Standardisation of Active Modified Atmosphere Storage in Indi Lime (*Citrus aurantifolia* Swingle) Fruits

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Abstract- Indi lime (*Citrus aurantifolia* Swingle), commonly known as Kagzi lime, is an important citrus fruit cultivated widely in the northern districts of Karnataka, particularly in the Indi region of Vijayapura. Despite its economic and nutritional importance, lime fruits are highly perishable and suffer considerable postharvest losses due to rapid physiological deterioration, microbial decay and improper storage conditions. Modified Atmosphere Packaging (MAP) is a promising postharvest technology that alters the gaseous environment surrounding the produce to reduce respiration, delay senescence and extend storage life. The present study was conducted during the year 2023–24 at the Department of Postharvest Management, College of Horticulture, University of Horticultural Sciences, Bengaluru, to standardize active modified atmosphere storage conditions for Indi lime fruits. The experiment was laid out in a Completely Randomized Design with five treatments and four replications using LDPE bags (250 µm) with different gas compositions *viz.,* passive MAP (control), 4% O_2 + 2% CO_2 + 94% N_2, 6% O_2 + 4% CO_2 + 90% N_2, 8% O_2 + 6% CO_2 + 86% N_2 and 10% O_2 + 8% CO_2 + 82% N_2. Fruits were stored at 10 ± 2°C and evaluated at 10-day intervals for physiological, biochemical and sensory parameters. Results revealed that active MAP significantly influenced fruit quality during storage. Treatment T4 (8% O_2 + 6% CO_2 + 86% N_2) was found to be the most effective in maintaining fruit quality by reducing physiological loss in weight, preserving firmness and colour, maintaining moisture content, lowering respiration rate and delaying biochemical changes compared to passive MAP. The treatment also recorded reduced decay incidence. Thus, indi lime fruits stored under T4 conditions maintained acceptable quality for up to 60 days of cold storage, followed by a short shelf life under ambient conditions.

Keywords: Citrus, Indi lime, Kagzi lime, Modified atmosphere packaging, Postharvest quality, Storage life

I.INTRODUCTION

Indi lime (*Citrus aurantifolia* Swingle) belonging to the family Rutaceae, is an important citrus fruit widely cultivated in the tropical and subtropical regions of India. Among the citrus fruits, lime ranks third after mandarin and sweet orange in terms of commercial importance. India is one of the major producers of lime globally and the crop plays an significant role in the horticultural economy [19]. The Indi region of Vijayapura district in Karnataka (16.82° N latitude and 76.18° E longitude) is particularly known for the cultivation of high-quality Kagzi lime, which possesses desirable attributes such as thin peel, high juice content, characteristic aroma and high vitamin C content [7]. In Karnataka, on an average Kagzi lime cultivated in area of about 13.1 thousand hectares with an annual production of 3,06,210 metric tons [21]. Notably, more than half of the total production in Vijayapura district comes from the Indi taluk alone. Owing to its unique qualities, Indi lime has received a Geographical Indication (GI) tag, highlighting its regional importance [16].

Lime fruits are widely used in beverages, culinary preparations, pickles and food processing industries [26]. In addition to culinary importance, they are highly valued for their medicinal and nutritional properties, particularly their high vitamin C content [28]. It exhibits several health promoting properties, including anti-cancer, anti-inflammatory, anti-diabetic, anti-bacterial and antifungal activities [1].

Despite these benefits, lime fruits are highly perishable and susceptible to rapid quality deterioration during storage, due to moisture loss, respiration, microbial decay, mechanical damage during transportation and improper storage conditions [15]. These factors significantly reduce the shelf life and market quality of the fruits.

To minimize these losses, appropriate postharvest handling practices are essential for maintaining the quality and extending shelf life, which depend on proper handling, treatment, storage and transportation of harvested produce. One such solution for this is Modified Atmosphere Packaging (MAP) [11]. It involves modifying the composition of gases surrounding the produce, typically by reducing oxygen levels and increasing carbon dioxide concentration, which helps to slowdown the respiration and microbial growth [30]. The technique can be applied either passively, where the atmosphere develops naturally due to the respiration of produce within the package, or actively by flushing the package with a predetermined gas mixture. This helps to delay ripening, reduce weight loss, maintain firmness and preserve colour and nutritional quality in several fruits [34]. However, the optimal gas composition varies depending upon the crop type and the storage conditions.

By prolonging longer availability across the different regions, MAP supports growers and consumers by reducing postharvest losses and enhancing market opportunities [35]. Therefore, evaluating the MAP for Indi lime becomes essential to determine its potential in maintaining quality, minimizing losses and ensuring a consistent supply of market-acceptable fruits. However, limited information is available regarding the suitable modified atmosphere composition for prolonged storage of Indi lime. Hence, the present investigation was undertaken to standardize active modified atmosphere storage conditions for Indi lime fruits and to evaluate their effects on physiological, biochemical and sensory characteristics during storage.

II.MATERIALS AND METHODS

The present investigation entitled “Standardisation of Active Modified Atmospheric Storage in Indi Lime (*Citrus aurantifolia* Swingle) fruits” was conducted in the Department of Postharvest Management, College of Horticulture, University of Horticultural Sciences, Bengaluru during the year 2023–24. Fresh lime fruits (cv. Kagzi) were harvested at the mature stage and sorted to remove damaged, diseased and misshapen fruits and graded for uniform size, shape and colour. Then the fruits were washed using 200 ppm sodium hypochlorite solution for surface sanitation and subsequently air-dried for five hours to remove surface moisture. The experiment was conducted using 250 g fruits per package in LDPE bags (250 μm thickness) under five treatments with four replications in a Completely Randomized Design (CRD) and Duncan's Multiple Range (DMRT) Test was carried out using the R studio software. The packaged fruits were stored under cold storage conditions at a temperature of 10 ± 2°C and evaluated at every 10-days interval. The study consisted of five treatments; *viz.,* Passive MAP (without gas flushing) (T_1); 4% O_2 + 2% CO_2 + 94% N_2 (T_2); 6% O_2 + 4% CO_2 + 90% N_2 (T_3); 8% O_2 + 6% CO_2 + 86% N_2 (T_4) and 10% O_2 + 8% CO_2 + 82% N_2 (T_5). These treatments were evaluated to determine the effect of different modified atmosphere composition on the storage quality and shelf life of Indi lime fruits. Observations were recorded on various physiological, biochemical and sensory parameters including physiological loss in weight (%), moisture content (%), fruit firmness (N), total soluble solids (°Brix), titratable acidity (%), ascorbic acid content (mg 100 ml^{-1}), antioxidant activity (FRAP method), respiration rate (mg CO_2 kg^{-1} h^{-1}), fruit decay (%), as well as storage and shelf life of fruits. Then the recorded data were statistically analysed using a Completely Randomized Design at 1% level of significance to determine the effect of different modified atmosphere treatments on the quality attributes and storage performance of Indi lime fruits.

The moisture content of fruits was determined at regular intervals by using four grams of finely chopped peel from each sample in a Sartorius electronic moisture analyser (Model MA 35). Fruit firmness was assessed by penetrating each sample with a 5 mm cylindrical probe moving at a speed of 2 mm/s, followed by an automatic return. The probe was set to penetrate 5 mm deep, with the pre-test and post-test speeds adjusted to 1 mm/s and 10 mm/s, respectively. The measurements were performed using a Texture Analyser (Model TA. HD Plus, Stable Micro Systems, UK).

Physiological loss in weight was recorded using a high-precision electronic weighing balance (Sartorius GmbH, Goettingen, Germany; Model GE812) at 10-days interval throughout the storage period. These readings were used to calculate the cumulative PLW, which was expressed as the percentage of weight loss using the following formula:

$$\text{Physiological loss in weight (\%)} = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \times 100$$

The titratable acidity of lime fruit juice was determined using the titration method. For this, 1ml of the sample was diluted with 25 mL of distilled water to obtain a uniform solution. The diluted sample was then titrated against 0.1N sodium hydroxide (NaOH) solution with 2-3 drops of phenolphthalein as the indicator. The endpoint of the titration was identified by the appearence of a light pink colour. The titratable acidity was calculated and expressed as a percentage of citric acid equivalent (AOAC, 1990).

$$\text{Titratable acidity (\%)} = \frac{T \times E \times N \times V_1 \times 100}{V_2 \times 1000 \times W}$$

Ascorbic acid content of the sample was estimated titrimetrically using 2, 6-dichlorophenol indophenol dye. The one-gram sample was diluted with 4% oxalic acid. Then, 25 ml of an aliquot taken from the sample was titrated against 2,6-dichlorophenol indophenol. The results were expressed as milligrams of ascorbic acid per 100 g of the sample (A0AC, 2006).

$$\text{Ascorbic acid content (mg } 100\text{ml}^{-1}) = \frac{0.5 \times V_2 \times 100 \times 100}{V_1 \times 5 \times \text{weight of sample}}$$

The respiration rate of the lime fruits with different gas compositions was measured after taking them out of the packages during their storage. The fruits were weighed enclosed in a hermetic container for specified time and head space gas concentration of CO_2, by piercing the probe of an auto oxygen/carbon dioxide analyser (Make: Quantek, Model: 902D Dual track) into the container through the septa fixed on the lid of the container and direct reading was noted down from the instrument screen. The respiration rate was calculated in mg kg^{-1} h^{-1} by using the formula:

$$\text{Respiration rate (mg kg}^{-1}\text{h}^{-1}) = \frac{\% \text{ CO}_2 \text{ x Container volume (ml) x 60}}{\text{[Fruits weight (kg)] x [Enclosing time (min)] x 100}}$$

The incidence of decay in lime fruits was evaluated visually and expressed as total decay. Fruits showing any external signs of rotting, such as mould growth, were classified as external decayed fruits. These fruits were recorded and removed from the lot. The percentage of fruits affected by decay was then calculated using the following formula:

$$\text{Decay incidence (\%)} = \frac{\text{Number of discarded fruits at each sampling date}}{\text{Total number of fruits in treatment}} \text{x100}$$

The total soluble solids of lime fruits were measured using a hand refractometer (Erma Optical Works Ltd., Tokyo, Japan; range 0–32°B) and readings were adjusted to 20°C and expressed as °Brix [26]. The total antioxidant activity of lime fruits was determined using the FRAP method explained by [6]. Organoleptic evaluation of lime fruits was conducted based on colour, texture, taste, aroma and overall acceptability by a panel of ten semi-trained judges, where lime juice was diluted in a 1:3 (lime Juice and water) using a nine-point Hedonic scale as laid out by [2]. Shelf life of fruit was determined after removing the lime fruits from low temperature storage (10±2ºC) and observing their quality under ambient conditions until they became unfit for composition.

III.RESULTS AND DISCUSSION

The physicochemical properties of fresh lime fruits were evaluated prior to the application of any postharvest treatments in order to establish the initial quality parameters and baseline data for the study (Table 1). The analysis revealed that the fruits had an average fruit weight of 47.7 g with juice content of 48.96% and TSS of 6.5°Brix indicating moderate sweetness and good juice yield. The fruits had moisture content of 83.9%, which reflects the high water content typical of citrus fruits and contributes to their perishability. The titratable acidity of 8.15%, antioxidant activity of 75 mg AAE 100ml^{-1} while ascorbic acid content of 32 mg 100 ml^{-1}, demonstrating that lime fruits are good source of natural antioxidants and vitamin C. The respiration rate of the fruits was observed as 17.1 mg CO_2 kg^{-1} h^{-1} at 25 °C, suggesting a relatively active metabolic rate under ambient conditions, which contributes to faster postharvest deterioration. Additionally, the fruit texture measured 51.8 N, reflecting acceptable firmness at the time of harvest. Based on these initial quality attributes, the shelf life of fresh lime fruits under ambient storage conditions was recorded as approximately 7 days, highlighting the highly perishable nature of the fruit and the need for appropriate postharvest handling and storage techniques to extend its marketable life. Similar reports were noted by [15], [11] and [26] in fruit crops.

Physiological weight loss increased progressively during the storage period in all treatments (Table 2-Fig.1). Among the different atmospheric conditions, fruits stored under T_4 (8% O_2 + 6% CO_2) recorded the lowest PLW with values of 0.40, 0.90, 1.60, 2.30, 2.90 and 3.50 per cent on the 10, 20, 30, 40, 50 and 60th days of storage, respectively (Plate 1-6). The reduced weight loss under this treatment indicates the effectiveness of modified atmosphere in reducing metabolic activity such as respiration and transpiration. These findings are in agreement with earlier reports on citrus fruits stored under controlled atmospheric conditions [31]. In contrast, the highest weight loss was observed in T_1 (Passive MAP), reaching 7.03% at 60 days of storage, which could be attributed to higher transpiration and respiration. A similar rapid decline under non-modified storage was reported in Kaghzi lime [14]. Physiological loss in weight (PLW) is closely correlated with storage temperature, relative humidity and the type of packaging used, in addition to the inherent metabolic activities of the fruits. Higher storage temperatures accelerate respiration and transpiration rates, leading to increased moisture loss and consequent reduction in fruit weight. Similarly, low relative humidity increases the vapour pressure deficit between the fruit surface and the surrounding air, thereby promoting greater water loss through transpiration and ultimately contributing to higher PLW during storage.

The initial moisture content of fresh lime fruits was 83.90 per cent, which gradually declined during the storage period across all the treatments (Table 3-Fig.2). On the 40th day of storage, the highest moisture content (82.26%) was recorded in fruits stored under T_4 (8% O_2 +6% CO_2), followed by T_5 (10% O_2 + 8% CO_2) with 82.01 per cent, suggesting that a moderate O_2–CO_2 ratio helps in reducing moisture loss by lowering the respiration and transportation rate without causing physiological stress to the fruits. Comparable reductions in moisture loss under MAP have been reported in grapefruit stored under modified atmospheres (Chaudhary *et al.,* 2015). While the lowest (80.82%) moisture content was observed in fruits stored under passive T_1 (MAP) at 40th day, which could be attributed to relatively higher metabolic activity and water loss. By the end of 60 days of storage, the maximum moisture content (81.25%) was still maintained in T_4 (8% O_2 + 6% CO_2) followed by T_5 (10% O_2 + 8% CO_2) (80.93%), whereas the minimum moisture content (78.31%) was recorded in T_1 (passive MAP). The mean moisture content across treatments declined from 83.90 per cent (initial) to 80.20 per cent after 60 days of storage, indicating a steady loss of moisture with time of storage. These findings are similar to Kaghzi lime under non-modified storage [14] and in citrus fruits [31].

The initial texture of fresh lime fruits was recorded as 51.80 N, which showed a continuous decline during storage in all the treatments (Table 4-Fig.3). On the 40th day of storage, the highest texture firmness (48.20 N) was observed in fruits stored under T_4 (8% O_2 + 6% CO_2), followed by T_5 (10% O_2 + 8% CO_2) at about 47.70 N and T_3 (6% O_2 + 4% CO_2) at 47.58 N. The retention of higher firmness under these modified atmosphere conditions indicates that reduced oxygen and elevated carbon dioxide levels slows down the metabolic activity and delay the degradation of cell wall components responsible for fruit softening. In contrast, the lowest texture value (43.80 N) was recorded in fruits under passive MAP (T_1). Similarly, firmness reduction under conventional storage has been reported in citrus fruits stored without atmospheric modification [23]. By the end of 60 days of storage, fruits packed in T_4 (8% O_2 + 6% CO_2) retained the highest firmness (45.60 N), followed by T_5 (44.50

N) and T_3 (44.20 N), whereas the lowest firmness (38.00 N) was observed in T_1 (passive MAP) indicating that reduced O_2 level combined with elevated CO_2 concentration helps in reducing enzymatic breakdown of cell wall components, thereby maintaining structural integrity of fruit tissue. These observations were consistent with the role of MAP in delaying of softening in citrus [4]. Similarly, [33] also noted that modified atmospheres helps to maintain textural integrity by reducing respiration and delaying structural degradation in fruit tissues.

The respiration rate of fresh lime fruits increased steadily during storage across all the treatments, reflecting the progression of metabolic activity and senescence (Table 5-Fig.4). The highest increase was observed in T_1 (Passive MAP) from 17.10 to 42.50 mg CO_2 kg^{-1} h^{-1} by 60 DAS due to unrestricted oxygen availability, which accelerates metabolic activity and promotes physiological deterioration. Higher O_2 levels enhance the oxidative breakdown of substrates resulted in higher heat and CO_2 production, consequently increased respiration, leading to faster physiological deterioration, as noted in citrus stored under ambient conditions [15]. In contrast, fruits stored under T_4 (8% O_2 + 6% CO_2) exhibited the lowest increase in respiration rate, reaching only 26.00 mg CO_2 kg^{-1} h^{-1} by end of storage, indicating that reduced O_2 combined with elevated CO_2 effectively suppressed respiration by limiting electron transport process and inhibiting the metabolic enzyme activity. The balanced gas composition slows down the respiration without inducing anaerobic stress, thereby helping to maintain fruit quality during storage. Elevated CO_2 levels are known to reduce ethylene synthesis and delay metabolic changes in citrus, thereby improving the storage stability [25]. Similarly, reduced O_2 has been reported to lower respiratory demand and prolongs the postharvest life by slowing biochemical reactions associated with ripening and senescence [29].

The highest TSS was consistently recorded in Passive MAP (T_1), reaching 8.90°B at 60 days of storage (Table 6-Fig.5). This rapid increase may be attributed to higher respiration and moisture loss under unrestricted atmospheric conditions, where elevated O_2 availability stimulates oxidative respiration, enhancing the conversion of stored polysaccharides and organic acids into simple sugars, thereby increasing the TSS levels. Simultaneously, the absence of CO_2 enrichment fails to suppress respiratory enzyme activity, resulting in faster metabolic turnover and accelerated ripening. Similar increases in TSS have been reported in citrus fruits stored without atmospheric modification, where rapid senescence leads to greater accumulation of soluble solids during storage [17]. In contrast, lowest TSS value was observed in T_5 (10% O_2 + 8% CO_2) with 7.60°B indicating that reduced O_2 and elevated CO_2 slowed metabolic activity and delayed biochemical changes associated with ripening, helping to maintain the internal quality and extended the storage life of lime fruits.

The titratable acidity of fresh lime fruits declined gradually during storage in all the treatments reflecting the utilization of organic acids in respiratory metabolism during the storage period (Table 7-Fig.6). The lowest TA was consistently recorded in Passive MAP (T_1), reaching 6.40 per cent at 60 days, while the highest TA occurred in T_4 (8% O_2 + 6% CO_2) with 7.60 per cent. The highest retention of acidity under modified atmosphere conditions indicates that reduced oxygen and elevated carbon dioxide levels slows down the respiratory metabolism and delay the utilization of organic acids, thereby helping to preserve fruit quality during storage. Similarly, the ascorbic acid content at 60 days was recorded in T_4 (8% O_2 + 6% CO_2) with 29.5mg100ml^{-1} with the highest retention of about 92.22 per cent followed by T_5 (10% O_2 + 8% CO_2) and T_3 (6% O_2 + 4% CO_2), while the lowest ascorbic acid content was found in Passive MAP (T_1) with 17.5 mg100ml^{-1} corresponding to the least retention of 54.68 per cent. The better retention of ascorbic acid under modified atmosphere conditions may be attributed to reduced oxidative degradation and slower metabolic activity. Similar trend of high antioxidant activity was recorded in T_4 (8% O_2 + 6% CO_2) with 67.0 mgAAE 100 ml^{-1} at 60 days of storage, whereas the lowest was found in Passive MAP (T_1) with 48.0 mgAAE 100 ml^{-1}. These results indicate that modified atmosphere storage effectively slows down the oxidative reactions and metabolic degradation, thereby helping to retain bioactive compounds and maintain the nutritional quality of lime fruits during prolonged storage.

The ascorbic acid content of fresh lime fruits declined steadily during storage in all treatments. The fastest reduction was observed in T_1 (Passive MAP) from 32.00 to 17.50 mg100ml^{-1} by 60 DAS with the least retention of 54.68 per cent (Table 8-

Fig.7). This rapid declined may be attributed to higher oxygen availability under passive conditions, which accelerates the oxidative degradation of vitamin C during respiration and senescence. Similar reductions in ascorbic acid content under ambient storage conditions have been reported in citrus fruits due to increased enzymatic oxidation and metabolic activity [18]. In contrast, fruits stored under T_4 (8% O_2 + 6% CO_2) retained the highest ascorbic acid (29.50 mg100ml^{-1}), indicating that reduced oxygen and elevated carbon dioxide concentration effectively slowed oxidative reactions and metabolic degradation. Among the MAP treatments, T_4 (8% O_2 + 6% CO_2) proved to be the most effective with highest retention of about 92.22 per cent, followed by T_5 (10% O_2 + 8% CO_2) and T_3 (6% O_2 + 4% CO_2). This suggests that a balanced gas atmosphere, coupled with low temperature, minimal physical injury and reduced physiological stress helps to maintain vitamin C stability by suppressing respiration and limiting exposure to oxidative stress. These findings align with [25], who reported that MAP preserves internal fruit quality by slowing biochemical deterioration during storage and in citrus fruits [10].

Total antioxidant content of fresh lime fruits declined steadily during storage in all treatments, with the largest decrease in T_1 (Passive MAP) from 75.10 to 48.00 mgAAE 100ml^{-1} by 60 DAS due to faster oxidative degradation under normal oxygen conditions, which accelerates metabolic activity and the action of oxidative enzymes during fruit senescence (Table 9-Fig.8). Similar reductions in antioxidant capacity during storage have been reported in citrus as senescence and oxidative enzymes increase lead to the degradation of bioactive compounds [9]. In contrast, fruits stored under T_4 (8% O_2 + 6% CO_2) exhibited the slowest decline, in antioxidant content, retaining 67.00 mgAAE 100ml^{-1}, indicating that reduced O_2 and elevated CO_2 limited the oxidative reactions. Among MAP treatments, T_4 (8% O_2 + 6% CO_2) maintained the highest antioxidant levels, followed by T_5 (10% O_2 + 8% CO_2) and T_3 (6% O_2 + 4% CO_2), suggesting that balanced gas composition helps to suppress respiration and reduce the formation of reactive oxygen species, thereby protecting antioxidant compounds during storage. Modified atmosphere storage has been shown to preserve phenolic compounds, moisture and essential vitamins and minerals, thereby enhancing the antioxidant stability in citrus fruits during storage [4]. In addition, reduced oxygen levels slow enzymatic oxidation by inhibiting oxidative enzymes responsible for phenolic degradation [12].

The storage life of lime fruits at low temperature (10 ± 2 °C) remained constant at 60 days in the T_4 (8% O_2 + 6% CO_2) and T_5 (10% O_2 + 8% CO_2) and 40 days in the T_3 (6% O_2 + 4% CO_2) and T_2 (4% O_2 + 2% CO_2) and the least was recorded in Passive MAP (T_1). At the beginning of storage, all the treatments recorded a shelf-life score of 7 days under ambient condition after removal from cold storage (Table 15). By 20–30 DAS, the shelf life was slightly declined to 6–6.5 days across the treatments. At 40 DAS, fruits stored under T_1 recorded a shelf life of 3 days, whereas T_2, T_3, T_4 and T_5 recorded 5 days. At 50 DAS, T_1 showed only 2 days of shelf life, T_2 and T_3 had 2.5 days and T_4 and T_5 has retained 4 days. By 60 DAS, the lowest shelf life (1 day) was recorded in T_1, while T_4 and T_5 still maintained a shelf life of 3 days under ambient conditions. Overall, the data indicated that MAP treatments, especially T_4 (8% O_2 + 6% CO_2) and T_5 (10% O_2 + 8% CO_2), were most effective in extending the storage and shelf life of lime fruits under ambient conditions compared to Passive MAP (T_1). This may be attributed to reduced respiration, delayed senescence and lower microbial decay during storage and marketing. Similar findings were reported in citrus [24].

IV.CONCLUSION

The study demonstrated that active modified atmosphere packaging significantly improves the storage life and quality of Indi lime fruits. Among the treatments tested, 8% O_2 + 6% CO_2 + 86% N_2 (T_4) proved to be the most effective gas composition for maintaining fruit quality during storage. This gas composition maintained higher firmness, moisture, acidity, antioxidants, vitamins and mineral content throughout 60 days of storage. Along with, it also recorded the lowest respiration rate, weight loss and decay percentage. Overall, active MAP extended the both storage and shelf life, ensuring better marketability and consumer acceptability. Therefore, 8 per cent O_2 + 6 per cent CO_2 can be recommended as the ideal packaging atmosphere for long-term storage of Indi lime fruits.

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Table 1. Physio-chemical properties of Fresh Indi lime (*Citrus aurantifolia* Swingle) fruits used for the experiment

Sl. No.	Parameter	Values
1	Fruit weight (g)	47.70
2	Juice (%)	48.96
3	TSS (°B)	6.50
4	Moisture (%)	83.90
5	Respiration rate (mg CO_2 kg^{-1} h^{-1})	17.10
6	Texture (N)	51.80
7	Titratable acidity (%)	8.15
8	Antioxidants (mg AAE $100g^{-1}$)	75.00
9	Ascorbic acid (mg$100g^{-1}$)	32.00
10	Shelf life (No. of days)	7.00

Table 2. Effect of active modified atmosphere package on physiological loss in weight (%) of Indi lime fruits under low temperature storage (10±2ºC)

Physiological loss in weight (%)						
Treatments	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS
T_1 (Passive MAP)	0.900[a]	1.625[a]	2.800[a]	4.000[a]	5.300[a]	7.025[a]
T_2 (4% O_2 + 2% CO_2)	0.700[ab]	1.200[ab]	2.100[ab]	3.200[b]	4.100[b]	5.000[b]
T_3 (6% O_2 + 4% CO_2)	0.600[b]	1.100[ab]	1.900[b]	2.800[bc]	3.600[c]	4.400[c]
T_4 (8% O_2 + 6% CO_2)	0.400[b]	0.900[b]	1.600[b]	2.300[d]	2.900[d]	3.500[e]
T_5 (10% O_2 + 8% CO_2)	0.500[b]	1.000[b]	1.800[b]	2.600[cd]	3.300[c]	3.900[d]
Mean	0.62	1.17	2.04	2.98	3.84	0.151
S. Em±	0.091	0.204	0.241	0.143	0.103	0.107
CD @ 5%	0.275	-	0.726	0.430	0.311	0.323
CD @ 1%	0.380	-	1.004	0.594	0.430	0.446
F-test	*	NS	*	**	**	**

* Significant at 5% level   * * Significant at 1% level   NS: Non significance
DAS: Days after storage

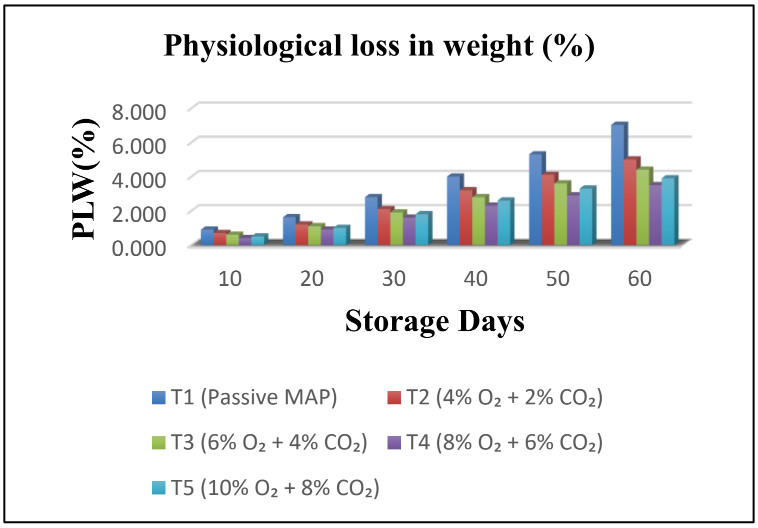

Fig. 1: Effect of active modified atmosphere package on physiological loss in weight (%) of Indi lime fruits under low

Table 3. Effect of active modified atmosphere package on moisture (%) of Indi lime fruits under low temperature storage (10±2°C)

Moisture (%)							
Treatments	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS
T_1 (Passive MAP)	83.900	83.438^{c}	82.850^{c}	81.838^{c}	80.825^{d}	79.738^{e}	78.313^{e}
T_2 (4% O_2 + 2% CO_2)	83.900	83.613^{bc}	83.188^{b}	82.425^{b}	81.513^{c}	80.750^{d}	79.988^{d}
T_3 (6% O_2 + 4% CO_2)	83.900	83.688^{ab}	83.275^{ab}	82.600^{ab}	81.838^{b}	81.175^{c}	80.500^{c}
T_4 (8% O_2 + 6% CO_2)	83.900	83.863^{a}	83.438^{a}	82.850^{a}	82.263^{a}	81.763^{a}	81.250^{a}
T_5 (10% O_2 + 8% CO_2)	83.900	83.775^{ab}	83.363^{ab}	82.675^{ab}	82.013^{b}	81.425^{b}	80.925^{b}
Mean	83.90	83.68	83.22	82.48	81.69	80.97	80.20
S. Em±	--	0.072	0.061	0.081	0.069	0.077	0.082
CD @ 5%	--	0.218	0.184	0.244	0.208	0.233	0.247
CD @ 1%	--	0.302	0.254	0.337	0.287	0.322	0.341
F-test	--	**	**	**	**	**	**

* Significant at 5% level * * Significant at 1% level NS: Non significance

DAS: Days after storage

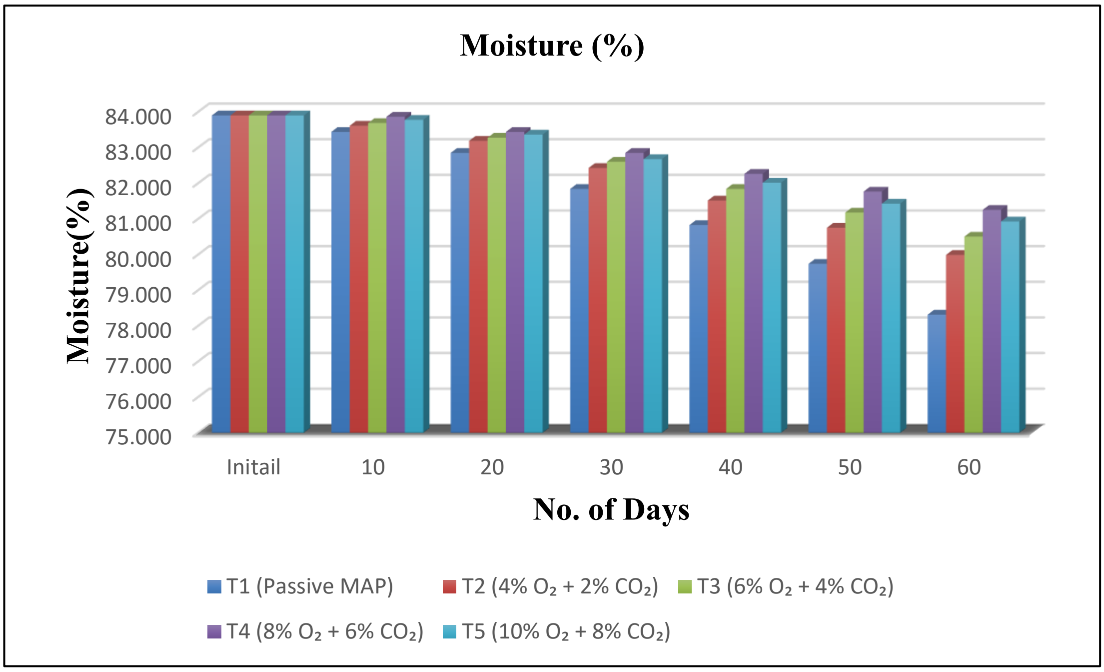

Fig. 2: Effect of active modified atmosphere package on moisture (%) of Indi lime fruits under low temperature storage (10±2°C)

Table 4. Effect of active modified atmosphere package on the texture of Indi lime fruits under low temperature storage (10±2°C)

Texture (N)							
Treatments	0 DAS	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS
T_1 (Passive MAP)	51.800	50.625^{d}	48.375^{d}	46.100^{d}	43.800^{d}	41.200^{e}	38.000^{e}
T_2 (4% O_2 + 2% CO_2)	51.800	51.000^{c}	49.800^{c}	48.175^{c}	46.200^{c}	44.400^{d}	42.025^{d}
T_3 (6% O_2 + 4% CO_2)	51.800	51.400^{ab}	50.200^{b}	49.025^{b}	47.575^{b}	46.025^{c}	44.200^{c}
T_4 (8% O_2 + 6% CO_2)	51.800	51.600^{a}	50.800^{a}	49.600^{a}	48.200^{a}	47.000^{a}	45.600^{a}
T_5 (10% O_2 + 8% CO_2)	51.800	51.325^{b}	50.400^{b}	49.200^{b}	47.700^{b}	46.425^{b}	44.500^{b}
Mean	51.800	51.190	49.915	48.420	46.695	45.010	42.865
S. Em±	--	0.077	0.104	0.106	0.090	0.085	0.074
CD @ 5%	--	0.232	0.313	0.320	0.272	0.257	0.223
CD @ 1%	--	0.321	0.433	0.442	0.376	0.355	0.308
F-test	--	**	**	**	**	**	**

* Significant at 5% level * * Significant at 1% level NS: Non significance

DAS: Days after storage

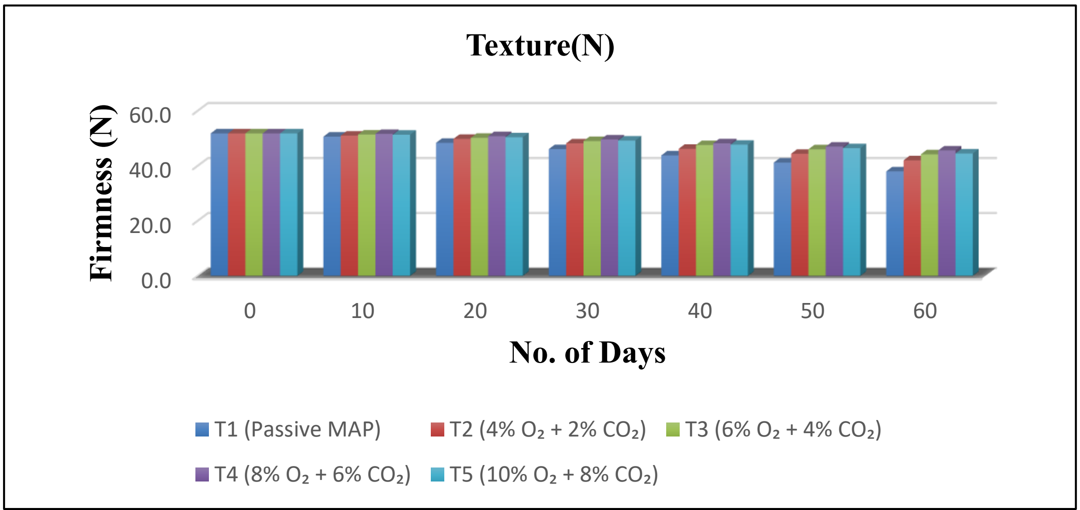

Fig. 3: Effect of active modified atmosphere package on texture (N) of Indi lime fruits under low temperature storage (10±2°C)

Table 5. Effect of active modified atmosphere package on the Respiration rate of Indi lime fruits under low temperature storage (10±2ºC)

Respiration rate (mg CO_2 kg^{-1} h^{-1})							
Treatments	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS
T_1 (Passive MAP)	17.100	22.000^{a}	25.500^{a}	29.000^{a}	33.000^{a}	38.500^{a}	42.500^{a}
T_2 (4% O_2 + 2% CO_2)	17.100	17.500^{b}	18.200^{b}	18.975^{b}	20.200^{b}	26.000^{b}	30.200^{b}
T_3 (6% O_2 + 4% CO_2)	17.100	17.400^{b}	18.000^{c}	18.800^{bc}	19.800^{c}	23.500^{c}	27.000^{c}
T_4 (8% O_2 + 6% CO_2)	17.100	17.300^{b}	17.900^{c}	18.700^{c}	19.700^{c}	22.500^{e}	26.000^{e}
T_5 (10% O_2 + 8% CO_2)	17.100	17.600^{b}	18.125^{c}	18.900^{c}	19.900^{c}	23.000^{d}	26.500^{d}
Mean	17.100	18.360	19.545	20.875	22.520	26.700	30.440
S. Em±	--	0.111	0.090	0.074	0.063	0.061	0.077
CD @ 5%	--	0.335	0.272	0.223	0.191	0.183	0.233
CD @ 1%	--	0.463	0.376	0.308	0.264	0.252	0.323
F-test	--	**	**	**	**	**	**

* Significant at 5% level * * Significant at 1% level NS: Non significance
DAS: Days after storage

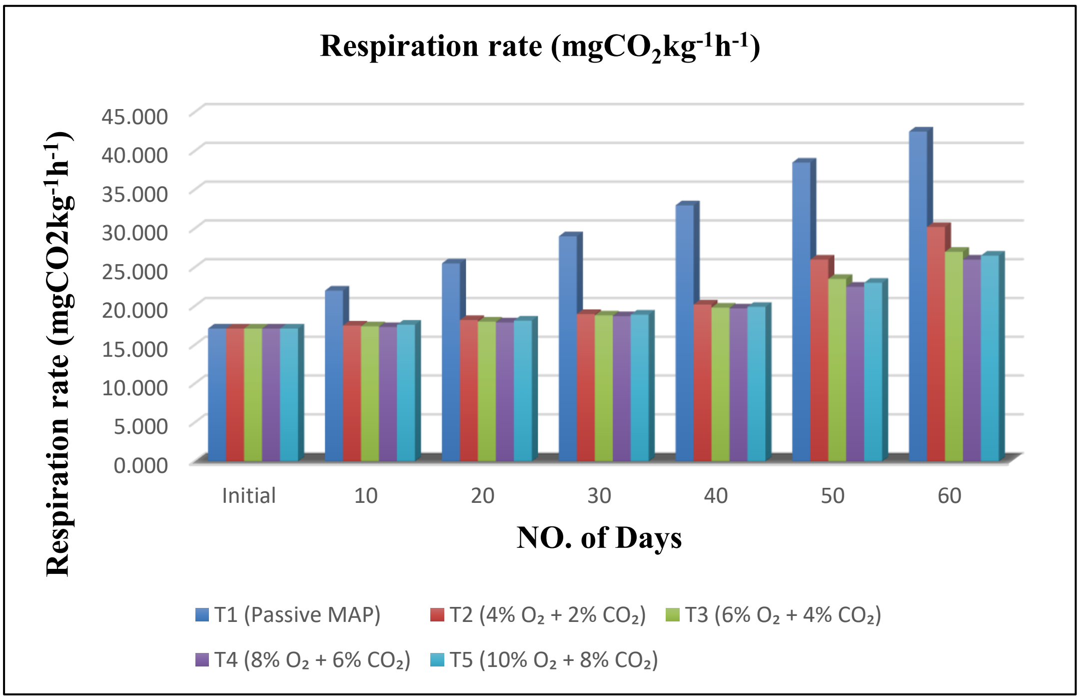

Fig. 4: Effect of active modified atmosphere package on Respiration rate of Indi lime fruits under low temperature storage (10±2ºC)

Table 6. Effect of active modified atmosphere package on TSS (^{0}B) of Indi lime fruits under low temperature storage (10±2°C)

TSS (^{0}B)							
Treatments	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS
T_1 (Passive MAP)	6.500	6.900^a	7.250^a	7.700^a	8.100^a	8.450^a	8.900^a
T_2 (4% O_2 + 2% CO_2)	6.500	6.725^b	6.900^c	7.200^c	7.500^c	7.850^c	8.200^c
T_3 (6% O_2 + 4% CO_2)	6.500	6.775^{ab}	7.050^b	7.350^b	7.675^b	8.100^b	8.500^b
T_4 (8% O_2 + 6% CO_2)	6.500	6.675^b	6.800^c	7.000^d	7.100^e	7.400^d	7.700^d
T_5 (10% O_2 + 8% CO_2)	6.500	6.700^b	6.850^c	7.050^d	7.250^d	7.500^d	7.600^d
Mean	6.500	6.755	6.970	7.260	7.525	7.860	8.180
S. Em±	--	0.041	0.034	0.037	0.040	0.037	0.041
CD @ 5%	--	0.125	0.103	0.110	0.122	0.110	0.123
CD @ 1%	--	0.172	0.142	0.152	0.168	0.152	0.170
F-test	--	*	**	**	**	**	**

* Significant at 5% level   * * Significant at 1% level   NS: Non significance

DAS: Days after storage

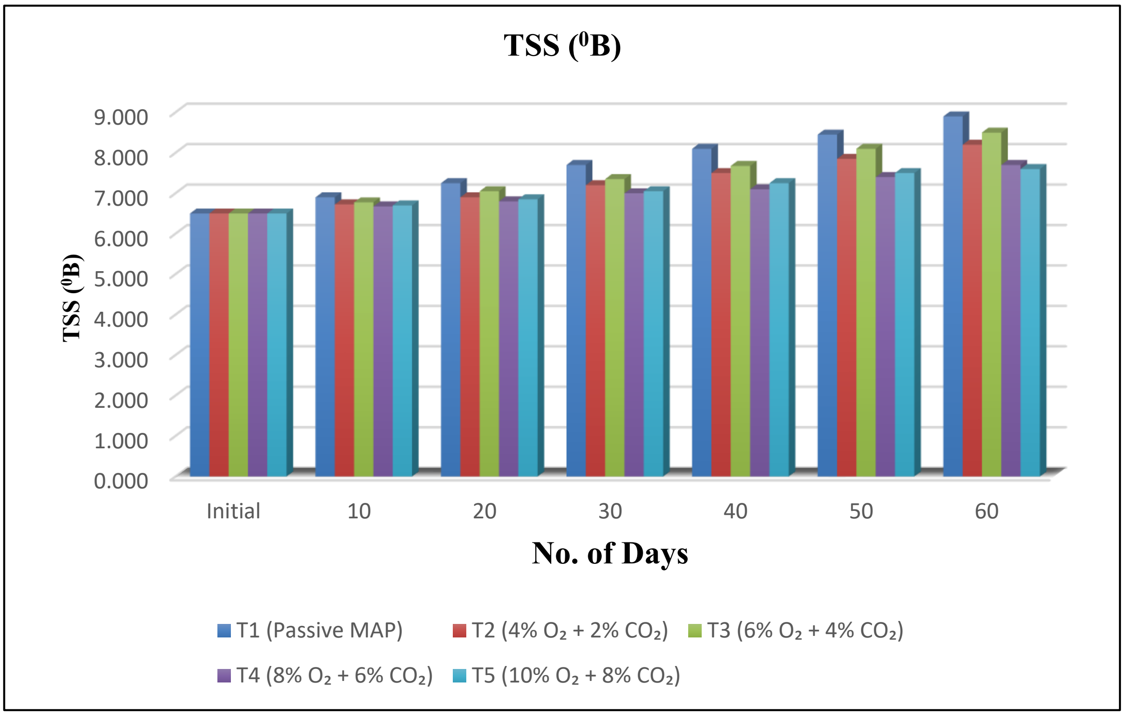

Fig. 5: Effect of active modified atmosphere package on Total soluble solids (^{0}B) of Indi lime fruits under low temperature storage (10±2°C)

Table 7. Effect of active modified atmosphere package on Titratable acidity of Indi lime fruits under low temperature storage (10±2°C)

Titratable acidity (%)							
Treatments	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS
T_1 (Passive MAP)	8.15	7.900[b]	7.600[c]	7.300[d]	7.000[d]	6.700[d]	6.400[d]
T_2 (4% O_2 + 2% CO_2)	8.15	8.000[b]	7.800[b]	7.600[c]	7.400[c]	7.200[c]	7.000[c]
T_3 (6% O_2 + 4% CO_2)	8.15	8.050[a]	7.900[ab]	7.750[b]	7.600[b]	7.450[b]	7.300[b]
T_4 (8% O_2 + 6% CO_2)	8.15	8.100[a]	8.000[a]	7.900[a]	7.800[a]	7.700[a]	7.600[a]
T_5 (10% O_2 + 8% CO_2)	8.15	8.075[a]	7.975[a]	7.875[a]	7.775[a]	7.675[a]	7.575[a]
Mean	8.15	8.025	7.855	7.685	7.515	7.345	7.175
S. Em±	--	0.036	0.038	0.036	0.038	0.036	0.038
CD @ 5%	--	0.108	0.115	0.108	0.115	0.108	0.115
CD @ 1%	--	0.150	0.159	0.150	0.159	0.150	0.159
F-test	--	*	**	**	**	**	**

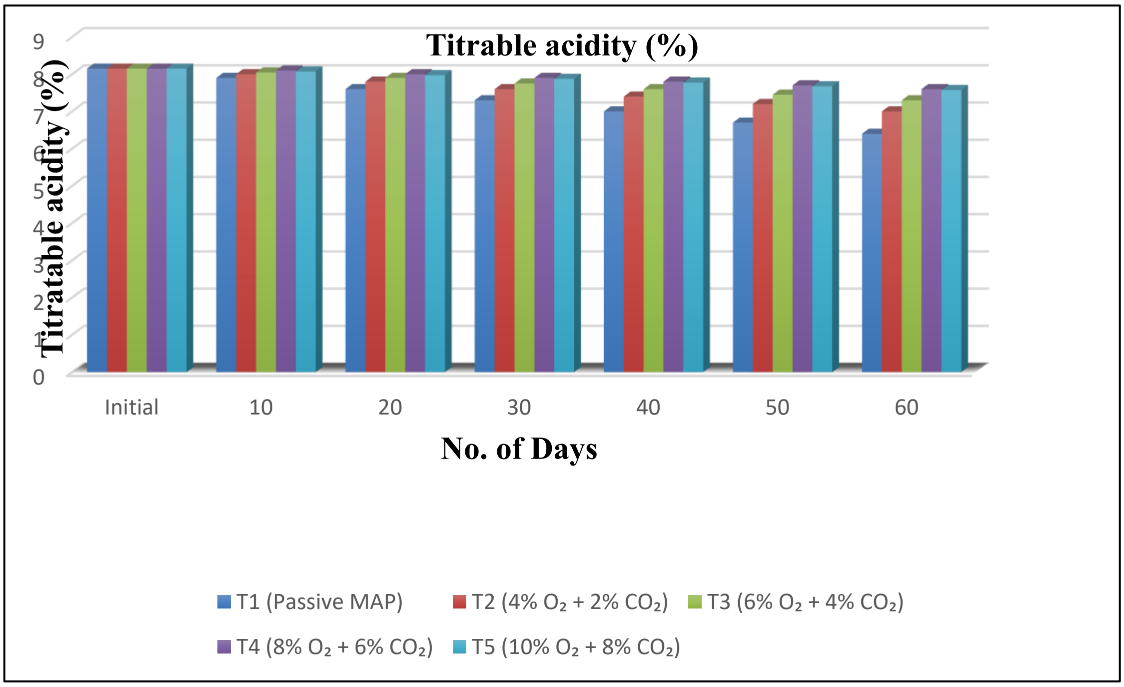

Fig. 6: Effect of active modified atmosphere package on Titrable acidity (%) of Indi lime fruits under low temperature storage (10±2°C)

Table 8. Effect of active modified atmosphere package on ascorbic acid content of Indi lime fruits under low temperature storage (10±2°C)

Ascorbic acid (mg $100ml^{-1}$)								
Treatments	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS	Retention (%)
T_1 (Passive MAP)	32.000	29.500[d]	26.500[e]	23.525[e]	21.000[e]	19.000[e]	17.500[e]	54.68
T_2 (4% O_2 + 2% CO_2)	32.000	30.800[c]	29.500[d]	28.000[d]	26.500[d]	25.000[d]	23.800[d]	74.38
T_3 (6% O_2 + 4% CO_2)	32.000	31.200[b]	30.475[c]	29.800[c]	29.000[c]	28.200[c]	27.500[c]	85.93
T_4 (8% O_2 + 6% CO_2)	32.000	31.625[a]	31.225[a]	30.800[a]	30.425[a]	30.000[a]	29.500[a]	92.22
T_5 (10% O_2 + 8% CO_2)	32.000	31.525[a]	30.775[b]	30.425[b]	29.800[b]	29.300[b]	28.800[b]	90.00
Mean	32.000	30.930	29.695	28.510	27.345	26.300	25.420	79.44
S. Em±	--	0.077	0.088	0.085	0.074	0.077	0.071	-
C.D. @ 1%	--	0.321	0.366	0.355	0.308	0.323	0.295	-
C.D. @ 5%	--		0.265	0.257	0.223	0.233	0.213	-
F-test	--	**	**	**	**	**	**	-

* Significant at 5% level * * Significant at 1% level NS: Non significance

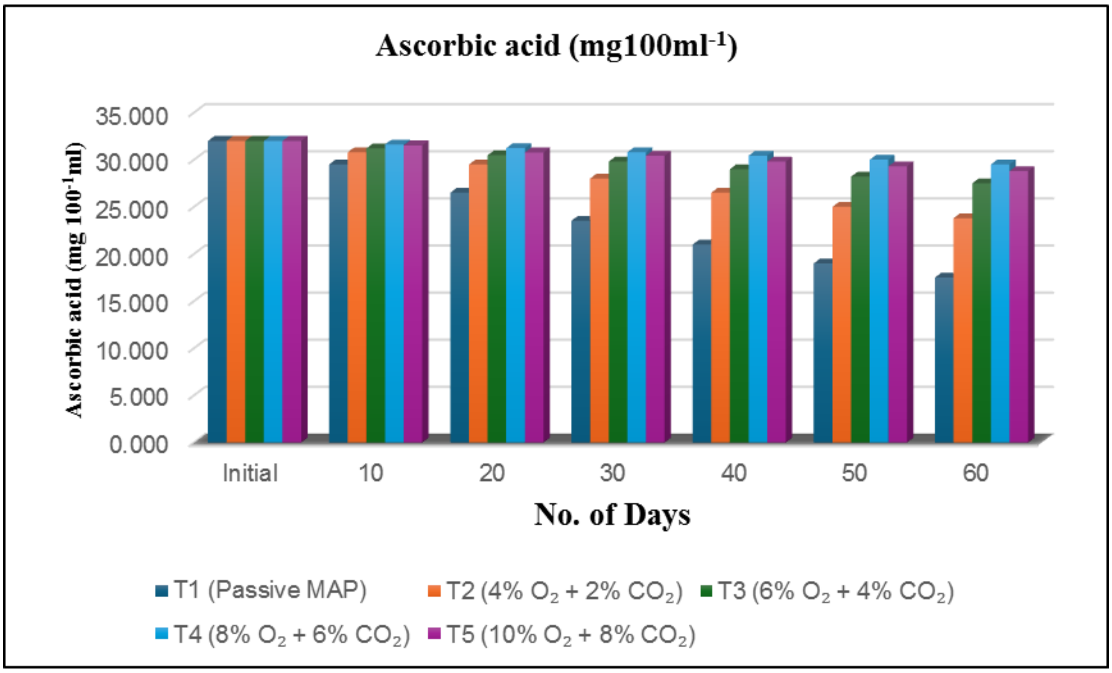

Fig. 7: Effect of active modified atmosphere package on ascorbic acid content of Indi lime fruits under low temperature storage (10±2°C)

Table 9. Effect of active modified atmosphere package on Total Antioxidant (mg AAE $100ml^{-1}$) content of Indi lime fruits under low temperature storage (10±2°C)

Total Antioxidant (mg AAE $100ml^{-1}$)							
Treatments	Initial	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS
T_1 (Passive MAP)	75.100	72.500^d	70.000^d	66.500^d	61.000^e	55.000^d	48.000^e
T_2 (4% O_2 + 2% CO_2)	75.100	72.000^e	69.500^c	66.000^e	61.500^d	55.000^d	48.500^d
T_3 (6% O_2 + 4% CO_2)	75.100	73.500^c	72.000^e	70.500^c	68.000^c	64.500^c	60.000^c
T_4 (8% O_2 + 6% CO_2)	75.100	74.200^a	73.500^a	72.000^a	71.000^a	69.500^a	67.000^a
T_5 (10% O_2 + 8% CO_2)	75.100	74.000^b	72.975^b	71.500^b	70.000^b	68.000^b	65.000^b
Mean	75.100	73.240	71.595	69.300	66.300	62.400	57.700
S. Em±	--	0.048	0.053	0.041	0.075	0.080	0.093
CD @ 5%	--	0.146	0.159	0.123	0.227	0.240	0.281
CD @ 1%	--	0.201	0.220	0.170	0.314	0.332	0.388
F-test	--	**	**	**	**	**	**

* Significant at 5% level   * * Significant at 1% level   NS: Non significance
DAS: Days after storage

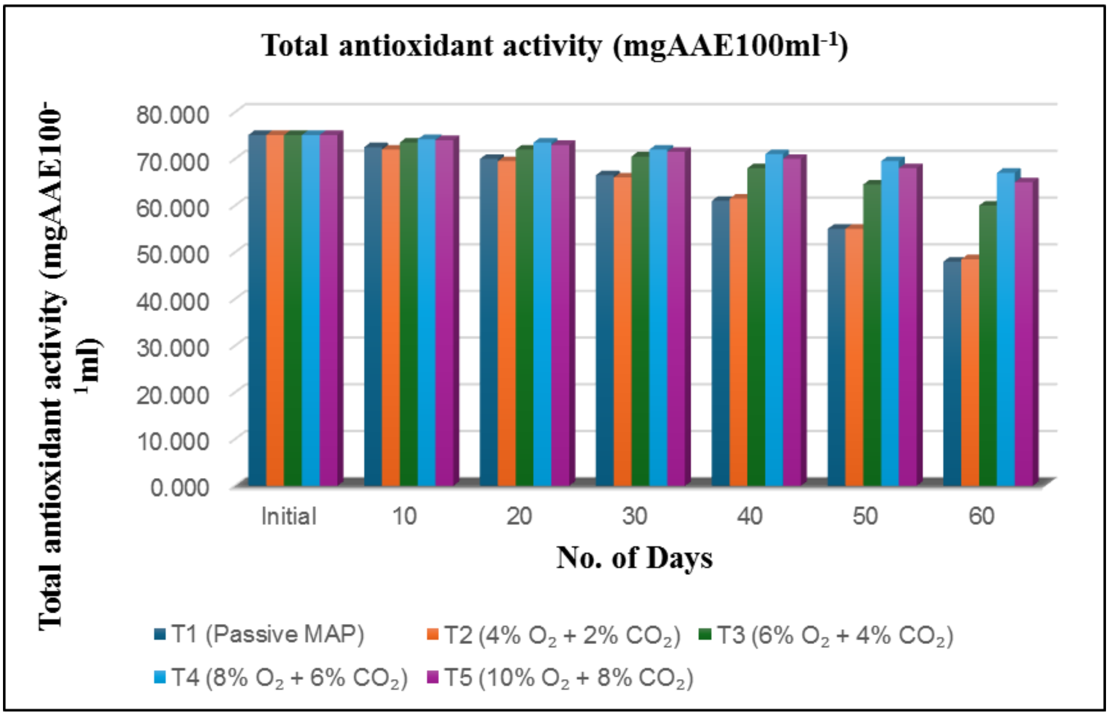

Fig. 8: Effect of active modified atmosphere package on Total antioxidant activity of Indi lime fruits under low temperature storage (10±2

Table 10. Effect of active modified atmosphere package on storage life(10±2ºC) and shelf life at ambient condition (25±5 ºC) of Indi lime fruits

Treatments	Storage life (Days) at low temperature (10±2ºC)	Shelf life (Days) at ambient conditions (25±5 ºC)						
		0 DAS	10 DAS	20 DAS	30 DAS	40 DAS	50 DAS	60 DAS
T_1 (Passive MAP)	30	7	7	6	6	3	2	1
T_2 (4% O_2 + 2% CO_2)	40	7	7	6	6.5	5	2.5	2
T_3 (6% O_2 + 4% CO_2)	40	7	7	6	6.5	5	2.5	2
T_4 (8% O_2 + 6% CO_2)	60	7	7	6	6.5	5	4	3
T_5 (10% O_2 + 8% CO_2)	60	7	7	6	6.5	5	4	3
Mean	46	7	7	6	6.4	4.6	3	2.2

DAS: Days after storage