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Research Article

Storage and shelf-life evaluation of Indian spinach beet (*Beta vulgaris* cv. Pusa Bharati) employing various packaging materials

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Abstract
Leafy vegetables are a common source of vitamins and minerals in the human diet; however, they have a short shelf life due to their high metabolic activity and poor storage conditions. Considering this point, the storage and shelf-life studies of Indian spinach beet (*Beta vulgaris* cv. Pusa Bharati) were executed under three storage conditions, i.e. ambient temperature (S_0), Zero Energy Cool Chamber (ZECC) (S_1) and Cold Room (S_3) in combination with packaging material [Low Density Polyethylene (LDPE) perforated (P_1) and non-perforated (P_2); Biodegradable perforated (P_3) and non-perforated (P_4); banana leaf (P_5)]. The interaction between storage and packaging was studied by examining the effect on physicochemical characteristics, such as physiological loss in weight (PLW), ascorbic acid content (AA), spoilage, and overall acceptability, to evaluate quality and shelf life. It was observed that PLW% increased rapidly and AA decreased rapidly in ambient conditions across all treatments. In Cold room conditions, a minimum increase in PLW% and a minimum decrease in AA were recorded, with the highest mean coupled with LDPE. S_2P_2 obtained the highest overall acceptability score, extending the shelf life of produce up to 8 days. S_1P_0 recorded the minimum increase in PLW and the minimum decrease in firmness, and AA extended shelf life by up to 4 days. However, in terms of overall profit in storing vegetables in different systems, S1P0 showed a higher Benefit-Cost (B-C) ratio than the other conditions. Furthermore, S_1P_5 and S_2P_5 showed similar results to S_1P_2 and S_2P_2, acting as a barrier to minimize metabolic activity for a shorter duration.

Keywords: Banana leaf packaging; Indian Spinach Beet; Low Density Polyethylene (LDPE); low temperature, Physiological loss in weight (PLW); , Zero Energy Cool Chamber(ZECC)

INTRODUCTION

Spinach beet, also known as Indian beet, desi palak, or beet leaf, is one of the common leafy vegetables grown in tropical and sub-tropical areas of India, including Uttar Pradesh, Maharashtra, West Bengal, and Gujarat. *Beta vulgaris* Cv. Pusa Bharati (2n = 18) belongs to the family Chenopodiaceae and has marginal and succulent leaves, green midrib, and leaf veins. The crop is generally eaten as a pot herb, and, compared to spinach or carrots, it is richer in vitamins A, B, and C. Additionally, it contains a respectable amount of calcium, iron, phosphorus, manganese, potassium, protein, fibre, and ascorbic acid. It also offers strong antioxidant protection against cancer and cardiovascular illnesses (Chen *et al.*, 2021). Despite being rich in nutrition and a relatively inexpensive food source, it is unavailable to all due to its highly perishable nature and short shelf life. One of the major causes of the unavailability of produce is the lack of storage techniques after harvesting, resulting in significant postharvest losses of 20 to 50% for horticultural items (Majubwa *et al.,* 2022). In the case of Indian Spinach, approximately 25% of the produce is lost post-harvest due to high moisture content (Prasad *et al.*, 2018), primarily due to poor management and inadequate storage. Leafy vegetables exhibit elevated respiration and metabolic activities that persist post-harvest, leading to their subsequent deterioration at various stages of post-harvest management, including improper handling, inadequate packaging, and insufficient storage techniques and systems.

To maintain the quality of the produce and prolong its shelf life, crops must be cooled to the ideal storage temperature and stored under proper conditions. Temperature and humidity are the two most crucial factors in extending storage life while maintaining quality. Low temperature reduces respiration and microbial incidence in fruits and vegetables. Generally, fresh fruits and vegetables require low temperatures, ranging from 0°C to 13°C, and high relative humidity, from 80% to 95%, to reduce metabolic activities such as transpiration and respiration rates (Shende, 2018).

The optimum temperature for storing leafy vegetables is 0–5 °C or above. Such temperature can be maintained by enclosing produce in cold storages with large, spacious areas for storing bulk produce or evaporating cold chambers, which are cost-effective, environmentally friendly, and do not require skilled labour. Cold Rooms, which are considered the best storage system, are mechanical precision instruments where temperature and humidity can be controlled depending on the nature of the commodity for a longer period, thereby maintaining the quality of the produce (Krishnakumar and Dayanandkumar, 2002). Whereas a zero-energy cool chamber (ZECC), developed by Roy and Khurdiya in 1983 at IARI, Pusa, is an evaporative cool chamber made of bricks and sand, where freshly harvested produce can be stored for a short duration before marketing to avoid middlemen. In such structures, the shelf life of the produce can be extended by using ZECC, as it provides a 10-15°C lower temperature than the outside environment with high relative humidity (Roy and Khurdiya, 1986; Roy and Pal, 1991). This method is effective for various crops, including tomato, cabbage, broccoli, brinjal, leafy vegetables, passion fruit, orange, mango, and others (Singh and Satapathy, 2006; Yadav *et al.*, 2010; Dash *et al.*, 2016; Singh *et al.*, 2022).

The shelf life of the crop can be further extended by employing an effective packaging system. Packaging acts as a barrier against outside conditions, such as oxygen, moisture, light, and microorganisms, to prolong its shelf life. It is not only required for preservation but also for safe storage and handling procedures (Sharma and Thakur, 2019). Packaging helps maintain high humidity inside and reduces weight loss and wilting of crops (Brandl and Mandrell, 2002). Low-density polyethylene (LDPE) is good for packaging the commodity but is not environmentally friendly. Therefore, there is a need to find an eco-friendly and sustainable alternative for it. It is essential to choose a suitable storage and packaging system for leafy vegetables, given their highly perishable nature. Keeping the above points in view, the shelf life study of Indian spinach beet (Beta vulgaris cv. Pusa Bharati) leaves was carried out by storing them in different storage systems employing various packages to assess the quality of the produce during the storage period. Furthermore, the Benefit-Cost Ratio was calculated to achieve a more precise and accurate result analysis of the overall profit that may be achieved from storing Indian Spinach beet during marketing after extending its shelf life.

MATERIALS AND METHODS

The study was conducted in the laboratory of Amity Institute of Horticulture Studies and Research, Amity University, Uttar Pradesh. The experiment was conducted over two years, from 2021 to 2022 (December to January). Indian Beet (*Beta vulgaris* cv. Pusa Bharati) was grown in the fields of Amity University, Noida, located in Uttar Pradesh. Leaves were harvested manually in the morning period (11±1°C, 54% RH) based on their commercial maturity. These were kept loosely in ice-packed, insulated Tan 90 boxes (10 kg/box) and then transferred to the laboratory for further processing. The spinach beet leaves were harvested and subjected to post-harvest management according to the treatment plan (Fig. 1).

The experiment was laid out in a one-factorial design with packaging material in ZECC, with three replications each. The details of treatments are given in Table 1.

Where, S_0: Ambient Condition (Control);S_1: ZECC Storage;S_2: Cold chamber; P_0: No packaging;P_1: LDPE non-perforated (100 micron; size:30X30cm);P_2: LDPE perforated (100 micron; size:30X30cm; 2% vents);P_3: Biodegradable non-perforated(50 micron) (package made of vegetable starch);P_4: Biodegradable perforated (50 micron; 2% vents) (package made of vegetable starch); P_5: Banana Leaf Packaging

The physicochemical analysis, including physiological loss in weight (PLW%), firmness (kg/cm²), ascorbic acid (mg/100g), overall acceptability, and spoilage, was recorded at 0, 3, 6, and 9-day intervals, with a sensory evaluation conducted at the end of the 9-day storage period. Furthermore, the benefit-cost ratio was calculated for the quantified vegetable, considering a pre-installed storage system. The study will not only help enhance the shelf life of Indian Spinach beet through packaging and storage, but also provide input for farmers to adopt the technique best suited to them, thereby increasing their profit from the sale of their goods.

Physiological loss in weight (PLW):

Indian Beet spinach was weighed regularly, and weight loss was calculated during storage compared to the initial weight recorded before storage. The estimation

Table 1. Treatment plan for the study of Indian spinach beet leaves in different storage conditions employing different packaging materials

Condition	Treatments
Ambient Condition	S_0P_0, S_0P_1, S_0P_2, S_0P_3, S_0P_4, S_0P_5
Zero Energy Cool Chamber	S_1P_0, S_1P_1, S_1P_2, S_1P_3, S_1P_4, S_1P_5
Cold Chamber	S_2P_0, S_2P_1, S_2P_2, S_2P_3, S_2P_4, S_2P_5

S_0:Ambient Condition (Control);S_1: ZECC Storage;S_2: Cold chamber;P_0: No packaging;P_1: LDPE non-perforated (100 micron; size:30X30cm);P_2: LDPE perforated (100 micron; size:30X30cm; 2% vents);P_3: Biodegradable non-perforated(50 micron) (package made of vegetable starch);P_4: Biodegradable perforated (50 micron; 2% vents) (package made of vegetable starch);P_5: Banana Leaf Packaging

was conducted according to the established approach outlined in Ranganna (2014). PLW was recorded in the percentage of weight loss. The formula used for calculation is:

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

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

Firmness

The firmness was measured using a hand-operated firmness tester known as a penetrometer (Fruit Pressure Tester, FT 327). The tester was equipped with a 4 mm diameter plunger inserted into the produce. The reading on the penetrometer was noted and expressed in kg/cm^2.

Ascorbic acid content (mg/100g)

Ascorbic acid was determined using the 2,6-dichlorophenol—indophenol visual titration method (Johnson, 1948), as reported in Ranganna (2014). The samples were prepared in 3% metaphosphoric acid and titrated with a 2,6-dichlorophenolindophenol dye solution until the pink colour persisted for 15 seconds. The ascorbic acid was calculated using the formula given below and expressed in mg/100g.

Ascorbic acid (mg/100g)= Titre x Dye factor x Volume made up x 100/ Volume of aliquot for estimation x Volume or weight of sample …..Equation (2)

Overall acceptability evaluation

The evaluation was carried out after harvesting and storage. The consumer panel consisted of ten semi-trained judges who evaluated the sensory characteristics, colour, appearance, texture, and overall acceptability of the leaves. The scores were documented on a scorecard utilizing a 9-point hedonic scale, as indicated in Ranganna (2014). It gauges how well-liked or disliked a particular product is by consumers on a scale of "like extremely" to "dislike extremely."

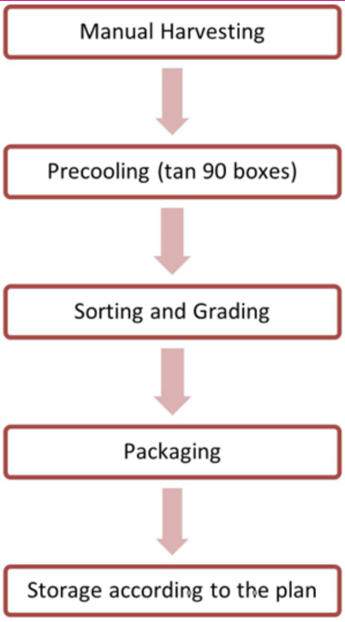

Fig. 1. *Flow chart on Post Harvest Methodology of Indian spinach beet*

Spoilage

The spoilage was recorded by eye estimation from the number of leaves in each lot spoilage from the initial day; calculated by the following formula:

$$Spoilage\ \% = \frac{number\ of\ spoiled\ units}{(Total\ number\ of\ units)} * 100$$
…Equation (3)

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

Statistical analysis

The OPSTAT software was used to statistically analyze the data recorded. The results obtained were subjected to an ANOVA analysis under a two-factor design. The confidence level assumed for the data was 95% ($p < 0.05$) (Panse and Sukhatme, 1985).

Benefit Cost Ratio

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

$$BCR = \frac{\text{Net Return of the produce}}{\text{Total Cost of the produce}}$$
………………..Equation no. (4)

RESULTS AND DISCUSSION

Physiological loss in weight (PLW %)

The physiological loss in weight increased during the storage period due to metabolic activities such as respiration and transpiration, leading to moisture loss and the shrivelling of the produce. The results of PLW of spinach beet leaves are given in Fig 2. While analyzing data, it was revealed that storage and packaging conditions significantly affected the moisture content of the spinach beet leaves. Generally, spinach has a moisture content of approximately 95% (Murcia *et al.*, 2020). On the initial day, the moisture loss was recorded as 0%. With the advancement of the storage period, it was noted that there was an increase in physiological weight loss. The individual effect of different storage on the PLW of spinach beet was statistically significant, as shown in Fig. 2. The maximum loss in PLW was observed in S_0, i.e., the ambient condition, with 17.80%, 25.32%, and 50.43% loss during days 3, 6, and 9, respectively. The minimum loss in PLW was recorded in S_1P_0, i.e., ZECC without packaging. The PLW recorded was 4.34%, 7.88%, and 9.53% on days 3, 6, and 9, respectively. This may be due to the low temperature in ZECC coupled with a high relative humidity of 90-95% in the ZECC chamber. Storage S_2 showed a significant difference compared to S_0 and S_1, with values of 6.07%, 11.60%, and 15.56% at days 3, 6, and 9, respectively. A higher loss of moisture compared to ZECC may be due to the low relative humidity of 80-85% in the cold chamber. The results can be elucidated by the findings of Ambuko *et al.* (2017) in the case of Amaranthus leaves, where minimum PLW was recorded in leaves when stored in an evaporative cooling system compared to ambient temperature The temperature and relative humidity affect the Vapour Pressure Difference between the produce and the environment which may affect the water loss (Camelo, 2004).. Low temperature and high relative humidity might be the cause of extending vegetable shelf life.

PLW increases throughout the 9-day storage period, as indicated by the interaction effect of various storage conditions and packing treatments. All the packaging treatments were statistically significant from each other at a 1% level of significance. The data revealed that the maximum PLW was recorded in S_0P_3, with values of 45.07%, 67.57%, and 80.19%, respectively, on days 3, 6, and 9. The maximum loss may be due to high ambient temperature, low humidity and package interaction with the product. The minimum loss in PLW was recorded in S_1P_1 as 1.71%, 3.42%, and 4.65% on days 3, 6, and 9, respectively. ZECC had a significant influence on PLW during storage. This was followed by S_2P_1, with values of 2.12%, 5.12%, and 6.72% on days 3, 6, and 9, respectively. S_1P_1, was statistically significant with interaction(s) S_0P_0, S_0P_2, S_0P3, S_0P_4, S_0P_5, S_1P_0, S_1P_3, S_1P_4, S_2P_0, S_2P_3, S_2P_4, S_2P_5 emerged as statistically significant at the 0.01 level, whereas S_1P_2, S_1P_5, S_2P_1 and S_2P_2 did not show any significant effect at the confidence level 0.05. The low reduction in PLW in the LDPE package may be due to high relative humid conditions inside the package, leading to a decrease in the respiration rate of Indian spinach. This may be caused by the inhibitory activity of enzymes (Burton 1978). The retention of high dry matter in packed produce compared to unpacked produce might be due to lower respiration rate and other metabolic activities. Further, the results inferred from the observation by Ghosal *et al.* (2019) in the case of leafy vegetable spinach, where PLW increased during storage, even when packaged. It was also reported in the case of okra, where LDPE packages showed statistically different results from the control, which may be due to the difference between the internal water pressure of the produce and the surrounding environment, resulting from its biochemical activities, as interpreted by Paulus *et al.* (2021). Minor water loss may result in wilting, shrinkage, and diminished firmness, which can alter their physical characteristics (Chen *et al.*, 2024). Banana leaf packaging, i.e., P_5, showed significant effects at a confidence level of 0.01. At day 3, S_1P_5 showed non-significant results with S_1P_1, S_1P_2, S_2P_1, S_2P_2 and S_2P_5. Forero-Cabrera *et al.* (2017) reported that the minimum loss in weight was recorded in lulo fruit when packaged in banana leaf as compared to the control. It can be observed that banana leaf packaging can create a suitable environment for short-term crop storage; however, it is not suitable for long-term use. In the case of LDPE packages, the minimum PLW was recorded compared to other packaging materials. A similar result was reported by Mahara and Karki (2024), where bananas were stored in different packaging materials, including banana leaf and polyethene (PE). PE showed a minimum loss in PLW, whereas banana leaf showed a significant result compared to the control.

Firmness (kg/cm^2)

The firmness was significantly influenced by the storage condition and packaging material used (Fig. 3). The firmness during the experiment ranged from 4.37 kg/cm^2 to 0.4 kg/cm² under different storage conditions and packaging materials. On the initial day, the firmness of spinach beet was observed to be 4.37±0.17 kg/cm^2. This significant decrease during storage may be due to the dissolution of parenchymal cells (Ahmmed *et al.*, 2019). The data revealed that the highest firmness loss among all the storage conditions is in S_0 i.e. control (2.55 kg/cm^2, 1.93 kg/cm^2 and 0.61 kg/cm^2) and the lowest firmness loss in S_1 (4.00 kg/cm^2, 3.76 kg/cm^2 and 3.05 kg/cm^2) at day 3, 6 and 9 respectively. The firmness during the storage period decreased with an increase in the number of days in all conditions. This may be due to the loss of moisture during storage. The results were consistent with those of Kad *et al.* (2022), who found that the firmness of green capsicum (cv. Indra) diminished under ZECC and cold storage in all treatment combinations as the storage period rose.

The interaction effect of combining different storage conditions with packaging treatment shows increased

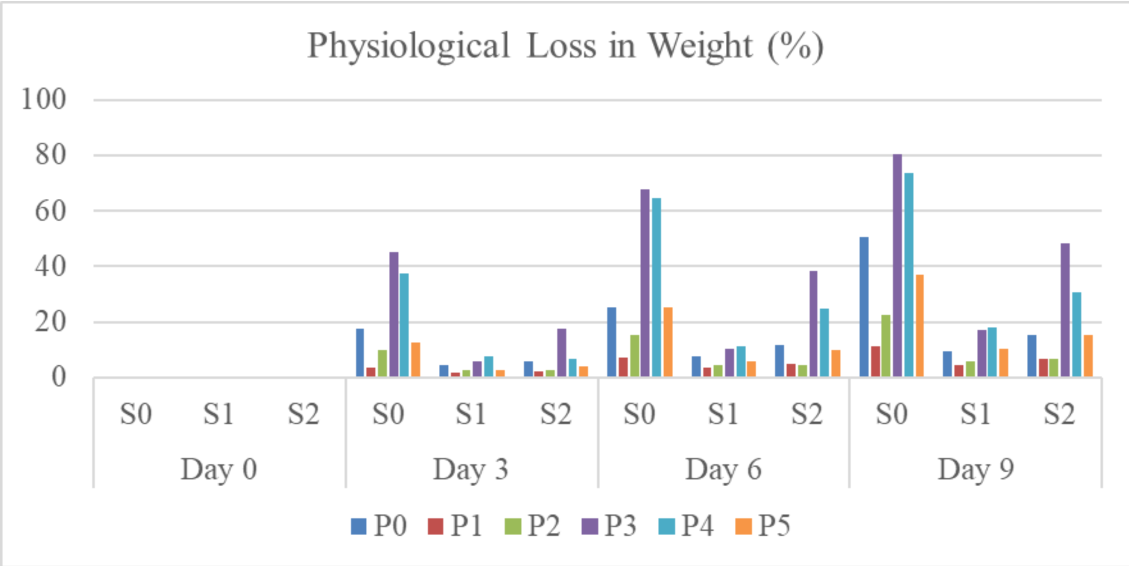

Fig. 2. *Physiological loss in weight of Indian spinach beet during the storage period*

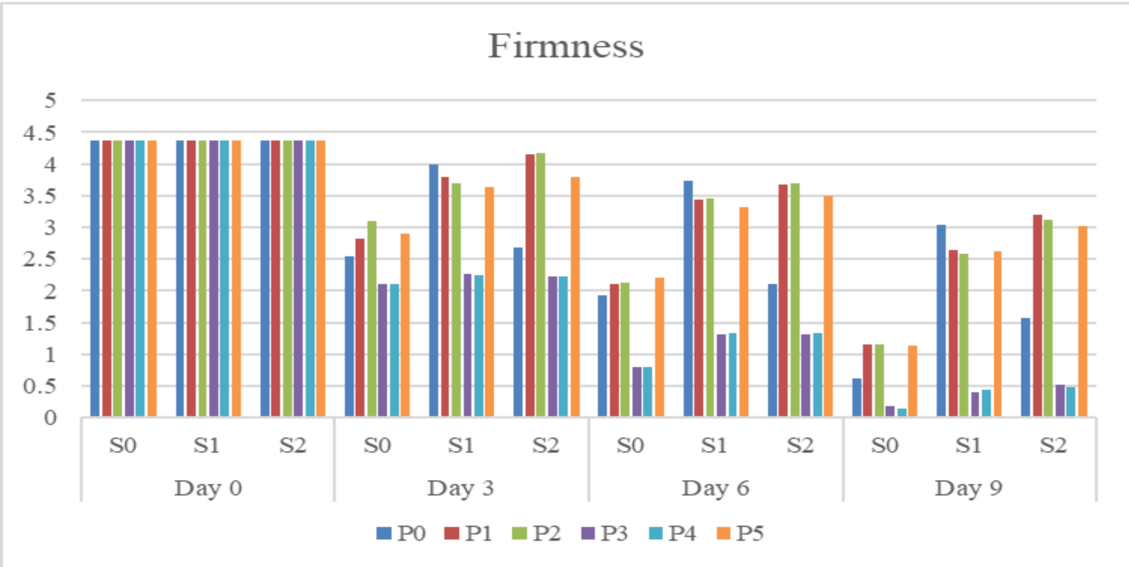

Fig. 3. *Effect on firmness of Indian spinach beet during the storage period*

firmness loss during the storage period. The maximum decrease in firmness was observed in S_0P_3, i.e., the ambient condition with non-perforated biodegradable packages, and in S_0P^4, i.e., the ambient condition with non-perforated biodegradable packages. This may be due to the high ambient temperature and the interaction of spinach beet with vegetable starch-made biodegradable packages, which have an end firmness of 0.19 and 0.15 kg/cm². On day 3, S_2P_2 exhibited the maximum firmness retention, with a value of 4.17 kg/cm², followed by S_2P_1 (4.15 kg/cm²) and S_1P_1 (4.00 kg/cm²). While reviewing the interactions, it was noted that the interaction in S_2P_1 was statistically significant compared to all the other interactions, except that it reached significance at the 0.01 level with S_1P_0 and S_2P_2. On day 6, the maximum retention of firmness was recorded as 3.7 kg/cm^2 in S_2P_2, followed by S_1P_0, S_2P_1, and S_2P_5. According to the interaction analysis, it was reported that interaction S_2P_2 was statistically significant at the 0.01 level compared to other combinations, whereas S_1P_0, S_1P_1, S_1P_2, S_2P_1, and S_2P_5 failed to reach statistical significance. On day 9, no significant difference was recorded in S_2P_1, S_2P_2, and S_2P_5 at a confidence level of 0.05, with values of 3.2, 3.1, and 3.0 kg/cm²˒ respectively. The texture of the vegetable depends on the cell walls of the vegetative cells. The decreased firmness may be due to moisture loss, which decreases the turgidity of the cell, the thinning of the cell wall, or the degradation of pectin, as reported by Ahmmed *et al.* (2019) in the case of Indian spinach. The minimum decrease in firmness indicates a more desirable quality. The decrease in firmness was recorded as findings in case of peach by Mahajan *et al.* (2015), Okra by Indore *et al.* (2016) and in the case of avocado by Buthelezi and Mafeo (2024), where LDPE proved to be better in maintaining the firmness when

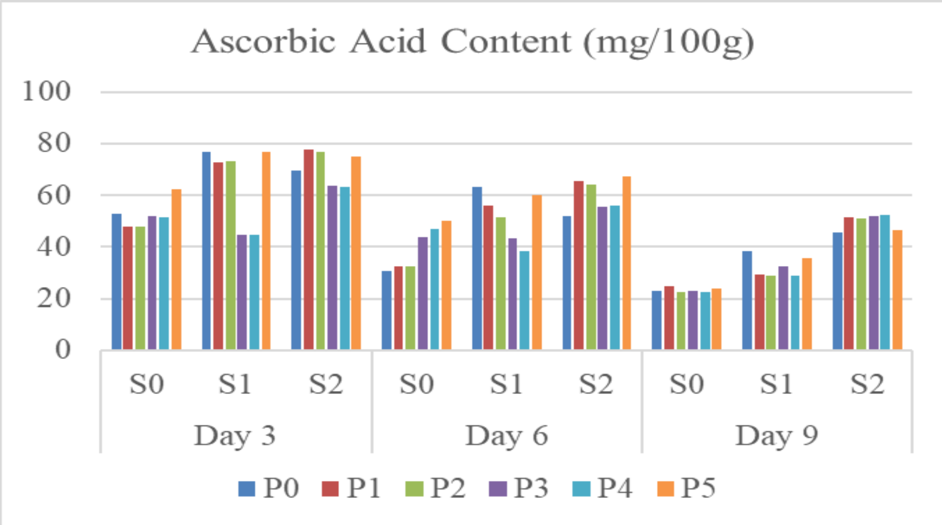

Fig. 4. *Effect on ascorbic acid content of Indian spinach beet during the storage period*

compared to the control without packaging.

Ascorbic acid (mg/100g)

Ascorbic acid content, i.e., Vitamin C content, is an important indicator for judging the quality of Indian beet spinach. Ascorbic acid is a compound sensitive to destruction that can happen during the post-harvest management of produce at various steps such as storage, packaging, physical damage, etc. Fresh vegetables have more ascorbic acid content compared to stored vegetables. During storage, it has been generally observed that the ascorbic acid content gradually decreases due to temperature and other conditions that affect it (Lee and Khadar 2000).

The effect on AA content during storage is shown in Fig. 4. The ascorbic acid content during the experiment ranged from 86.85 mg/100g to 23.11 mg/100g. . On the initial day, the pooled ascorbic acid content was recorded as 86.85 mg/100g, which was gradually reduced during the 9 days of storage. The individual effect of each storage on the ascorbic acid content was statistically significant. Among the three storage conditions, the maximum ascorbic acid content was recorded in S_1 on days 3 and 6, with values of 76.93 mg/100g and 63.28 mg/100g, respectively. Minimum ascorbic acid was recorded on S_0 with values as 52.74, 30.72 and 23.11 mg/100g, respectively. At day 9, maximum ascorbic acid content was recorded in S_2 with a value of 45.78mg/100g. The decrease in ascorbic content may be due to an increase in storage time, during which respiration may have played a vital role in its reduction (Sharma *et al.,* 2011). Low temperatures, high relative humidity, and avoidance of microbial growth slow the metabolic activity of the produce, helping to retain its ascorbic acid content.

Furthermore, the interaction effect of combining different storage conditions with packaging treatment reveals a statistically significant decrease in ascorbic acid content. At day 3, the maximum retention of ascorbic acid content was recorded in S_2P_1, with a value of 77.68 mg/100 g, followed by S_2P_2, with a value of 76.69 mg/100 g. It was established that interaction S_2P_1, was statistically significant with interaction(s) S_0P_0, S_0P_1, S_0P_2, S_0P_3, S_0P_4, S_0P_5, S_1P_3, S_1P_5, S_2P_3, S_2P_4 and signified significance at the 0.01 level. S_0P_0 was found to be statistically significant at the 0.05 level, whereas S_1P_1, S_1P_2, S_1P_5, S_2P_2, and S_2P_5 were found to be non-significant. It can be said that the ZECC with LDPE packaging (S_1P_1 & S_1P_2) and banana packaging (S_1P_5), as well as the cold chamber with LDPE packaging (S_2P_1 & S_2P_2) and banana leaf packaging (S_2P_5), showed no significant difference at the 0.05 level. Minimum retention of ascorbic acid content at day 3 in the interaction was recorded in S_1P_3 and S_1P_4. This may be due to the high relative humidity and waterlogging inside the packages, which can cause fungal infection within the packaging when it interacts with the vegetable starch component.

At day 6, maximum ascorbic acid retention was recorded in S_2P_5 with a value of 67.41 mg/100g, followed by S_2P_1 (65.67 mg/100g) and S_2P_2 (64.06 mg/100g). The three interactions showed a non-significant effect when statistically analyzed. The minimum ascorbic acid was recorded in spinach beet stored in ambient conditions without packaging. On day 9, the maximum retention was recorded in S_2P_1 and S_2P_2, and a detailed examination revealed that they were significant compared to the other treatments. S_2P_3 and S_2P_4 were recorded with high ascorbic acid content, but the packages had waterlogging and fungal infection. Kader (2002) reported that the loss of ascorbic content in vegetables and fruits is caused by temperature and water loss. The results are similar to those of Indore *et al.* (2016) in okra, where the maximum retention without packaging was observed in the ZECC condition until day 9. In contrast, with packaging, maximum retention was observed in the cold room with a 200-gauge LDPE. The results also align with the findings of Garande *et al.* (2019) in the case of leafy vegetables, namely fenugreek, coriander, spinach, and Amaranthus, packed in LDPE 200 gauge (2% vent). The highest ascorbic acid content was recorded in refrigerated conditions, followed by ZECC and the control.

Spoilage %

The spoilage in the Indian spinach beet increased from 6% to 100% across all treatment procedures performed during the study, as shown in Table 2. The individual effect of each storage on spoilage/marketability showed significant effects, with maximum spoilage in S0, at values of 29.00%, 49.83%, and 100% at days 3, 6, and 9, respectively. The minimum spoilage is recorded in S_1, followed by S_2, during the storage period. It has been observed that fungal infection occurred in the ZECC storage after 6 days of storage and blackening and wilting occurred in cold storage from day 3 in the case of Indian spinach beet. The findings correlated with those of Sundaram (2016) in the case of okra, brinjal, radish, bitter gourd, and lab lab, where marketability was high in the case of ZECC compared to the control. Furthermore, in ambient conditions, the data revealed that LDPE performed better than banana leaf packaging and biodegradable packaging among the three packaging materials. The banana leaf packaging dried during storage, and in the case of biodegradable packaging, the leaves were stored in a dried state.

The interaction effect of combining different storage conditions with packaging treatment shows statistically significant results. During the 9-day storage period, minimal spoilage was recorded in S_2P_1 and S_2P_2, with no significant difference. However, waterlogging was observed inside the LDPE Packaging, which may be due to the microenvironment created within the packaging material. The water droplets accumulated due to the vapour evolved during the metabolic processes of transpiration and respiration. This was followed by S_1P_1 and S_1P_2, where the packages showed less spoilage than those kept in Ambient conditions. However, fungal infection was recorded after day 6 in the packages. Kad *et al. (2022) also found that rotting was more rapid in ZECC compared to cold storage in the case of capsicum during the* 40-day storage period. Also, Prasad et al. (2018) reported that the highest number of days to 50% colour change and rotting occurred in spinach beet stored in LDPE packaging when treated with benzoic acid, whereas the minimum days of 50% colour change and rotting occurred in the control without packaging. The maximum spoilage was recorded in biodegradable packages, both perforated and non-perforated, kept in ZECC or cold rooms, with fungal infection inside the packages. This may be due to the presence of starch and water, which provides an environment conducive to the growth of foreign organisms. There was little significant difference between the LDPE and banana leaf packaging kept in ZECC during the 3-day storage period. The result aligns with the findings of Forero-Caberara *et al.* (2017), where the use of banana leaf packaging resulted in reduced deformation and mechanical damage to lulos.

Overall acceptability evaluation

The sensory evaluation of the stored Indian Spinach Beet was conducted by judges at 0, 3, 6 and 9 days, as provided in Table 3. The initial effect on colour was recorded as a mean value of 8.78, and the initial effect on overall acceptability was 8.86.

At day 3, the maximum colour score was obtained by S_2P_2 followed by S_2P_1 and S_1P_1. Analysis of the result by Duncan's Multiple Range Test (DMRT) indicated that S_1P_0, S_1P_1, S_1P_2, S_1P_5, S_2P_1, S_2P_2 and S_2P_5 falls under same group 'a'. Whereas S_0P_0, S_2P3 and S_2P_4 fell under the same group labelled as 'd'. On day 6, the

Table 2. Effect of packaging and storage on spoilage in Indian spinach beet

Storage / packag-	Day 3				Day 6				Day 9			
	S_0	S_1	S_2	Mean P	S_0	S_1	S_2	Mean P	S_0	S_1	S_2	Mean P
P_0	29.00	6.00	12.33	15.78	49.83	21.67	38.00	36.50	100.00	48.67	46.67	65.113
P_1	36.34	13.17	3.33	17.61	47.33	47.83	13.67	36.28	100.00	63.33	23.00	62.11
P_2	36.34	12.83	3.33	17.50	49.33	48.00	13.17	36.83	100.00	63.84	23.34	62.39
P3	100.00	42.00	33.67	58.56	100.00	100.00	48.00	82.67	100.00	100.00	65.00	88.333
P_4	100.00	42.34	37.17	59.83	100.00	100.00	48.83	82.94	100.00	100.00	67.84	89.278
P_5	27.84	14.17	7.83	16.61	41.00	44.33	41.00	42.11	71.67	63.33	54.33	63.108
Mean S	54.92	21.75	16.28		64.58	60.31	33.78		95.28	73.19	46.70	
S x P	2.375				1.838				2.657			
CD (5%)	S=0.969, P=1.371				S=1.061, P=1.838				S=1.085, P=1.534			

Table 3. Effect of storage on Sensory characteristics of Indian spinach beet

Treatment	Colour			Overall Acceptability		
	Day 3	Day 6	Day 9	Day 3	Day 6	Day 9
S_0P_0	4.37	1.34	1.00	4.47	3.04	1.00
S_0P_1	5.34	3.82	1.00	5.30	3.25	1.55
S_0P_2	5.50	3.90	1.00	5.33	3.24	1.52
S_0P_3	1.50	1.00	1.00	3.70	1.00	1.00
S_0P_4	1.50	1.00	1.00	3.94	1.00	1.00
S_0P_5	6.75	4.67	2.09	5.96	4.17	2.17
S_1P_0	8.27	7.27	2.65	8.40	7.03	4.03
S_1P_1	8.04	6.74	4.03	7.37	5.43	3.60
S_1P_2	8.04	5.95	3.72	7.29	5.07	3.55
S_1P_3	5.50	1.50	1.00	5.35	1.00	1.00
S_1P_4	5.50	1.50	1.00	5.40	1.00	1.00
S_1P_5	8.25	5.38	3.59	8.27	6.58	4.04
S_2P_0	6.01	5.08	4.27	5.40	4.85	4.17
S_2P_1	8.37	7.07	6.95	8.33	7.07	7.00
S_2P_2	8.40	7.29	6.90	8.40	7.29	7.02
S_2P_3	4.25	1.00	1.00	4.45	1.00	1.00
S_2P_4	4.27	1.00	1.00	4.55	1.00	1.00
S_2P_5	8.19	6.70	6.23	8.19	6.80	6.24
CD (5%)	0.714	0.874	0.433	0.352	0.16	0.202

maximum score was achieved by S_2P_2, with a mean of 7.29. The analysis revealed that treatments S_1P_1, S_1P_2, S_2P_1, S_2P_2 and S_1P_5 are statistically at par as they all belong to group 'a'. The data suggest that treatments S_0P_0, S_0P_5, S_0P_4, S_1P_3, S_1P_4, S_2P_3 and S_2P_4 have non-significant means, being all categorized under group 'f'. Treatment S_0P_3 reveals the minimum mean at 1.00. At day 9, S_1P_2 shows the maximum mean score 6.95.

The maximum score of overall acceptability at day 3 was recorded in S_1P_0 and S_2P_2 followed by S_2P_1 and S_1P_5. All the mentioned treatments exhibit similar non-significant differences and fall under category ‘a’ surpassing the other treatments. Compared to the other treatment S_0P_3 and S_0P_4 exhibited the minimum mean score. At day 6, S_2P_2 had the highest mean of 7.29, surpassing the others in terms of effect, but the result was non-significant compared to S_1P_1 and S_0P_0. Treatment S_0P_0 had the minimum mean score. At day 9, the analysis revealed that S_0P_0, S_0P_3, S_0P_4, S_1P_3, S_1P_4, S_2P_3 and S_2P_4 had the minimum mean score. The highest mean score was obtained by S_2P_1 and S_2P_2 followed by S_2P_5.

LDPE packaging in combination with the cold room was the best considering the overall acceptability. The results of the present findings can be compared with results obtained by Jaggi *et al*. (2005), where fenugreek and spinach were acceptable till day 6 when stored in perforated LDPE at low temperature, This was also reported by Indore *et al*. (2016) in case of okra, where okra stored in LDPE packaging has the highest overall acceptability upto 15 days compared to ZECC and Ambient temperature. ZECC without packaging was better than the ZECC with LDPE packaging, which might be due to the formation of water droplets within the LDPE packaging material, followed by leaf yellowing. Biodegradable Packages, combined with three storage conditions (i.e., ambient (S0P3 and S0P4), ZECC (S1P3 and S1P4), and Cold room (S_2P_3 and S_2P_4), had the lowest score in overall acceptability due to fungal infection. This may be due to the interference of the moisture content released during metabolic activities with the vegetable starch present in biodegradable packages. Vegetable starch generally contains two types of molecules, amylose and amylopectin, displaying physical features such as thermal behaviour, rheology, solubility, swelling, hydrolysis, and degradation (Rashwan *et al.*, 2024). The water and starch together may have provided a humid environment and lack of air circulation inside the package, leading to bacterial or mould growth that spoiled the spinach beet, as explained in the manual "Prevention of post-harvest food losses fruits, vegetables and root crops" by the Food and Agriculture Organisation (FAO, 1989).

Benefit Cost Ratio (BCR)

The Cost-Benefit Ratio was used to determine the viability of the chosen vegetable storage conditions. The cost-benefit ratio for all three storage conditions and packaging interactions with Indian spinach beet was assessed, considering the pre-installed setup for ZECC and the Cold Chamber. The spinach beet leaves stored in ambient conditions, both with and without packaging (S_0P_0, S_0P_1, S_0P_2, S_0P_3, S_0P_4, and S_0P_5), had a shelf life of 1-2 days and showed BCR of less than 1 on day 3, concluding that this system is not cost-effective. The BCR estimated for ZECC (S_1P_0) on day 3 was 1.18, which was more than one, resulting in a positive net value. Whereas the BCR in cold storage (S_2P_0) was determined to be 0.60, which is less than one, resulting in a negative outcome.

The interaction effect of storage and packaging showed notable result while calculating BCR. On day 3, BCR calculated S_1P_2 and S_1P_3 were 1.25 whereas BCR in S_2P_1 and S_2P_2 was 1.18. The storage in ZECC showed high positive result when compared to Cold room on day 3. On day 6, BCR in both conditions, i.e., ZECC and Cold storage with packaging P_1 and P_2, showed a negative result with a BCR less than 1. The BCR of S_1P_2 and S_1P_3 was lower i.e. 0.6 lower than BCR of S_2P_1 and S_2 P_2 was 0.81. The storage of spinach beet was cost-effective using LDPE packaging for a duration of 3 days. On day 3, the BCR calculated for S_1P_5 and S_2P_5 was 1.37 and 1.21, respectively, showing similar positive results as LDPE packaging in ZECC and Cold storage. On day 6, BCR calculated of S_1P_5 and S_2P_5 was 0.77 and 0.99 respectively. This shows that banana leaf packaging can be used till day 6 without gaining any profit from the selling.

The cost-benefit ratio can assist farmers in determining the economic viability of selecting a storage system to maximize their return. Compared to ambient storage and cold chambers, produce stored in ZECC can provide higher cash for small-scale farmers during shorter storage duration. The results are consistent with Kamal and Pandey (2018), who found that ZECC had a higher Cost-Benefit ratio compared to the general condition in the case of leafy vegetables, brinjal, tomato, and cauliflower. ZECC can serve as a suitable alternative for short-term storage.

Indian spinach beet leaves are commonly grown and consumed vegetable having good nutritional quality. As it is highly perishable in nature and has a short storage span, its post-harvest management becomes of utmost importance to reduce deterioration. Vegetables stored for days must compete with fresh vegetables in the market. The use of a different storage system, coupled with affordable and environmentally friendly packaging, can not only enhance the shelf life but also generate good remuneration for their crop. The outcome of this study will serve as a prerequisite for the use of ZECC and cold room, as well as LDPE and environment-friendly banana leaf packaging, to enhance shelf life and benefit farmers by generating profits.

Conclusion

The study demonstrated that different storage conditions, coupled with different packaging materials, can be effective in enhancing the shelf life and quality of Indian spinach beet. Notably, the preceding study concluded that the optimal treatment was a cold room combined with perforated LDPE packing (S_2P_2), which increased the shelf life of Indian Spinach beet by up to 8 days. The produce showed the minimum PLW, maximum retention of ascorbic acid content, and a high score of 8.4 for overall acceptability, effectively maintaining colour, appearance, quality, and texture throughout storage. The product stored in the said conditions made the spinach beet marketable up to 7 days. This was followed by S_2P_1, i.e., the Cold Room with non-perforated LDPE packaging, and S2P5, i.e., the Cold Room with Banana packaging. LDPE packaging restricted the microbial growth and slowed the metabolic activity of the produce. However, Cold Chambers can be utilized by large-scale farmers for the storage of large-scale production or multiple productions together, as it will be more profitable, as shown when calculating the BCR. ZECC without packaging (S_0P_0) showed better results during the short-term storage of Indian spinach beet leaves, extending the shelf life of the produce up to 4 days. LDPE packaging inside ZECC (S_1P_1 and S_1P_2) was as effective in reducing the PLW; however, the high relative humidity in the building, along with microbial incidence, shortened the shelf life. ZECC showed a high BCR, with a positive result on day 3. Hence, from the above result, it can be stated that ZECC may be utilized as an on-farm short-term storage facility by small-scale farmers for Indian spinach beet leaves. Additionally, banana leaf packaging in ZECC and Cold Storage (S_1P_5 and S_2P_5, respectively) yielded similar results to LDPE in both storage systems. Based on the results, future studies can be recommended for using environmentally friendly packaging and storage systems to enhance shelf life.

Conflict of interest

The authors declare that they have no conflict of interest.

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