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EFFECT OF INTEGRATED CROP MANAGEMENT AND MODIFIED ATMOSPHERE PACKAGING ON SHELF LIFE AND QUALITY OF OKRA FRUITS (*ABELMOSCHUS ESCULENTUS* L.)

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ABSTRACT

Okra (*Abelmoschus esculentus* L.), an economically important vegetable, suffers substantial postharvest losses due to physiological deterioration during storage. This study aimed to assess the impact of integrated crop management and packaging conditions on the shelf life and quality of okra fruits. The experiment was laid out in a Factorial Completely Randomized Design (FCRD) with nine treatment combinations of recommended fertilizer doses (100%, 75%, and 50% RDF) integrated with three organic modules, and two storage conditions: open storage at ambient temperature and Modified Atmosphere Packaging (MAP). The results indicated that the combination of 100% RDF with Organic Module-1 under MAP ($L_1M_1S_2$) significantly improved postharvest attributes such as average fruit weight, reduced physiological loss in weight (PLW), and prolonged shelf life up to 10.38 days. MAP significantly decreased moisture loss and slowed ripening, thereby preserving ascorbic acid, chlorophyll, and total soluble solids (TSS) better than ambient storage. Among all treatments, $L_1M_1S_2$ consistently retained superior nutritional and visual quality throughout storage. The synergistic effect of balanced nutrient supply and advanced packaging effectively mitigated postharvest deterioration. These findings emphasize the role of integrated crop and postharvest management practices in reducing postharvest losses and enhancing marketability of okra, contributing to sustainable horticultural production and food security.
***Keywords*:** Ascorbic acid, chlorophyll content, integrated crop management, Modified atmosphere packaging and okra shelf life.

Introduction

Vegetables play a vital role in human nutrition as they provide essential vitamins, minerals, carbohydrates, and dietary fiber necessary for a healthy diet. Their nutritional importance is especially critical in developing countries like India, where undernourishment remains a major concern among children and adults. Besides their nutritional value, vegetables also offer medicinal benefits and contribute to overall health protection. Okra [*Abelmoschus esculentus* (L.) Moench], commonly known as lady's finger and locally as bhindi in India, is an important vegetable crop native to tropical and subtropical Africa, with a chromosome number of 2n=130. It belongs to the family Malvaceae and is widely cultivated as a rainy and summer season crop (Adeboye and Oputa, 1996). Okra is one of the oldest and most traditional vegetable crops grown across tropical and subtropical lowland regions of Asia, Africa, the Americas, and warmer Mediterranean areas. It is a cross-pollinated crop with outcrossing rates ranging from 11.8 to 60 per cent (Martin, 1979).

Okra has diverse industrial and nutritional uses. Its dried stems and roots are used for clarifying sugarcane juice in gur or jaggery manufacture in India, and its fully ripe fruits and fibrous stems are used in the paper industry. Nutritionally, okra is an excellent source of iodine and is beneficial in treating goiter, genito-urinary disorders, spermatorrhea, and chronic dysentery. The fruits are also preserved by drying or freezing for off-season use. Dried okra fruits contain 13–22 per cent edible oil and 20–24 per cent protein, making them suitable for refined edible oil production. The dry fruit skin and fibers are valuable for manufacturing paper, cardboard, and fibers (Bose *et al.*, 2003). According to Markose and Peter (1990), 100 g of fresh okra pods contain approximately 89.6% moisture, along with significant amounts of potassium (103 mg), calcium (90 mg), magnesium (43 mg), phosphorus (56 mg), vitamin C (18 mg), and trace metals such as iron and aluminum.

India is the world's largest producer of okra, exporting fresh and frozen okra primarily to the Middle East, UK, Western Europe, and the USA. In 2020–21, okra cultivation covered about 513,000 hectares in India, producing approximately 646,600 metric tons of green fruits with an average productivity of 11.63 t/ha (Anonymous, 2021). Okra accounts for around 4.9% of the total vegetable cultivation area and contributes 3.3% to total vegetable production in the country. West Bengal leads in area and production, while Jammu and Kashmir show the highest productivity. Major okra-producing states include West Bengal, Andhra Pradesh, Bihar, Odisha, Gujarat, Jharkhand, Telangana, Karnataka, and Tamil Nadu. For export-quality produce, okra is grown in Maharashtra regions such as Nasik, Ozar, Saikheda, Dindhori, Kolhar, Naraingaon, and Sholapur, contributing significantly to foreign exchange earnings, accounting for approximately 60% of fresh vegetable exports.

Postharvest handling is a crucial stage in delivering quality fresh fruits and vegetables to markets or storage facilities (Genanew, 2013). During postharvest operations including harvesting, handling, processing, storage, and transportation produce is subjected to various stresses leading to quality degradation (Kumar *et al.,* 2015). Losses of fresh horticultural produce can reach 20–50% in developing countries compared to 5–25% in developed countries (Kader, 2002). Producers can incur up to 20% losses due to transportation delays alone. Moreover, storage conditions significantly affect produce quality since respiration, transpiration, and ethylene production rates increase with temperature, accelerating deterioration (Abubakari and Rees, 2011; Kabir *et al.,* 2020).

To mitigate such losses during transportation and storage, innovative approaches like Modified Atmosphere Packaging (MAP) have been developed. MAP employs polymeric films that regulate gas exchange, maintaining high CO_2 and low O_2 concentrations around the produce to slow respiration and extend shelf life (Beckles and Technology, 2012). According to recent studies, effective preservation of vegetables depends on multiple factors including adequate protection through packaging, selection of suitable materials, application of MAP, and optimal storage conditions (Prabhadharshini *et al.*, 2023; Swetha *et al.,* 2023). These strategies preserve the nutritional and organoleptic quality of vegetables, extend shelf life, and contribute to reducing global food waste. Such efforts align with Sustainable Development Goal (SDG) 12, promoting responsible consumption and production (United Nations, 2015).

In particular, polymeric packaging materials such as polypropylene and polyethylene have demonstrated efficacy in balancing functionality, sustainability, and safety, especially for perishable vegetables (Singh & Lal Banerjee, 2023). Biaxially oriented polypropylene (BOPP) and low-density polyethylene (LDPE) films are commonly used for packaging and storing various vegetables, including nettle leaves, and are well-suited for MAP applications (Mampholo *et al.,* 2013; Dujmović *et al.,* 2024). MAP works by modifying the internal gas atmosphere oxygen (O_2), carbon dioxide (CO_2), and nitrogen (N_2) thereby slowing oxidation, enzymatic reactions, and microbial growth to extend shelf life and preserve bioactive components (Fang & Wakisaka, 2021). These packaging innovations not only reduce postharvest losses but also enhance food security, which is a critical component of SDG 2 (United Nations, 2015).

This research addresses the critical need to develop effective strategies that enhance the shelf life and maintain the nutritional quality of okra fruits. By integrating crop management practices including balanced fertilization and organic amendments with Modified Atmosphere Packaging (MAP), the study provides a sustainable solution to reduce postharvest deterioration. The results demonstrate that this integrated approach not only improves fruit quality attributes such as ascorbic acid, chlorophyll content, and weight retention but also extends marketability. Such findings are highly valuable for farmers, exporters, and supply chain stakeholders aiming to minimize losses, improve profitability, and deliver better-quality produce to consumers. Moreover, it aligns with food security goals and promotes environmentally responsible agricultural practices by reducing input wastage and postharvest waste. The outcomes can guide policy formulation, on-field training, and technology dissemination, especially in developing countries.

Materials and Methods

The present investigation was conducted during 2022–23 at the College of Horticulture, Rajendranagar, affiliated with Sri Konda Laxman Telangana State Horticultural University, to evaluate the effect of storage and packing conditions on the quality and shelf life of okra.

Experimental design

The study followed a Factorial Completely Randomized Design (FCRD) with two factors:

- **Factor 1:** Nine treatments from a preceding field experiment.
- **Factor 2:** Two storage and packaging conditions.

A total of 18 treatment combinations were evaluated, each replicated three times.

Field experiment (Source of Fruits)

Okra fruits were harvested from the earlier field experiment comprising 9 treatments (details below). The harvested fruits were used for shelf-life and quality evaluation under two storage and packaging conditions.

Treatment details

Factor 1: Field experiment treatments

Each field treatment is a combination of fertilizer dose and organic module:

- **L1:** 100% Recommended Dose of Fertilizers (RDF)
- **L_2:** 75% RDF
- **L_3:** 50% RDF

Each level was combined with the following Organic Modules:

Organic Module 1 (M_1):

- Soil application: *Trichoderma viride* @ 5 kg/ha in FYM + Neem cake @ 250 kg/ha
- Seed treatment: *Trichoderma viride* @ 4 g/kg seed
- Foliar sprays (10-day intervals):
  - Panchagavya @ 3%
  - Neem oil @ 5%
  - *Beauveria bassiana* @ 5 g/L (from flowering)
  - *Bacillus thuringiensis* @ 1 kg/ha (from flowering)

Organic Module 2 (M_2):

- Soil application: Pseudomonas fluorescens @ 5 kg/ha in FYM + Neem cake @ 250 kg/ha
- Seed treatment: *Bacillus macerans* @ 3% w/w
- Foliar sprays (10-day intervals):
  - Vermiwash @ 10%
  - NSKE @ 5%
  - Metarhizium anisopliae @ 5 g/L (from flowering)
  - NPV @ 250 LE/ha (from flowering)

Organic Module 3 (M_3):

- Soil application: VAM @ 10 kg/ha in FYM + Neem cake @ 250 kg/ha
- Seed treatment: Beejamrit @ 10%
- Foliar sprays (10-day intervals):
  - Jeevamruth @ 10%
  - Neemastra @ 5%
  - *Lecanicillium lecanii* @ 5 g/L (from flowering)
  - Trichoderma + Pseudomonas spp. @ 5 g/L (from flowering)

Factor 2: Storage and packaging conditions

- **S_1:** Open at room temperature (Ambient: 28 ± 2°C)
- **S_2:** Modified Atmosphere Packaging (MAP)

Treatment combinations:

T_1: L_1M_1 + Open at room temperature (S_1)

T_2: L_1M_1 + Modified atmosphere packaging (MAP) (S_2)

T_3: L_1M_2 + Open at room temperature (S_1)

T_4: L_1M_2 + Modified atmosphere packaging (MAP) (S_2)

T_5: L_1M_3 + Open at room temperature (S_1)

T_6: L_1M_3 + Modified atmosphere packaging (MAP) (S_2)

T_7: L_2M_1 + Open at room temperature (S_1)

T_8: L_2M_1 + Modified atmosphere packaging (MAP) (S_2)

T_9: L_2M_2 + Open at room temperature (S_1)

T_{10}: L_2M_2 + Modified atmosphere packaging (MAP) (S_2)

T_{11}: L_2M_3 + Open at room temperature (S_1)

T_{12}: L_2M_3 + Modified atmosphere packaging (MAP) (S_2)

T_{13}: L_3M_1 + Open at room temperature (S_1)

T_{14}: L_3M_1 + Modified atmosphere packaging (MAP) (S_2)

T_{15}: L_3M_2 + Open at room temperature (S_1)

T_{16}: L_3M_2 + Modified atmosphere packaging (MAP) (S_2)

T_{17}: L_3M_3 + Open at room temperature (S_1)

T_{18}: L_3M_3 + Modified atmosphere packaging (MAP) (S_2)

Fruit handling and storage

Freshly harvested, tender green okra fruits of uniform size (7–9 cm), shape, and color (bright green) were collected from each treatment plot. After sorting for quality and physical defects, the fruits were divided into two storage conditions:

- **S_1:** Stored open in plastic bowls at ambient room temperature.
- **S_2:** Packaged using Modified Atmosphere Packaging (MAP).

Modified Atmosphere Packaging (MAP) Details:

- Material: Perforated LDPE film (107 µm thickness, 0.075 m²)
- Sealing: Impulse sealing machine
- Gas composition analysis: PBI Dansensor Checkpoint II
- Water vapor permeability: Measured using Labthink TSY-W3 tester

All treatments were replicated thrice and stored at ambient conditions (28 ± 2°C). Data on shelf life and quality parameters were recorded during storage.

Observations recorded; The observations were recorded after every alternate day.

Average fruit weight (g)

Known quantities of fruits were kept in each treatment to record the weight of fruits. The weight of the fruits was recorded using electronic weighing balance (Model: Sartorius, BSA 320 2S d=0.01g) before storage. Thereafter, the weights were recorded regularly at every alternate day during storage.

Physiological loss in weight (%)

Weight loss of fresh fruits was calculated from the differences in weight between the start of the experiment and each storage period, according to below formula. The weight of the fruits was recorded using electronic weighing balance (Model: Sartorius, BSA 320 2S d=0.01g). The loss of weight in grams in relation to initial weight was calculated and expressed as percentage.

$$\text{PLW}(\%) = \frac{\text{Initial weight - final weight}}{\text{Initial weight}} \times 100$$

Shelf life (days)

Okra fruits were observed periodically at the time of taking weights for PLW calculation. The marketability in terms of the overall shelf life of okra fruits was determined taking into account the general appearance, spoilage/rotting, and PLW (%). The number of days the fruits were in edible condition was taken as the shelf life or keeping quality and expressed in days

TSS (°Brix)

Total Soluble solid contents (TSS) were obtained using Hanna digital refractometer model H196801; the values were expressed in °Brix (corrected for the temperature of 20℃). For the TSS reading, homogenized pulp was used. The pulp was obtained from four whole okra fruits (without seeds), which were homogenized with the aid of a blender. The mixture was then inserted in the calibrated refractometer with distilled water to obtain the °Brix.

Ascorbic acid (mg/100 g)

The ascorbic acid content in potato was determined by 2, 6-dichlorophenol indophenol visual titration method as followed by Ranganna (1986) and expressed in mg 100 g^{-1}.

Preparation of 2, 6- dichlorophenol indophenols dye solution

The sodium salt of 2, 6 dichlorophenol indophenol dye of 50 mg was weighed into a beaker and 42 mg of sodium bicarbonate and dissolved in 150 ml of hot distilled water. The volume was made up to 200 ml with distilled water.

Preparation of 3 per cent metaphosphoric acid

Metaphosphoric acid of 30 g was dissolved in a small quantity of distilled water and the volume was made up to 1000 ml.

Procedure

A freshly grounded sample of 10 g was blended with 3 per cent metaphosphoric acid and made up to 50 ml with 3 per cent HPO_3. The contents were filtered through the Whatman No.1 filter paper. 10 ml of the HPO_3 extract was taken and titrated against standard 2, 6-Dichloro phenol indophenol dye to a pink endpoint.

The ascorbic acid content of the sample was calculated by adopting the following equation

$$\frac{\text{Titre value} \times \text{Dye factor} \times \text{Volume made up} \times 100}{\text{Aliquot of extract taken for estimation} \times \text{Weight of sample taken for estimation}}$$

Dye factor = 0.5/ Average burette reading for standardization of dye solution

Chlorophyll content in fresh fruit (mg/100 g)

Total chlorophyll content was determined by the homogenization of 3 g of the median part of fresh fruits with 10 mg of magnesium sulphate and 30 mL of 80% (v/v) acetone. The resultant suspension was filtered and measured in a 50 ml volumetric flask. Total chlorophyll content was determined spectrophotometrically at wavelengths of 645 and 663 nm according to the methodology of Arnon (1949).

Results and Discussion

The results of shelf life and quality attributes of okra during storage are statistically analyzed, presented and discussed in this chapter under the following headings.

Average fruit weight (g)

The effect of storage and packing conditions *i.e*., open at room temperature, modified atmosphere packaging (MAP) with nine treatments from the field experiment (different levels of RDF + organic modules) on average fruit weight (g) in okra are presented in Table 1. There was a significant difference among different levels of RDF + organic modules and storage and packing conditions. Interaction effect has found non-significant difference with respect to average fruit weight.

Highest average fruit weight on 2nd and 4th day of storage (14.89 g and 14.00 g respectively) was recorded in L_1M_1 (100 % RDF + organic module-1) which is followed by L_1M_3 (100 % RDF + organic module-3) (14.26 g and 13.40 g on 2nd and 4th day of storage, respectively) whereas, lowest average fruit weight on 2nd and 4th day of storage (10.52 g and 9.73 g, respectively) was reported in L_3M_2 (50% RDF + organic module -2).

On 2nd and 4th day of storage maximum fruit weight (13.22 g and 13.11 g, respectively) was recorded in S_2 (modified atmosphere packaging), minimum fruit weight (12.03 g and 10.42 g, respectively) was noticed in S_1 (open at room temperature).

Interaction effect has no significant difference between different levels of RDF + organic modules and storage and packing conditions on 2nd and 4th day of storage.

The mean values of average fruit weight recorded on the 6th, 8th, and 10th day of storage are presented in Table 1. A consistent decreasing trend in average fruit weight was observed with the progression of storage duration, indicating a gradual loss of moisture and physiological quality over time. Among the treatments, L_1M_1 (100% Recommended Dose of Fertilizers integrated with Organic Module 1) recorded the highest average fruit weight throughout the storage period. This could be attributed to the enhanced nutrient availability, which likely promoted vigorous physiological activity and contributed to better assimilate partitioning towards the developing fruits. Additionally, the presence of growth-promoting substances such as auxins and cytokinins in panchagavya, a component of Organic Module 1, may have stimulated cell division and elongation, thereby increasing fruit weight. These reserves may also have supported the synthesis of pectin compounds, which help maintain cell wall integrity, reducing fruit weight loss during storage (Bhattarai and Budathoki, 2005; Arivazhagan *et al.,* 2019).

Furthermore, among the storage and packaging conditions, S_2 (Modified Atmosphere Packaging) recorded the maximum average fruit weight during storage. This could be due to the ability of the packaging film to limit water vapor diffusion to the external environment, thereby maintaining high relative humidity inside the package. This microenvironment reduced both respiration and transpiration rates, which are the major causes of weight loss in stored produce. In contrast, fruits stored under open conditions (S_1) experienced greater weight loss, primarily due to the larger gradient in water vapor pressure between the fruit surface and the surrounding atmosphere. This gradient led to excessive moisture loss and depletion of internal reserves due to increased metabolic activities such as respiration and transpiration (Singh *et al.,* 2020).

Physiological loss in weight (%)

The data pertaining to physiological loss in weight (PLW) (%) presented in the Table 2 revealed significant difference among treatments on 2nd and 4th day of storage. PLW (%) values showing an increasing trend from 2nd day to 10th day of storage.

On 2nd and 4th day of storage lowest physiological loss in weight (4.70% and 10.36%, respectively) was recorded in L_1M_1 (100 % RDF + organic module-1) which is at par with L_1M_3 (100 % RDF + organic module-3) (4.87 % and 10.62 %, respectively), while, highest physiological loss in weight on 2nd and 4th day (6.25 % and 13.25 %, respectively) was noticed in L_3M_2 (50 % RDF + organic module -2).

Among storage and packing conditions lowest physiological loss in weight on 2nd and 4th day of storage (0.86 % and 1.64 %, respectively) was observed with S_2 (modified atmosphere packaging) while, highest physiological loss in weight on 2nd and 4th day of storage (9.81 % and 21.92 %, respectively) was noticed with S_1 (open at room temperature).

Interactions between different levels of RDF + organic modules and storage and packing conditions was found significant difference, $L_1M_3S_2$ (100% RDF + organic module-3 + modified atmosphere packaging) recorded significantly least physiological loss in weight on 2nd day of storage (0.59 %), which is at par with $L_1M_1S_2$ (100% RDF + organic module-1 + modified atmosphere packaging) (0.62 %) and $L_1M_2S_2$- 100% RDF + organic module-2 + modified atmosphere packaging (0.69%).

On 4th day of storage $L_1M_1S_2$ (100 % RDF + organic module-1 + modified atmosphere packaging) noticed least physiological loss in weight (1.15 %) which is at par with $L_1M_3S_2$ (100 % RDF + organic module-3 + modified atmosphere packaging) (1.24 %) and $L_1M_2S_2$ (100 % RDF + organic module-2+ modified atmosphere packaging). While, highest physiological loss in weight on 2nd and 4th day (11.20 % and 24.15 %, respectively) was observed with $L_3M_2S_1$ (50% RDN + organic module-2 + open at room temperature).

The mean values recorded with respect to physiological loss in weight at 6th, 8th and 10th day during storage are tabulated in Table 2. The increasing trend of physiological loss in weight with advancement of storage has been reported.

The high loss of fruit weight resulted from the loss of water in to the atmosphere during the storage period, because the water vapor pressure of the fruits was higher than the water vapor pressure of the surrounding, resulting in a water vapor deficit, water vapor migrated from a higher pressure to a lower pressure, causing the loss of product weight (Kader, 2002). The weight loss was due to uncontrolled water loss and food reserve from tissues of okra due to biochemical activities such as transpiration and respiration (Santi *et al*., 1992).

Significantly least physiological loss in weight (PLW) of okra fruits was observed in the treatment L_1M_1 (100% RDF + Organic Module 1), as presented in Table 2. This reduction in weight loss can be attributed to the application of 100% recommended dose of fertilizers (RDF), along with farmyard manure (FYM), *Trichoderma viride* @ 5 kg/ha enriched in FYM, and the regular foliar spraying of 3% panchagavya solution. These inputs likely enhanced the plant's nutrient status, promoting efficient photosynthesis and the accumulation of food reserves. These reserves may have contributed to the synthesis of pectin compounds, which play a crucial role in maintaining cell wall integrity, thereby reducing cellular breakdown and subsequent weight loss during storage. Additionally, the micronutrients present in Organic Module 1 may have further strengthened cellular structures, contributing to reduced PLW (Bhattarai and Budathoki, 2005; Arivazhagan *et al.,* 2019).

Among the storage and packing conditions, fruits stored under Modified Atmosphere Packaging (MAP) (S_2) exhibited lower physiological loss in weight compared to those stored in open room conditions (S_1). The controlled atmosphere created by MAP likely slowed down the respiration and transpiration processes by maintaining a high relative humidity inside the package and limiting water vapor diffusion. This protective environment helped in minimizing moisture loss and preserving fruit quality, which aligns with the findings of Singh *et al.* (2020). Similar results have been previously reported by Negi and Roy (2004), Reddy *et al.* (2013), and Indore *et al.* (2016), particularly in okra and other vegetables.

A significant interaction effect was also recorded between nutrient management practices and storage methods. The combination $L_1M_1S_2$ (100% RDF + Organic Module 1 + MAP) recorded the lowest PLW, further emphasizing the synergistic impact of optimal nutrient input and modified atmosphere storage. The benefits observed may be due to a combination of robust fruit cell structures, enriched by micronutrients and pectin synthesis from L_1M_1, and the MAP-induced reduction in transpiration and respiration rates due to elevated humidity levels inside the packaging (Anurag *et al.,* 2016). Supporting evidence from other crops includes the work of Vanndy *et al.* (2008), who reported that MAP extended tomato shelf life by 6–9 days while reducing ripening and weight loss without affecting quality. Similarly, Shankarprasad and Shivanand (2018) noted that ivy gourd fruits stored in non-perforated polyethylene and polypropylene MAP exhibited better shelf life and moisture retention with minimal physiological weight loss.

Shelf life (days)

The results presented in Table 3 clearly indicate that both the levels of recommended dose of fertilizers

(RDF) integrated with different organic modules and the storage and packing conditions significantly influenced the shelf life of okra fruits. Among the storage conditions, Modified Atmosphere Packaging (MAP) (S2) significantly outperformed open storage at room temperature (S1), with an average shelf life of 7.55 days compared to 4.70 days under open conditions. This suggests that MAP effectively prolongs the shelf life of okra by slowing down respiration and moisture loss, thereby reducing deterioration.

With regard to fertilizer and organic module combinations, the highest shelf life (10.38 days) was recorded in the treatment L_1M_1 (100% RDF combined with Organic Module 1) under MAP. The same treatment under open conditions resulted in a shelf life of 5.32 days, reflecting nearly a two-fold increase when stored under MAP. This highlights the strong influence of both nutrient management and storage conditions on postharvest performance. In contrast, the lowest shelf life was observed in L_3M_2 (50% RDF with Organic Module 2), which recorded only 4.22 days under open storage and 5.50 days under MAP. Overall, a clear trend was observed wherein treatments with higher fertilizer levels (L_1) and more comprehensive organic management (particularly Module 1) resulted in longer shelf life, while reduced fertilizer levels (L_2 and L_3) combined with less effective organic inputs resulted in poor postharvest longevity.

The interaction effect between nutrient management and storage method was found to be significant, indicating that the impact of storage conditions varied depending on the fertilizer-organic module combination. This interaction further reinforces the importance of integrated nutrient management in combination with proper postharvest handling techniques to enhance the marketability and storage potential of okra. Therefore, the combination of 100% RDF with Organic Module 1 and Modified Atmosphere Packaging was found to be the most effective in maintaining the postharvest quality and extending the shelf life of okra fruits.

The maximum shelf life with treatment $L_1M_1S_2$ (100% RDF + organic module-1 + modified atmosphere packaging) (Table 3) might be due to increased nutrient reserves might have resulted in increased photosynthesis which will helps in synthesis of enough food reserves and these food reserves might help in synthesis of pectin compounds. The pectin compounds are responsible for cell integrity and less physiological loss in weight during storage and storing these fruits in MAP (S_2) has reduced chlorophyll degradation, restricted respiration rate, reduced physiological loss in weight which cumulatively resulted in increased shelf life of okra in the present investigation (Bhattarai and Budathoki, 2005; Arivazhagan *et al.*, 2019).

Total Soluble solids (°Brix)

The data regard to total soluble solids (TSS) presented in the Table 4showed significant difference among different levels of RDF + organic modules and storage and packaging and interaction between the treatments showed non-significant difference.

On 2nd and 4th day of storage, highest TSS (7.31 and 7.43 °Brix respectively) was noticed in L_1M_1 (100% RDF + organic module-1) which is at par with L_1M_3 (100% RDF + organic module-3) (7.22 and 7.40 °Brix respectively) while, lowest TSS was recorded with L_3M_2 (50 % RDF + organic module-2) (6.11 and 6.25 °Brix respectively).

Maximum TSS on 2nd and 4th day of storage (6.94 and 7.20 °Brix respectively) was recorded with S_1 (open at room temperature) while, minimum TSS on 2nd and 4th day of storage (6.67 and 6.73 °Brix respectively) was registered with S_2 (modified atmosphere packaging).

Interaction effect has no significant difference between different levels of RDF + organic modules and storage and packing conditions with respect to TSS on 2nd and 4th day of storage.

The mean values of Total Soluble Solids (TSS) recorded on the 6th, 8th, and 10th day of storage are presented in Table 4. TSS is an important indicator of fruit quality, representing the concentration of sugars, carbohydrates, proteins, fats, minerals, and organic acids in the fruit. A higher TSS value indicates a greater concentration of these soluble solids, which directly influences the taste and ripeness of the produce (Abiso *et al.,* 2015). During storage, the highest TSS values were recorded in fruits stored under open room conditions (S_1). This increase in TSS over time is likely due to the degradation of pectin and the hydrolysis of polysaccharides (mainly starch) into simple sugars, a natural process during fruit ripening (Munhuewyi, 2012).

Among the different nutrient management treatments, the L_1M_1 combination (100% RDF + Organic Module 1) recorded the highest TSS throughout the storage period. The application of higher nitrogen levels under L_1 may have enhanced biomass production and subsequently increased the synthesis of photoassimilates, many of which contribute to the soluble solids in the cell sap, particularly sugars (Arivazhagan *et al.,* 2019). This aligns with the understanding that TSS accumulation during storage is primarily associated with ripening and the conversion of carbohydrates into simpler, soluble forms.

In contrast, fruits stored under Modified Atmosphere Packaging (S_2) recorded lower TSS values compared to those stored in open conditions. This reduction is likely due to the limited water loss from fruits and the slowed respiratory metabolism resulting from decreased oxygen and elevated carbon dioxide levels inside the MAP environment (Singh *et al.,* 2020). The restricted gaseous exchange in MAP slows the ripening process, thereby retarding the conversion of polysaccharides into sugars (Chitarra and Chitarra, 2005). Furthermore, the relatively higher TSS in S1 can also be attributed to greater moisture loss, which concentrates the fruit pulp and increases the proportion of soluble solids (Moretti and Pineli, 2005). These findings are consistent with earlier studies reported by Tigist *et al*. (2013) in tomato and Patel *et al. (*2016) in okra, confirming that open storage conditions tend to enhance TSS due to both ripening and water loss-induced concentration effects.

Ascorbic acid (mg/100g)

There was a significant difference among different levels of RDF + organic modules and storage and packing conditions. Non-significant difference was noticed for interactions between different levels of RDF + organic modules and storage and packing conditions with respect to ascorbic acid (mg/100g) content at 2nd day of storage while, significant difference was noticed on 4th day of storage. Ascorbic acid (mg/100g) content showed decreasing trend with the increase in storage period at room temperature up to 10th day (Table 5).

Highest ascorbic acid content on 2nd and 4th day of storage (14.34 mg/100 g and 13.47 mg/100 g respectively) was recorded in L_1M_1 (100% RDF + organic module -1) which at par with L_1M_3 (100 % RDF + organic module-3) (14.07 mg/100 g) and L_1M_2 (100% RDF + organic module -2) (14.03 mg/100 g) on 2nd day of storage, whereas, lowest ascorbic acid content on 2nd and 4th day of storage (10.74 and 9.49 mg/100 g respectively) was reported in L_3M_2 (50% RDF + organic module -2) .

On 2nd and 4th day of storage maximum ascorbic acid content (13.05 mg/100g and 12.55 mg/100g respectively) was recorded in S_2 (modified atmosphere packaging), while, minimum ascorbic acid content (12.02 mg/100g and 10.52 mg/100g respectively) was noticed in S_1 (open at room temperature).

Interaction effect has no significant difference between different levels of RDF + organic modules and storage and packing conditions on 2nd with respect to ascorbic acid content. Whereas, on 4th day there was significant difference observed among the interactions. Highest ascorbic acid content *i.e.,* 14.26 mg/100g was recorded in $L_1M_1S_2$ (100% RDF +organic module - 1+modified atmosphere packaging) which is at par with $L_1M_3S_2$ (100% RDF + organic module-3 + modified atmosphere packaging) (13.99 mg/100g) and $L_1M_2S_2$ (100% RDF + organic module-2 + modified atmosphere packaging) (13.98 mg/100g), while lowest ascorbic acid content (8.23 mg/100g) was noticed in $L_3M_2S_1$ (50% RDF + organic module -2 + open at room temperature).

The mean values recorded with respect to ascorbic acid content at 6th, 8th and 10th day during storage were tabulated in Table 5. The decreasing trend of ascorbic acid content with advancement of storage has been reported.

Ascorbic acid, being a form of carbohydrate, is closely linked to the plant's carbohydrate synthesis pathways. Hence, any factor enhancing carbohydrate production is likely to increase the ascorbic acid content as well. In the present study, the maximum ascorbic acid content was observed with the application of L_1M_1 (100% RDF + Organic Module 1). This could be attributed to the synergistic effect of inorganic fertilizers and organic inputs, which provided a balanced supply of macro- and micronutrients, thereby promoting photosynthetic efficiency and sugar synthesis, ultimately leading to higher ascorbic acid accumulation in okra fruits. Additionally, the presence of potassium in higher amounts, as noted by Mohit *et al*. (2019), may have contributed to slowing down the enzymatic oxidation of ascorbic acid, thus aiding in its retention. These results are in close agreement with the findings of Anuja and Archana (2012) in bitter gourd, and those of Murmu *et al.* (2012) and Rajyalaxmi *et al.* (2015) in tomato, who also reported increased ascorbic acid content from integrated use of organic and inorganic nutrient sources.

Storage conditions had a notable effect on ascorbic acid retention. Fruits stored under Modified Atmosphere Packaging (MAP) (S_2) retained higher levels of ascorbic acid throughout the storage period. This can be explained by the low oxygen and elevated carbon dioxide environment created inside MAP, which slows respiration and reduces oxidative degradation of ascorbic acid (Singh *et al*., 2020). Conversely, fruits stored in open conditions (S_1) exhibited the lowest ascorbic acid content, which may be due to the oxidation of L-ascorbic acid to dehydroascorbic acid under exposure to oxygen, light, and enzymatic activity (Mahajan *et al.,* 2016; Plaza *et al.,* 2006). According to Selmon (1994), the degradation of ascorbic acid during storage is primarily due to its water solubility, thermal degradation, and enzymatic oxidation. A declining trend in ascorbic acid content with increased storage duration was also documented by Mota *et al.* (2010), Rani *et al.* (2015), Indore *et al.* (2016), and Patel *et al.* (2016).

A significant interaction was observed between nutrient management and storage method on the 4th day of storage, where $L_1M_1S_2$ (100% RDF + Organic Module 1 + MAP) recorded the highest ascorbic acid content. This could be due to the enhanced accumulation of carbohydrates and secondary metabolites from L_1M_1 treatment enriched with FYM, *Trichoderma viride* @ 5 kg/ha, and 3% panchagavya sprays which contribute to ascorbic acid biosynthesis. The MAP further helped preserve this ascorbic acid by creating a high-humidity, low-respiration environment, minimizing moisture loss and oxidative reactions. This combination effectively slowed the ripening process, thereby maintaining higher ascorbic acid content during storage (Mahajan *et al.,* 2016).

Chlorophyll (mg/100g) content

The effect of different levels of RDF + organic modules and storage and packaging on chlorophyll (mg/100 g) content of okra was presented in the Table 6 showed significant difference for among the treatments. The chlorophyll content showed a decreasing trend with increasing the storage period (Table 6).

Highest chlorophyll content on 2nd and 4th day of storage (0.99 mg/100 g and 0.93 mg/100 g respectively) was recorded in L_1M_1 (100% RDF + organic module -1) which is followed by L_1M_3 (100 % RDF + organic module -3) (0.95 mg/100 g and 0.90 mg/100 g, respectively) whereas, lowest chlorophyll content on 2nd and 4th day of storage (0.53 mg/100g and 0.47 mg/100g respectively) was reported in L_3M_2 (50% RDF + organic module -2).

On 2nd and 4th day maximum chlorophyll content (0.78 mg/100g and 0.76 mg/100g respectively) was recorded in S_2 (modified atmosphere packaging), minimum chlorophyll content (0.70 mg/100g and 0.61 mg/100g respectively) was noticed in S_1 (open at room temperature).

Interaction effect has found significant difference between different levels of RDF + organic modules and storage and packing conditions on 2nd and 4th day of storage with respect to chlorophyll content. On 2nd day maximum chlorophyll content (1.05 mg/100 g) was noticed in $L_1M_1S_2$ (100 % RDF + organic module-1+ modified atmosphere packaging) which is followed by $L_1M_2S_2$ (100% RDF + organic module-2+ modified atmosphere packaging) (1.00 mg/100 g) and $L_1M_3S_2$ (100 % RDF + organic module-3+ modified atmosphere packaging) (1.00 mg/100g).

On 4th day maximum chlorophyll content (1.00 mg/100g) was noticed in $L_1M_1S_2$ (100% RDF + organic module-1+ modified atmosphere packaging) which is at par with $L_1M_3S_2$ (100 % RDF + organic module-2 + modified atmosphere packaging) (0.98mg/100 g) and $L_1M_2S_2$ (100% RDF + organic module-2+ modified atmosphere packaging) (0.97 mg/100 g). While, minimum chlorophyll content on 2nd and 4th day (0.50 mg/100g and 0.41 mg/100g respectively) was observed with $L_3M_2S_1$ (50% RDF + organic module-2 +open at room temperature).

The mean values recorded with respect to chlorophyll content at 6th, 8th and 10th day during storage tabulated in Table 6. The decreasing trend of chlorophyll content with advancement of storage has been reported.

The treatment L_1M_1 (100% RDF + Organic Module-1) recorded the highest chlorophyll content in okra fruits, which can be attributed to the enhanced mineralization and mobilization of essential nutrients such as Fe, N, P, and S. The improved availability and uptake of these nutrients facilitated greater chlorophyll synthesis. This increase in chlorophyll content is likely associated with an elevated photosynthetic rate in plants, as reported by Karanatsidis and Berova (2009). The enhanced photosynthesis likely contributed to the production of pectin-like substances and increased vitamin C, both of which play a role in antioxidant activity and maintaining cell integrity. These factors cumulatively improved fruit quality by reducing chlorophyll degradation during storage.

The preservation of fruit color is critical throughout production, storage, and marketing, as it influences consumer acceptance. Fruits stored under Modified Atmosphere Packaging (MAP, S_2) retained significantly higher chlorophyll content compared to those stored openly at room temperature (S_1), which exhibited greater chlorophyll loss and noticeable color deterioration. The low oxygen and high carbon dioxide environment within MAP effectively slows chlorophyll degradation and delays yellowing, a key indicator of senescence in non-climacteric vegetables such as okra (Mota *et al.,* 2010). The accelerated loss of chlorophyll in open storage conditions can be explained by increased activity of chlorophyllase enzyme, exposure to elevated temperatures, and low humidity, as noted by Gong and Mattheis (2003). Similar trends of declining chlorophyll with prolonged storage have been reported in shredded cabbage (Rai *et al.,* 2009), okra (Indore *et al.,* 2016), and capsicum (Singh *et al.,* 2020).

Significant interaction effects were observed between fertilizer-organic module treatments and storage conditions on chlorophyll content. The combination $L_1M_1S_2$ (100% RDF + Organic Module-1 + MAP) showed the maximum retention of chlorophyll during storage. This can be explained by the timely availability of nutrients due to active mineralization and mobilization under L_1M_1 treatment, supporting robust chlorophyll synthesis in the fruits. Furthermore, storage under MAP conditions restricted respiration, promoted the synthesis of antioxidant compounds, and exposed the fruits to a low O_2 and high CO_2 atmosphere, all of which collectively reduced chlorophyll degradation (Krishnamoorthy *et al.,* 2019; Rani *et al*., 2015).

Conclusion

The study clearly demonstrated that postharvest quality and shelf life of okra can be substantially improved through a synergistic approach combining 100% Recommended Dose of Fertilizers (RDF) with Organic Module-1 and Modified Atmosphere Packaging (MAP). This integrated approach not only reduced physiological loss in weight but also enhanced retention of critical quality attributes like average fruit weight, chlorophyll, ascorbic acid, and total soluble solids during storage. Among the treatments, $L_1M_1S_2$ (100% RDF + Organic Module-1 + MAP) proved most effective, significantly extending the shelf life up to 10.38 days compared to 4.22 days under minimal inputs and open storage. The application of balanced nutrients ensured vigorous plant growth and higher nutrient reserves in fruits, while MAP minimized moisture and nutrient loss by creating a high-humidity, low-oxygen environment. This strategy can be a promising solution for farmers and supply chain managers aiming to reduce postharvest losses, enhance produce quality, and ensure economic returns. The outcomes align with global sustainability goals by promoting efficient resource use, reducing food waste, and supporting food and nutritional security. Therefore, adoption of integrated crop management with MAP is highly recommended for improving postharvest handling of okra and similar perishable horticultural crops.

Table 1: Effect of different levels of RDF integrated with organic modules and different storage, packing conditions on average fruit weight (g) of okra

Treatments	**2^{nd} day**			**4^{th} day**			**6^{th} day**		**8^{th} day**		**10^{th} day**	
	S_1	**S_2**	**Mean**	**S_1**	**S_2**	**Mean**	**S_1**	**S_2**	**S_1**	**S_2**	**S_1**	**S_2**
L_1M_1	14.25	15.53	14.89	12.56	15.44	14.00	*	15.22	*	14.84	*	14.33
L_1M_2	13.29	14.58	13.94	11.55	14.47	13.01	*	14.25	*	13.87	*	*
L_1M_3	13.61	14.90	14.26	11.99	14.80	13.40	*	14.57	*	14.22	*	13.75
L_2M_1	12.37	13.63	13.00	10.69	13.52	12.10	*	13.32	*	12.99	*	*
L_2M_2	11.31	12.47	11.89	9.86	12.35	11.10	*	12.21	*	11.90	*	*
L_2M_3	12.07	13.19	12.63	10.40	13.10	11.75	*	12.89	*	12.53	*	*
L_3M_1	10.83	11.97	11.40	9.22	11.87	10.54	*	11.66	*	11.30	*	*
L_3M_2	9.96	11.07	10.52	8.51	10.95	9.73	*	10.79	*	*	*	*
L_3M_3	10.54	11.60	11.07	9.04	11.51	10.27	*	11.31	*	*	*	*
Mean	12.03	13.22		10.42	13.11		*	12.91	*	10.18	*	*
	A	S	A X S	A	S	A X S	--	--	--	--	--	--
SE (m)	0.14	0.07	0.19	0.14	0.07	0.20	--	--	--	--	--	--
C.D. (5%)	0.40	0.19	NS	0.41	0.19	NS	--	--	--	--	--	--

'*': Okra pods unavailable for observation as all are spoiled/rejected

Factor: 1
L_1: 100% RDF M_1: Organic Module-1
L_2: 75% RDF M_2: Organic Module- 2
L_3: 50% RDF M_3: Organic Module- 3
A: Different levels of fertilizers and organic modules

Factor: 2
S_1: Open at room temperature
S_2: Modified Atmosphere Packaging (MAP)
S: Storage and packing conditions

Table 2: Effect of different levels of RDF integrated with organic modules and different storage, packing conditions on physiological loss in weight (%) of okra

Treatments	2nd day			4th day			6th day		8th day		10th day	
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	S_1	S_2	S_1	S_2
L_1M_1	8.78	0.62	4.70	19.57	1.15	10.36	*	2.56	*	5.00	*	8.24
L_1M_2	9.44	0.69	5.06	21.30	1.41	11.35	*	2.91	*	5.52	*	*
L_1M_3	9.15	0.59	4.87	20.00	1.24	10.62	*	2.79	*	5.14	*	8.26
L_2M_1	9.84	0.71	5.28	22.14	1.49	11.81	*	2.95	*	5.34	*	*
L_2M_2	10.14	0.93	5.54	21.64	1.89	11.76	*	2.98	*	5.47	*	*
L_2M_3	9.38	0.97	5.18	21.94	1.67	11.80	*	3.24	*	5.94	*	*
L_3M_1	10.25	0.81	5.53	23.64	1.68	12.66	*	3.39	*	6.41	*	*
L_3M_2	11.20	1.31	6.25	24.15	2.34	13.25	*	3.84	*	*	*	*
L_3M_3	10.15	1.12	5.63	22.94	1.92	12.43	*	3.56	*	*	*	*
Mean	9.81	0.86		21.92	1.64		*	3.14	*	4.31	*	*
	A	S	A X S	A	S	A X S	--	--	--	--	--	--
SE (m)	0.09	0.04	0.13	0.20	0.10	0.29	--	--	--	--	--	--
C.D. (5%)	0.26	0.12	0.36	0.58	0.27	0.82	--	--	--	--	--	--

'*': Okra pods unavailable for observation as all are spoiled/rejected

Factor: 1

L_1: 100% RDF M_1: Organic Module-1

L_2: 75% RDF M_2: Organic Module- 2

L_3: 50% RDF M_3: Organic Module- 3

A: Different levels of fertilizers and organic modules

Factor: 2

S_1: Open at room temperature

S_2: Modified Atmosphere Packaging (MAP)

S: Storage and packing conditions

Table 3: Effect of different levels of RDF integrated with organic modules and different storage, packing conditions on shelf life (days) of okra

Treatments	S_1	S_2	Mean
L_1M_1	5.32	10.38	7.85
L_1M_2	4.95	8.35	6.65
L_1M_3	5.00	8.85	6.93
L_2M_1	4.86	7.91	6.39
L_2M_2	4.55	7.24	5.90
L_2M_3	4.70	7.58	6.14
L_3M_1	4.40	6.21	5.31
L_3M_2	4.22	5.50	4.86
L_3M_3	4.28	5.92	5.10
Mean	4.70	7.55	
	A	S	AXS
SE (m)	0.07	0.03	0.09
C.D. (5%)	0.19	0.09	0.27

'*': Okra pods unavailable for observation as all are spoiled/rejected

Factor: 1

L_1: 100% RDF M_1: Organic Module-1

L_2: 75% RDF M_2: Organic Module- 2

L_3: 50% RDF M_3: Organic Module- 3

A: Different levels of fertilizers and organic modules

Factor: 2

S_1: Open at room temperature

S_2: Modified Atmosphere Packaging (MAP)

S: Storage and packing conditions

Table 4: Effect of different levels of RDF integrated with organic modules and different storage, packing conditions on TSS (^{o}Brix) of okra

Treatments	2nd day			4th day			6th day		8th day		10th day	
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	S_1	S_2	S_1	S_2
L_1M_1	7.41	7.21	7.31	7.63	7.22	7.43	*	7.29	*	7.33	*	
L_1M_2	7.29	7.02	7.16	7.51	7.12	7.32	*	7.16	*	7.23	*	
L_1M_3	7.34	7.09	7.22	7.65	7.15	7.40	*	7.19	*	7.21	*	
L_2M_1	7.22	6.98	7.10	7.48	7.08	7.28	*	7.14	*	7.18	*	*
L_2M_2	6.74	6.48	6.61	6.91	6.52	6.71	*	6.58	*	6.63	*	*
L_2M_3	7.04	6.78	6.91	7.56	6.84	7.20	*	6.91	*	6.94	*	*
L_3M_1	6.62	6.33	6.47	6.74	6.38	6.56	*	6.41	*	6.43	*	*
L_3M_2	6.29	5.92	6.11	6.51	5.98	6.25	*	6.10	*	0.00	*	*

L_3M_3	6.51	6.21	6.36	6.78	6.28	6.53	*	6.31	*	0.00	*	*
Mean	6.94	6.67		7.20	6.73		*	6.79	*	5.44	*	*
	A	S	A X S	A	S	A X S	--	--	--	--	--	--
SE (m)	0.08	0.04	0.12	0.05	0.03	0.08	--	--	--	--	--	--
C.D. (5%)	0.23	0.11	NS	0.16	0.07	NS	--	--	--	--	--	--

'*': Okra pods unavailable for observation as all are spoiled/rejected

Factor: 1 | Factor: 2

L_1: 100% RDF | M_1: Organic Module-1 | S_1: Open at room temperature

L_2: 75% RDF | M_2: Organic Module- 2 | S_2: Modified Atmosphere Packaging (MAP)

L_3: 50% RDF | M_3: Organic Module- 3

A: Different levels of fertilizers and organic modules | S: Storage and packing conditions

Table 5: Effect of different levels of RDF integrated with organic modules and different storage, packing conditions on ascorbic acid (mg/100g) of okra

Treatments	2nd day			4th day			6th day		8th day		10th day	
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	S_1	S_2	S_1	S_2
L_1M_1	13.96	14.72	14.34	12.68	14.26	13.47	*	13.98	*	13.78	*	13.12
L_1M_2	13.62	14.45	14.03	12.20	13.98	13.09	*	13.42	*	12.84	*	*
L_1M_3	13.84	14.29	14.07	12.31	13.99	13.15	*	13.42	*	12.95	*	12.41
L_2M_1	12.36	13.72	13.04	11.97	13.28	12.63	*	12.51	*	12.14	*	*
L_2M_2	11.26	12.29	11.77	9.86	11.71	10.78	*	11.26	*	10.54	*	*
L_2M_3	11.39	12.98	12.19	10.31	12.37	11.34	*	11.62	*	11.31	*	*
L_3M_1	10.82	11.92	11.37	8.37	11.30	9.84	*	10.89	*	10.28	*	*
L_3M_2	10.25	11.24	10.74	8.23	10.75	9.49	*	10.14	*	0.00	*	*
L_3M_3	10.72	11.81	11.27	8.75	11.29	10.02	*	10.81	*	0.00	*	*
Mean	12.02	13.05		10.52	12.55		*	12.01	*	9.32	*	*
	A	S	A X S	A	S	A X S	--	--	--	--	--	--
SE (m)	0.12	0.06	0.17	0.10	0.05	0.14	--	--	--	--	--	--
C.D. (5%)	0.34	0.16	NS	0.28	0.13	0.40	--	--	--	--	--	--

'*': Okra pods unavailable for observation as all are spoiled/rejected

Factor: 1 | Factor: 2

L_1: 100% RDF | M_1: Organic Module-1 | S_1: Open at room temperature

L_2: 75% RDF | M_2: Organic Module- 2 | S_2: Modified Atmosphere Packaging (MAP)

L_3: 50% RDF | M_3: Organic Module- 3

A: Different levels of fertilizers and organic modules | S: Storage and packing conditions

Table 6: Effect of different levels of RDF integrated with organic modules and different storage, packing conditions on chlorophyll (mg/100g) content of okra

	2nd day			4th day			6th day		8th day		10th day	
Treatments	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	S_1	S_2	S_1	S_2
L_1M_1	0.93	1.05	0.99	0.86	1.00	0.93	*	0.96	*	0.93	*	0.90
L_1M_2	0.86	1.00	0.93	0.76	0.97	0.87	*	0.92	*	0.90	*	*
L_1M_3	0.90	1.00	0.95	0.81	0.98	0.90	*	0.95	*	0.93	*	0.87
L_2M_1	0.78	0.84	0.81	0.67	0.81	0.74	*	0.78	*	0.75	*	*
L_2M_2	0.62	0.67	0.65	0.55	0.66	0.60	*	0.63	*	0.61	*	*
L_2M_3	0.70	0.75	0.73	0.61	0.72	0.67	*	0.68	*	0.64	*	*
L_3M_1	0.54	0.61	0.58	0.43	0.58	0.51	*	0.55	*	0.52	*	*
L_3M_2	0.50	0.55	0.53	0.41	0.53	0.47	*	0.50	*	*	*	*
L_3M_3	0.51	0.57	0.54	0.43	0.55	0.49	*	0.52	*	*	*	*
Mean	0.70	0.78		0.61	0.76		*	0.72	*	0.59	*	*
	A	S	A X S	A	S	A X S	--	--	--	--	--	--
SE (m)	0.007	0.004	0.011	0.008	0.004	0.011	--	--	--	--	--	--
C.D. (5%)	0.021	0.010	0.030	0.022	0.010	0.031	--	--	--	--	--	--

'*': Okra pods unavailable for observation as all are spoiled/rejected

Factor: 1 | Factor: 2

L_1: 100% RDF | M_1: Organic Module-1 | S_1: Open at room temperature

L_2: 75% RDF | M_2: Organic Module- 2 | S_2: Modified Atmosphere Packaging (MAP)

L_3: 50% RDF | M_3: Organic Module- 3

A: Different levels of fertilizers and organic modules | S: Storage and packing conditions

References

Abiso, E., Satheesh, N. and Hailu, A. (2015). Effect of storage methods and ripening stages on postharvest quality of tomato (*Lycopersicon esculentum* Mill) cv. Chali. *Annals of Food Science and Technology*, **6**(1), 127–137.

Abubakari, M. and Rees, D. (2011). The effects of postharvest handling and storage temperature on the quality and shelf life of tomato. *African Journal of Food Science*, **5**(7), 340–348.

Adeboye, O.C. and Oputa, C.O. (1996). Effects of Galex on growth and fruit nutrient composition of okra (*Abelmoschus esculentus*). *Journal of Agriculture*, **18**(2), 1–9.

Anonymous (2021). Area and Production. Ministry of Agriculture and Cooperation, Government of India. Available at, www.aps.dac.gov.in

Anuja, S. and Archana, S. (2012). Effect of organic nutrient on yield and quality of bitter gourd. *International Journal of Agriculture Science*, **8**, 205–208.

Anurag, R.K., Manjunatha, M. and Jha, S.N. (2016). Storage quality of shelled green peas under modified atmosphere packaging at different storage conditions. *Journal of Food Science and Technology*, **53**, 1640–1648.

Arivazhagan, E., Kandasamy, R. and Maniram, S. (2019). Influence of organic inputs on the growth, yield and quality of tomato (*Solanum lycopersicum* L.) cv. Sivam. *Annals of Plant and Soil Research*, **21**, 367–370.

Arnon, D.I. (1949). Copper enzymes in isolated chloroplasts, polyphenoloxidase in *Beta vulgaris*. *Plant Physiology*, **24**, 1–15.

Bhattarai, D.R. and Budathoki, K. (2005). Effect of organic manures on pre-and postharvest physiology and consumers' acceptability of cauliflower (*Brassica oleracea* var. *botrytis*). *Nepal Journal of Science and Technology*, **6**(1), 11–14.

Bose, T.K., Kabir, J., Maity, T.K., Parthasarathy, V.A. and Som, M.G. (2003). *Vegetable Crops*, Vol. 3. Naya Prokash, Calcutta, India, pp. 209–240.

Chitarra, M.I.F. and Chitarra, A.B. (2005). *Postharvest of Fruits and Vegetables, Physiology and Handling*, 2nd ed., FAEPE, Lavras, p. 785.

Dujmović, M., Kurek, M., Mlinar, Z., Radman, S., Opačić, N., Pišonić, P., Voća, S. and Šic Žlabur, J. (2024). Packaging matters, preservation of antioxidant compounds of fresh stinging nettle leaves (*Urtica dioica* L.). *Applied Sciences*, **14**(15), 6563.

Fang, Y. and Wakisaka, M. (2021). A review on the modified atmosphere preservation of fruits and vegetables with cutting-edge technologies. *Agriculture*, **11**(10), 992.

Genanew (2013). Effect of post-harvest treatments on storage behavior and quality of tomato fruits. *International Journal of Agriculture and Food Science*, **9**(1), 29–37.

Indore, H.D., Garande, V.K., Dhumal, S.S., Patgaonkar, D.R., Patil, V.S. and Sonawane, P.N. (2016). Effect of packaging materials and storage conditions on shelf life and quality of okra. *International Journal of Advanced Research*, **4**(11), 257–265.

Kabir, M.S.N., Rasool, K., Lee, W.H., Cho, S.I. and Chung, S. (2020). Influence of delayed cooling on the quality of tomatoes (*Solanum lycopersicum* L.) stored in a controlled chamber. *AIMS Agriculture and Food*, **5**(2), 272–285.

Kader, A.A. (2002). *Postharvest Technology of Horticultural Crops*. Oakland, University of California, Agriculture and Natural Resources, pp. 535.

Karanatsidis, G. and Berova, M. (2009). Effect of organic-N fertilizer on growth and some physiological parameters in pepper plants (*Capsicum annuum* L.). *Biotechnology & Biotechnological Equipment*, **23**, 254–257.

Krishnamoorthy, R., Alshatwi, A.A., Subbarayan, S., Vadivel, B., Periyasamy, V.S., Al-Shuniaber, M.A. and Athinarayanan, J. (2019). Impact of farm-made liquid organic nutrients jeevamrutham and fish amino acid on growth and nutritional status in different seasons of *Abelmoschus esculentus* – a self-sustainable field trial. *Organic Agriculture*, **9**, 65–79.

Kumar, V., Shankar, R. and Kumar. (2015). Strategies used for reducing postharvest losses in fruits and vegetables. *International Journal of Scientific & Engineering Research*, **6**(5), 130–137.

Mahajan, B.V., Dhillon, W.S. and Siddhu, M.K. (2016). Effect of packaging and storage environments on quality and shelf life of bell pepper (*Capsicum annuum* L.). *The Indian Journal of Agricultural Sciences*, **86**, 738–742.

Markose, B.L. and Peter, V. (1990). Review of research on vegetable and tuber crops. *Technical Bulletin 16*, Mannuthy, Kerala Agricultural University Press.

Martin, W.F. (1979). Okra, Potential multiple-purpose crop for the temperate zones and tropics. *Economic Botany*, **36**(3), 340–345.

Mohit, M.K., Singh, M.K., Singh, S.P. and Naresh, R.K. (2019). Effect of integrated use of organic and inorganic sources of nutrients on growth, yield quality and profitability of tomato (*Lycopersicon esculentum* Mill.) var. Pusa Rohini. *International Journal of Agricultural and Statistical Sciences*, **15**, 57–66.

Mampholo, B.M., Sivakumar, D., Beukes, M. and van Rensburg, W.J. (2013). Effect of modified atmosphere packaging on the quality and bioactive compounds of Chinese cabbage (*Brassica rapa* L. ssp. *chinensis*). *Journal of the Science of Food and Agriculture*, **93**(8), 2008–2015.

Moretti, C.L. and Pineli, L.L.O. (2005). Chemical and physical quality of eggplant fruits submitted to different postharvest treatments. *Food Science and Technology*, **25**, 339–344.

Mota, W.F., Finger, F.L. and Cecon, P.R. (2010). Preservation and postharvest quality of okra under different temperatures and forms of storage. *Horticultura Brasileira*, **28**, 12–18.

Munhuewyi, K. (2012). Postharvest losses and changes in quality of vegetables from retail to consumer, a case study of tomato, cabbage and carrot. *Master Thesis*, Stellenbosch, Stellenbosch University.

Murmu, K., Ghosh, B.C. and Swain, D.K. (2012). Yield and quality of tomato grown under organic and conventional nutrient management. *Archives of Agronomy and Soil Science*, **59**(10), 1–11.

Negi, P.S. and Roy, S.K. (2004). The effect of conditions of storage on shelf-life of green leafy vegetable. *European Food Research and Technology*, **215**, 485–488.

Patel, N., Patel, N.L. and Sangani, S.L. (2016). Effect of postharvest treatments, packaging materials and storage conditions on shelf life and quality of okra. *International Journal of Agriculture Sciences*, **8**(52), 2601–2605.

Plaza, L., Sanchez-Moreno, C. and Elez-Martinez, P. (2006). Effect of refrigerated storage on Vitamin C and antioxidant activity of orange juice processed by high pressure or pulsed electric fields with regard to low pasteurization. *European Food Research and Technology*, **223**, 487–493.

Prabhadharshini, M.K., Anand, M., Vethamoni, P.I., Amuthaselvi, G. and Janaki, P. (2023). Fresh insight, enhancing verdant leafy vegetable's shelf life via modified atmosphere packing and storage. *International Journal of Environment and Climate Change*, **13**(10), 1298–1307.

Rai, D.R., Narsaiah, K., Bharati, D.K., Reddy, P.M.K. and Brar, S.S. (2009). Modified atmosphere packaging of minimal processing and storage of shredded cabbage. *Journal of Food Science and Technology*, **46**(5), 436–439.

Rajyalaxmi, P., Saravanan, S. and Naik, M.L. (2015). Effect of organic manures and inorganic fertilizers on plant growth, yield, fruit quality and shelf life of tomato (*Solanum lycopersicum* L.) cv. PKM-1. *International Journal of Agricultural Science and Research*, **5**(2), 7–12.

Ranganna, S. (1986). *Handbook of Analysis and Quality Control of Fruit and Vegetable Products*. Tata McGraw Hill Publishing Company Limited, New Delhi.

Rani, M., Singh, J. and Kumar, D. (2015). Effect of different packaging material on chlorophyll and ascorbic acid content of the okra. *South Asian Journal of Food Technology and Environment*, **1**, 86–88.

Reddy, J.B., Bharati, P., Naik, K.R., Chimmad, B.V., Itagi, S.K. and Hasalkar, S. (2013). Effect of packaging materials on shelf life of minimally processed rajgira leaves (*Amaranthus paniculatus*). *Karnataka Journal of Agricultural Sciences*, **26**(2), 285–287.

Santi, R., Bhowmilk, S.R. and Jung, C.P. (1992). Shelf life of mature green tomatoes stored in controlled atmosphere and high humidity. *Journal of Food Science*, **57**, 948–951.

Selmon, I.D. (1994). Vitamin retention during blanching of vegetables. *Food Chemistry*, **49**, 137–147.

Shankarprasad, K.S. and Hongal, S. (2018). Effect of modified atmosphere packaging on shelf life and post-harvest quality of *Coccinia indica* Wight & Arn, A least known medicinal plant. *Journal of Pharmacognosy and Phytochemistry*, **3**, 266–270.

Singh, S., Chaurasia, S.N.S. and Prasad, I. (2020). Nutritional quality and shelf life extension of capsicum (*Capsicum annum*) in expanded polyethylene biopolymer. *Asian Journal of Dairy and Food Research*, **39**, 40–48.

Singh, A. and Lal Banerjee, S. (2023). Polymer composites as packaging materials. In, Bhandari, S., Gupta, P. and Dey, A. (eds), *Industrial Applications of Polymer Composites*. *Frontiers in Polymer Science*, Vol. 1, Bentham Books, pp. 20–57.

Swetha, P.S., Kavitha, M., Praneetha, S., Amuthaselvi, G., Janaki, P. and Kannan, B. (2023). Enhancing the shelf life of palak and coriander through modified atmosphere packaging under diverse storage environments. *International Journal of Environment and Climate Change*, **13**(10), 2670–2677.

Tigist, M., Workneh, T.S. and Woldetsadik, K. (2013). Effects of variety on the quality of tomato stored under ambient conditions. *Journal of Science and Technology*, **50**(3), 477–486.

United Nations (2015). The UN sustainable development goals. United Nations, New York. Available at, https,//www.un. org /sustainabledevelopment

Vanndy, M., Buntong, B., Acedo, A. and Weinberger, K. (2008). Modified atmosphere packaging to improve shelf life of tomato fruit in Cambodia. *Acta Horticulturae*, **804**, 453–458.