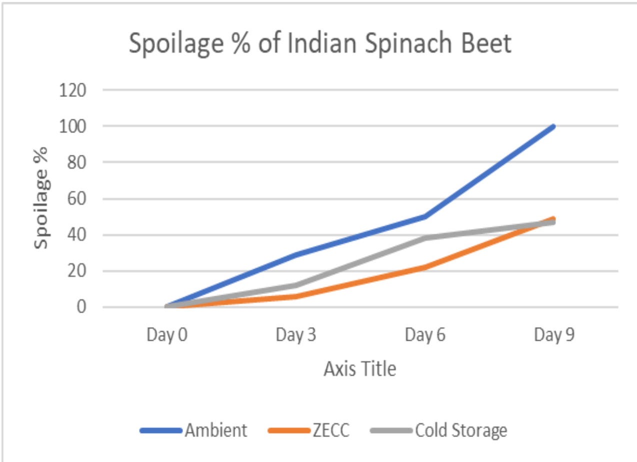

Fig. 8. *Spoilage in Indian spinach beet stored in ambient, zero energy cool chamber (ZECC) and cold storage condition*

Effect of storage on marketability/spoilage of okra and spinach beet

The physical appearance of harvested vegetables deteriorates daily if not adequately managed through temperature and relative humidity regulation. The deterioration of the vegetables was assessed by distinguishing the decaying, shrivelled, and yellow specimens from those that appeared fresh. The spoilage % was calculated during the storage period on days 3, 6, and 9. In okra, as shown in Figure 7, a notable difference was observed in $T_{1,}$ with the lowest mean of 12.9% and 30% on days 3 and 6, respectively. The maximum spoilage was recorded in T0 on days 3 and 6. In Indian spinach beet, as shown in Figure 8, T_1 emerged as unique, showing distinctive deviation from the other treatments. The lowest mean was recorded in $T_{1,}$ exhibiting values of 6% and 22.12% on day 3 and day 6. The highest mean was recorded in the T_0 control in the ambient condition with maximum spoilage at day 3 and day 6 having values of 29% and 49.83%, respectively, compared to all the other treatments. It has been observed that fungal infection occurred in the ZECC storage after 6 days of storage in both the cases of okra and Indian spinach beet and blackening and wilting occurred in cold storage from day 3. Sundaram (2016) reported that vegetable okra, brinjal, bitter gourd, radish, and lab showed a marketability percentage when stored in ZECC for a short term on the farm rather than stored at ambient temperature. As per Garande et al. (2019), the above results were also for green leafy vegetables wherein maximum yellowing, decay and rotting were recorded at room temperature due to faster senescence of vegetables attributed to high temperature and rapid metabolic activity.

Effect of storage on overall acceptability of okra and spinach beet

The overall acceptability of the vegetable is influenced by the product's intrinsic properties, including its appearance, aroma, colour, and taste. The overall acceptability was judged by panellists and scorers from 9 to 1 using the 9-point hedonic scale as reported in Ranganna (2014). The results were analysed for preference with data from untrained or semi-trained panellists to screen products for the consumer preference of the vegetable ranging from 'like extremely (9) to dislike

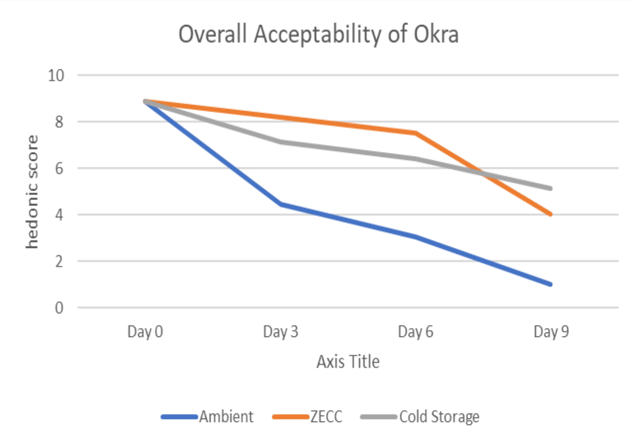

Fig. 9. *Overall Acceptability of Okra in Ambient, Zero Energy Cool Chamber (ZECC) and Cold Storage condition*

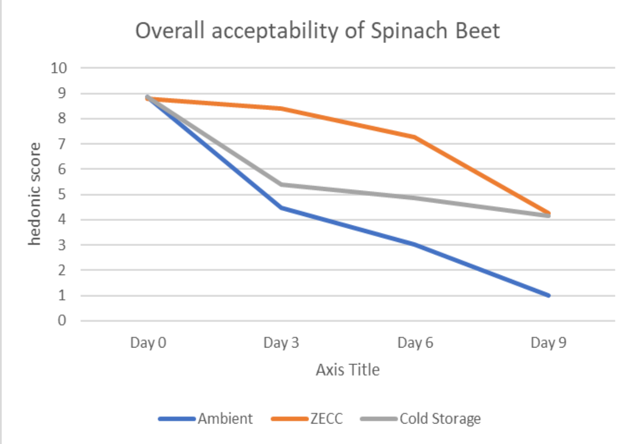

Fig. 10. *Overall Acceptability of Indian Spinach Beet in ambient, zero energy cool chamber (ZECC) and cold storage condition*

extremely (1). In okra, as illustrated in Figure 9, a notable disparity was observed among the three treatments, with T_0 demonstrating the lowest scores on days 3, 6, and 9, recording values of 4.4, 3.03, and 1, respectively. The produce appeared shrivelled, not firm, and dried compared to the other treatments, and fungal growth was observed after day 6. The highest score was recorded in T_1 at 8.2 and 7.52 on day 3 and day 6, as pods were fresh, green and firm. Fungal growth was observed in T_1 from day 8. T_2 scored 7.15, 6.42 and 5.15 on days 3, 6 and 9 respectively. The pods appeared firm, but slight blackening appeared on the surface, losing its aesthetic appearance. This may be due to pods exhibiting chilling injury when kept in cold temperatures, as tropical fruits and vegetables are stored in cold low temperatures (Adebisi *et al.,* 2009). In Indian spinach beet, as shown in Figure 10, the highest overall acceptability was recorded in T_1, which showed a notable difference from the other two treatments, exhibiting values of 8.4 and 7.2 at day 3 and day 6. The produce appeared fresh, firm, and green till day 3, while leaves were wilted, and yellowing was observed on day 6. T_3 exhibited a significant difference from the other treatments as the score was 5.4, 4.85 and 4.165 on day 3, day 6 and day 9, respectively. The leaves started wilting after the initial day of storage. This may be attributed to reduced relative humidity in cold storage facilities compared to ZECC. The lowest mean was observed in T_0 with scores of 4.4, 3.0, and 1 on day 3, day 6, and day 9. On day 9 of the examination, it was evident that treatments T_1 and T_2 exhibited similar effects. The lowest score was recorded in T_0 i.e., vegetables stored in ambient conditions during storage. ZECC can be utilized for temporary storage on farms (Jha and Kudos, 2006). The result follows Garande *et al.* (2019) for the storage of leafy vegetables and Indore *et al*. (2016) for okra where the shelf life and acceptability of the vegetable increased when stored in ZECC for a shorter duration and refrigerated storage.

Cost Benefit Ratio

The viability of the storage conditions for the chosen veggies was evaluated using the Cos-Benefit Ratio calculation. The cost-benefit ratio was calculated for all three storage conditions for okra and Indian spinach beet. The product's cost-benefit ratio was calculated considering the preinstalled setup for ZECC and Cold Chamber. The vegetables stored in ambient conditions showed BCR less than on day 3, concluding that this system is not cost-effective. Estimating the cost of selling the product with the cost of inputs was utilized during storage. The BCR after the storage of okra on day 3 in ZECC was calculated as 1.53, which is greater than 1, delivering a positive net value. The BCR of cold storage of okra on day 3 was calculated as 0.78, which is less than 1, delivering a negative result. On day 6, the BCR calculated after the storage of okra in ZECC was 1.22, delivering a positive result, whereas the BCR of the cold chamber was 0.65 less than 1. In the case of Indian spinach beet, the BCR calculated at day 3 for ZECC is 1.18, which is greater than 1, delivering a positive net value. The BCR of cold storage of Indian spinach beet on day 3 was calculated as 0.60, which is less than 1, delivering a negative result. Cost-benefit Ratio can help farmers to evaluate the economic feasibility of using which type of storage system to maximize their return. Compared to ambient storage and cold chambers, the produce stored in ZECC can provide more revenue for small-scale farmers. ZECC has a low maintenance cost when compared with a cold chamber system. The result is in accordance with Kamal and Pandey (2018) where the ZECC showed a higher Cost Benefit ratio when compared to the general condition in the case of leafy vegetables, brinjal, tomato and Cauliflower- ZECC is a good alternative to the highly expensive mechanical refrigeration to store horticultural com-

modities (Nitipong and Sukum 2011).
Okra and spinach beet are commonly grown vegetables in India sold by small-scale or marginal farmers in local areas or small *mandis* as soon as they are harvested due to their highly perishable nature. Reducing deteriorative reactions in horticulture products extends their shelf life, increasing their availability and stabilizing market supply and prices (Kumar et al., 2018). When vegetables are taken out of storage, it usually have to compete with much fresher produce on the market. Short term storage of produce on farms can benefit small-scale farmers by generating higher remuneration for their crops. The use of affordable and cost-effective storage techniques such as ZECC for fresh produce can not only enhance the shelf life of the produce but also earn profit for small-scale farmers as the only expenses incurred are water usage and disinfection. Among the three storage conditions for okra and spinach beet storage in the study, ZECC not only enhances shelf life but also generates profit. The outcome of this study will serve as a prerequisite for using ZECC on farms to maintain the quality and extend the shelf life of the crop while also benefiting farmers by providing good value for their crop for a longer duration.

Conclusion

The empirical study evaluated the storability, quality and cost-effectiveness of two common Indian vegetables, such as Indian spinach beet and okra, in three different environments: ambient, ZECC, and cold chamber. The okra in the cold chamber had a good level of ascorbic acid content and held moisture well, but because of the chilling injury, the product's external appearance was not up to par for marketing purposes. On the other hand, in ZECC, minimum reduction of PLW and firmness were recorded and maximum retention of ascorbic acid was recorded, showing the good quality of the product for selling and consuming. From the above results, it may be stated that ZECC can be utilized as a productive on-farm short-term storage system that small-scale and marginal farmers can use to extend shelf life by keeping product quality. With the use of ZECC, the shelf life of okra was extended up to 6 days and the shelf life of spinach beet was extended up to 3 days. Further, on the financial front, ZECC was more cost-effective than cold chambers as it required less maintenance than cold rooms. This may be beneficial for small-scale or marginal farmers as it can be utilized for on-farm storage purposes, and farmers can store the vegetables for a shorter duration while selling in markets.

Conflict of interest

The authors declare that they have no conflict of interest.

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