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Impact of Packaging Materials on the Shelf Life and Fruit Quality of Acid Lime (*Citrus aurantifolia* Swingle) under Ambient Storage Conditions

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ABSTRACT: Acid lime (*Citrus aurantifolia Swingle)* is a widely consumed citrus fruit, but its shelf life is limited. Therefore, an investigation was aimed to evaluate the efficacy of different packaging materials *viz*., Gunny bags, Nylon net bags, HDPE (High-density polyethylene), LDPE-film (Low-density polyethylene) and open crates on storage life and fruit quality of acid lime fruits (*Citrus aurantifolia* Swingle). The packed fruits were kept under ambient storage conditions up to 40 days. The fruits were analyzed at 5 days interval and assessed for different quality parameters. The results indicate variability among the different packaging treatments for physiological loss in weight, juice content, firmness, fruit decay percentage, total soluble solids (TSS), titratable acidity (TA), pH, Brix/acid ratio and organoleptic attributes. Among all packaging treatments, HDPE film with perforation was the most effective in maintaining various fruit quality parameters such as TSS, TA, pH, Brix/acid ratio, physiological loss in weight, juice content, firmness, least fruit decay percentage and better sensory attributes, upto 40 days in ambient storage.

Keywords: Post harvest, HDPE, Shelf life, Acid lime, Ambient storage.

INTRODUCTION

Acid lime is a citrus fruit belonging to the Rutaceae family. It's botanically called as *Citrus aurantifolia* Swingle. It has several vernacular names like Kagzi lime, 'Neebu or Nimbu' in Hindi and 'limbe hannu' in Kannada. This acid lime variety holds significant importance as a source of vitamin C and acetic acid. India ranks fifth in the global lime production with an area of 316 (000 Ha), yielding an annual production of 3628 (000 MT) metric tonnes (MT) with a productivity of 11.48 MT/Ha (Anon, 2021).

Karnataka ranks 5th in production of acid lime with 2.83 lakh tonnes accounting to 12,150 ha area. Nevertheless, they are also cultivated in Andhra Pradesh, Maharashtra, Tamil Nadu and Gujarat. Similar to many other fruits, lime fruits are perishable in nature (Jadhav *et al*., 2020). The peak arrival of acid lime fruits in markets typically occurs during the months of June - August and lean season March- May. During peak period, post-harvest losses could be significant, ranging from approximately 30 to 30.5 per cent (Jadhao *et al*., 2007; Ladaniya, 2004).

During the peak season, an oversupply of lime fruits leads to the market glut, resulting in unfavorable prices for producers, often leading to low prices (referred to as "throwaway prices"). Conversely, during the lean season, consumers may experience higher prices. Furthermore, the challenge arises of efficiently handling the surplus fruits, which can result in significant losses due to insufficient processing capabilities and a lack of post-harvest infrastructure facilities. Studies conducted on other citrus fruits provide insights that suggest lime fruits can also be preserved for extended periods in excellent condition by employing various packaging materials and techniques.

Post-harvest losses in fruits and vegetables are notably high in tropical conditions. One significant post-harvest issue in tropical regions is shriveling of citrus fruit, resulting from moisture loss when the fruits are exposed to high ambient temperatures and low relative humidity (Bantayehu *et al*., 2017). This leads to deteoration in appearance of the fruit, ultimately reducing its market appeal. Hence, for developing countries like India, implementing straightforward and cost-effective post-harvest practices such as employing diverse packaging materials significantly improve the outlook for reducing post-harvest losses in citrus fruits. In places where refrigeration and storage facilities are not available, packaging plays an important role to increasing storage life of fresh fruits (Gidagiri *et al*., 2020).

Storing fruits in polymeric films creates modified atmospheric conditions around the produce inside the package allowing lower degree of control of gases and can interplay with physiological processes of commodity resulting in reduced rate of respiration, transpiration and other metabolic processes of fruits (Zagory and Kader 1988). The present investigation was conducted to study the effect of different packaging materials on storage life and quality of acid lime fruits *cv.* Kagzi under ambient storage conditions.

MATERIALS AND METHODS

Fruits. Acid lime fruit were harvested at colour breaking stage (parrot green) from selected healthy trees at Horticultural Research and Extension Centre Tidagundi, Vijayapura (latitude of 160 49′ North and longitude 750 43′ East). The fruits were randomly harvested around the tree canopy with the help of clipper. Following the harvest, the fruits were transported to the Postharvest laboratory of Department of Post Harvest Technology, College of Horticulture, Bagalkot, UHS, Bagalkot. Uniform size and blemish-free fruit were selected and washed with Sodium hypochlorite 4% @ 2.5 ml L^{-1} and allowed to dry overnight to remove the excess surface moisture. The fruits were harvested from different trees but grown in the same block of orchard were used for investigation.

Packaging. To conduct the experiment 1 kg fruits were packed in each packaging materials. Different packaging materials were used *viz*., T_1- Gunny bags, T_2-Nylon net bags, T_3- HDPE (High density polyethylene), T_4-LDPE (Low density polyethylene) film and T_5-open crates. Open crates were treated as a control. To facilitate ventilation, holes were made in each side of LDPE and HDPE-films. Packed and the control fruits were stored at ambient conditions. Following parameters were recorded at 5 days storage interval, Physiological loss in weight, juice content, TSS (Total soluble solids), pH, titratable acidity (TA), Brix/acid ratio, firmness, fruit decay and sensory evaluations were assessed. Whilst these quality parameters were also assessed from the freshly harvested fruits to represent zero-day of ambient storage conditions. The experiments were carried out in completely randomized design, included four replications and five treatments. Each treatment included 1 kg fruits.

Estimation of TSS (Total soluble solids), pH, Titratable acidity, Brix/acid ratio of lime fruits. TSS (Total soluble solids): Total soluble solids of lime fruit juice extract was determined by using digital refractometer. The lime juice extracted by lime squeezer was used for measuring total soluble solids. The results were expressed as Degree Brix (Ranganna, 1986).

Titratable acidity: A known quantity of lime extract was titrated against 0.1 N NaOH solution using phenolphthalein indicators. 5 ml of lime juice extract was pippeted to volumetric flask and volume was made up to 100 ml with distilled water. After that 5 ml aliquot was titrated against 0.1 N sodium hydroxide (NaOH) solution using 3-4 drops of phenolphthalein indicator. End point of titration was appearance of light pink colour (Ranganna, 1997). The results were expressed as per cent anhydrous citric acid

$$\text{Titratable acidity (\%)} = \frac{\text{Titre value} \times \text{N of NaOH} \times \text{Vol. made up} \times \text{Eq. weight of acid}}{\text{Vol. of aliquot} \times \text{Vol. of sample taken} \times 1000} \times 100$$

pH: The pH of lime juice was measured by using digital pH meter at room temperature (Jackson, 1973).

Brix /acid ratio: The Brix/acid ratio was determined by taking ratio of total soluble solids to titratable acidity (Srivastava and Kumar, 2002) and calculated by using formula

$$\text{Brix / acid ratio} = \frac{\text{Total soluble solids}}{\text{Titratable acidity}}$$

Estimation of Physiological loss in weight, Juice contents, Firmness, and Fruit decay percentage:

Physiological loss in weight: The PLW of lime fruits calculated by percentage change between the initial weight and subsequent weights was determined, as described by El-Gioushy *et al*. (2022)

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

Juice Contents: The extracted juice of random fruit samples of each replicate was weighed and juice content was expressed as percent of fruit weight (w/w) (Zagzog and Mohsen 2012).

$$\text{Juice percentage (\%)} = \frac{\text{Weight of juice}}{\text{Fruit weight}} \times 100$$

Firmness: Fruit firmness was determined using texture analyzer (TAXT Plus Texture Analyser, Make: Stable Micro System, Model: Texture Export Version 1.22) by penetration test. The acid lime fruits were penetrated by using cylindrical 2 mm probe by programmed setting (Zhou and Li 2007).

Type of probe : Penetration probe
Test speed : 5.0 mm/s
Post test speed : 10.0 mm/s
Distance : 40 mm

Firmness was defined as maximum force (kg) required during test, which was expressed in Newton (N).

Fruit decay percentage: It was determined as percentage of decayed fruits, from the total fruits of each replication and each treatment (Zagzog and Mohsen 2012)

$$\text{Fruit decay percentage (\%)} = \frac{\text{Number of decayed fruits}}{\text{Total number of fruits taken}} \times 100$$

Sensory evaluation of lime fruits: Sensory evaluation of lime fruits was carried out by semi trained panelists consists of teachers and PG students of post-harvest management department, COH, Bagalkot. The sensory characteristics like peel colour, flavour, firmness, over all acceptability of fruits were evaluated, on a 5 point hedonic scale.

Statistical analysis. The data in respect of all the above parameters were tabulated and subjected to the statistical analysis using WASP software for Completely Randomized Design with critical difference (CD at 1%) was worked out.

RESULT AND DISCUSSION

TSS (Total soluble solids), pH, Titratable acidity, Brix/acid ratio of lime fruits. The data represented in Table 1 pertains to the TSS content of stored lime fruits. It is revealed that the TSS levels in these fruits exhibited a consistent upward trend as the storage duration progressed. Specifically, the mean TSS content increased from 7 to 7.58°B (Initial to 40 days of storage). At the end of storage period, the highest TSS content was obtained in treatment T_5 (Open crates) registered 7.74°B. In contrast, the treatment T_3 (HDPE) exhibited the lowest TSS content at 7.44 ˚B, followed by T_4 (LDPE) at 7.53°B.

Generally, there is an upward trend in the total soluble solids (TSS) content as the storage duration advances, as shown in Table 1. This trend may be attributed to the formation of mono and disaccharides from starch, which is subsequently utilized in the respiration and ripening processes of the fruits. The use of HDPE (T_3) packaging for lime fruits results in a slower rate of increase in TSS content, primarily because it reduces gas exchange with the external environment during storage. This, in turn, slows down catabolic reactions such as ripening and transpiration, ultimately extending the shelf life of acid lime fruits. These results align with similar findings on peach fruit by Sihag *et al*. (2005), custard apple by Tuwar and Ugreja (1999); Kinnow by Mahajan *et al*. (2005).

Titratable acidity: The data related the titratable acidity of lime fruits, which was affected by various packaging materials, has been presented in a Table 2.

On the 5th day of storage, the titratable acidity of lime fruits showed no significant changes. However, as the storage duration continued under ambient conditions, there were statistically variations observed among the different packaging materials. Over the course of the storage duration, the mean titratable acidity of the fruits decreased from an initial to 40 days of storage (7.56 to 5.95 %). At the end of the storage period, it was noted that treatment T_3 (HDPE) maintained the statistically highest titratable acidity of 6.22 per cent, followed by T_4 (LDPE) (6.11 %). Conversely, treatment T_5 (Open crates) exhibited the lowest titratable acidity at 5.63 per cent.

This reduction in acidity with prolonged storage can be attributed to the converting organic acids into sugars, a process associated with respiration (Wills *et al*., 1989). Corroborating results have been observed in reports where acidity (TA) of fruits total decreased under extended storage conditions (Bisen *et al*., 2012). HDPE (T_3) packaging materials exhibit the least reduction in titratable acidity in ambient conditions. HDPE is an effective barrier to gaseous exchange, significantly slowing down biochemical processes during storage. Thereby it extends the shelf life of acid lime fruits.

pH: The data illustrate that with respect to pH of the lime fruits presented in Table 3. This showed significantly different during the storage. Investigation demonstrates that different packaging materials have an impact on the consistently changing pH of lime fruits. From beginning to 40 DAS, the fruits mean pH increased in a trend from 1.98 to 2.55. At the end of the storage period T_3 (2.43) and T_4 (2.51) showed the least variation.

The increasing trend of pH is mainly due to reduction in acid content of fruits. Organic acids were used in the metabolic processes like respiration and ripening of the fruits. The lower pH observed in HDPE packaged fruits might be due to the delay in fruit deterioration processes, as suggested by Rajkumar *et al*. (2005). Additionally, the delay in the conversion of acids into sugars leads to the retention of higher acidity. These results were consistent with the findings of Gautam and Chundawat (1989), as observed in sapota fruit.

Brix/acid ratio. The data referring to the Brix/acid ratio as affected by various packaging materials had significant statistical variation during storage period is depicted in Table 4.

The Brix/acid ratio of lime fruits did not shown significant changes on the 5th day of storage. Further as storage period progressed it varies significantly. The mean Brix/acid ratio of the lime fruits displayed a rising trend, increasing from 1 to 1.28.

At the end of the storage period, statistically, the highest Brix/acid ratio in lime fruits was obtained in treatment (Open crates) T_5, *i.e.* 1.40. In contrast, the lowest Brix/acid ratio was found in treatment (HDPE) T_3, *i.e.* 1.20, this was on par with treatment T_4 (LDPE) with ratio of 1.23.

Typically, as the storage duration advances, the Brix/acid ratio tends to increase. This increase is primarily due to the rise in total soluble solids (TSS) and the decrease in acidity levels in the fruits as they continue to be stored. HDPE (T_3) packaging demonstrated significantly lower Brix/acid ratio, measuring 1.20 in ambient storage conditions. In contrast, open crates exhibited the highest Brix/acid ratio. This suggests that HDPE effectively regulated physiological processes such as transpiration and respiration, consequently reducing the conversion of organic acids into sugars.

Physiological loss in weight (PLW), Juice contents, Firmness and Fruit decay percentage:

Physiological loss in weight (PLW): The mean PLW increased from 0 to 34.09 per cent during the storage from initial to the end of storage under ambient storage. It is also clear from data PLW of open crate fruits (T_5) was highest in ambient storage (42.69 %) after 40 DAS and lowest in treatment T_3 *i.e.*, HDPE (ambient storage-27.38 %). This least loss of PLW in HDPE might be due to reduction of the transpiration and respiration rate by changing the gas composition in atmosphere of package. Similar findings were reported by Yadav *et al.* (2010) in mango, Chaudhary and Kumbhare (1979) in sweet orange.

Juice contents (%): The lowest juice content is observed in fruits that were stored in open crates (T_5). This could be attributed to direct exposure of the fruits to environment, which allows for increased transpiration and gaseous exchange, ultimately resulting in greater weight loss. The maximum juice retention obtained in treatment T_3 (HDPE) *i.e.* 36.11 per cent at 40 DAS under ambient storage (Table 6). The HDPE package reduces the transpiration and respiration due to modified atmosphere created in package which might also acts as a physical barrier for transpiration (Singh *et al*., 2018; Chaudhary and Kumbhare (1979).

Firmness (N). The firmness of the lime fruits exhibited a consistent and gradual increase from 26.30 to 31.07 N throughout the storage period, ranging from the initial to 40thDAS.

At the end of storage duration, it was observed that treatment T_5 (Open crates) recorded the highest firmness measurement at 33.94 N, followed by T_2 at 30.83 N. Conversely, the treatment T_3 (HDPE) had the lowest firmness at 29.97 N, followed by T_4 at 30.24 N, and T_1 at 30.38 N.

During ambient storage condition firmness of lime fruits increases despite of the treatments (Table 7). However, HDPE and LDPE packages reported slow rate of increasing in firmness of the fruits. Increase in fruit firmness observed in the present study could be due to a biophysical process which results in textural changes of the peel tissues that made the fruit hard and tough. The water loss in HDPE and LDPE is less results into slower rate of firmness increasing (Champa *et al*., 2020).

Fruit decay percentage: The incidence of fruit decay initially did not report any significant changes up to the first 30 days of the storage period. However, as the storage duration progressed, significant differences in fruit decay were recorded among the various treatments.

The mean percentage of fruit decay varied between 0.3 to 27 per cent from the 20th to 40th day of the storage duration. At the final stage of the storage period, statistically, the highest percentage of fruit decay was recorded in T_5 (Open crates) *i.e.* 40 per cent and this was on par with T_2 (35 %). Conversely, the lowest percentage of fruit decay was reported in T_3 (HDPE) *i.e.* 15 per cent and this was on par with T_4 (LDPE), which recorded a decay percentage of 16.30 per cent (Table 8). The highest fruit decay observed in open crates might be due to the more exposure of the fruits to the external environment leads to more loss of moisture content and fruits become hard (Zhao *et al*., 2022).

Sensory evaluation of lime fruits. The assessment of sensory attributes in fruits is a crucial tool for determining consumer acceptability. In this current study, semi-trained panelists were tasked with evaluating various sensory qualities, including color and appearance, firmness, juice flavor, and overall acceptability. Fruits with organoleptic scores exceeding 3.00 were regarded as the most acceptable by the panelists. This approach helps in identifying fruits that meet the desired sensory criteria and are likely to be well-received by consumers.

Colour and appearance. The sensory score for color and appearance indicated a decline in quality over the course of 40 days under ambient storage conditions (Table 9). The mean organoleptic evaluation scores for color and appearance ranged from 4.76 on the 5th day to 2.78 on the 40th day.

At the end of the storage the highest scores were consistently observed in T_3 (3.40) followed by T_4 (3.27) under ambient storage. In contrast least score observed in (open crtaes) T_5(1.07). This might be due to HDPE packages retard the ripening process and retain the acceptable fruit colour (Nasrin *et al*., 2023).

Flavour. The mean sensory evaluation scores for flavor exhibited a range of values from 4.69 on the 5th day to 2.52 on the 40th day after the storage period commenced (Table 10). Over the end of the storage period, treatment T_3 (HDPE) received the highest sensory score for flavor, with a score of 2.96, which was statistically significant. Following T_3, treatment T_4 received a score of 2.76 respectively. In contrast, treatment T_5 (Open crates) had the lowest sensory score for flavor of 1.94. This decline in flavor value might be due to increase ripening as the storage period progressed which leads to fruits enter the senescence phase and reduction in organic acid content in fruit (Nasrin *et al*., 2023).

Firmness: Firmness score of lime fruits considerably affected by different packaging materials under ambient condition and displayed in Table 11.

The average firmness score demonstrated a decline over the course of the storage period, starting at 4.65 and decreasing to 2.95. At the end of the storage period, treatment T_3 (HDPE) received the better acceptable firmness score, with a score of 3.23, and this was statistically significant. On the other hand, treatment T_5 (Open crates) received the lowest firmness score of 2.69. HDPE packaging materials played a vital role in preventing direct evapo-transpiration, reducing physiological loss in weight, and helping to maintain turgidity, higher firmness, and freshness. These findings similar with research conducted by Sonkar and Ladaniya (1999); Ladaniya and Singh (2001), emphasizing the importance of packaging materials in preserving fruit firmness during storage.

Overall acceptability: The sensory score for overall acceptability indicated a trend towards decline (Table 12). From the start of storage until the end of it, the average sensory score for overall acceptability ranges from 4.70 to 2.75. After 40 days of storage, the treatment T_3 had the statistically highest score recorded (3.19); it was on par with treatment T_4 (3.03), T_1 (2.89) and T_2 (2.73); T_5 had the lowest score (1.90) for overall acceptability of lime fruits. The highest overall acceptability score observed for the HDPE packaged lime fruits. Overall acceptability score mainly depends on all other sensory scores like colour and appearance, flavour and firmness which maintained better in the treatment T_3 (HDPE packaged fruits) (Nasrin *et al*., 2023).

Table 1: Effect of packaging materials on total soluble solids of acid lime fruits stored at ambient storage.

Treatments	Total soluble solids (°B)							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	7.20^{a}	7.28^{ab}	7.32^{abc}	7.36^{bc}	7.41^{ab}	7.49^{ab}	7.53^{b}	7.59^{bc}
T_2	7.23^{a}	7.30^{ab}	7.35^{ab}	7.39^{ab}	7.43^{ab}	7.52^{ab}	7.54^{b}	7.61^{b}
T_3	7.15^{a}	7.19^{c}	7.24^{c}	7.27^{d}	7.32^{b}	7.36^{c}	7.39^{c}	7.44^{d}
T_4	7.18^{a}	7.25^{b}	7.29^{bc}	7.33^{c}	7.38^{ab}	7.46^{b}	7.50^{b}	7.53^{c}
T_5	7.27^{a}	7.34^{a}	7.37^{a}	7.43^{a}	7.49^{a}	7.56^{a}	7.6^{3a}	7.74^{a}
Mean	**7.21**	**7.27**	**7.31**	**7.36**	**7.41**	**7.48**	**7.52**	**7.58**
S. Em±	0.04	0.02	0.02	0.02	0.03	0.02	0.02	0.02
CD at 1%	NS	0.06	0.08	0.05	0.11	0.08	0.05	0.07
Initial value: 7.00								

Table 2: Effect of packaging materials on titratable acidity of acid lime fruits stored at ambient storage.

Treatments	Titratable acidity (%)							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	7.19^{a}	7.06^{a}	6.78^{c}	6.57^{c}	6.43^{bc}	6.29^{c}	6.05^{b}	5.93^{b}
T_2	7.15^{a}	6.90^{b}	6.75^{c}	6.53^{c}	6.40^{bc}	6.25c	5.97^{bc}	5.87^{b}
T_4	7.27^{a}	7.13^{a}	6.98^{b}	6.81^{b}	6.70^{ab}	6.58^{b}	6.30^{a}	6.22^{b}
T_3	7.20^{a}	7.04^{a}	6.83^{a}	6.69^{a}	6.55^{a}	6.41^{a}	6.27^{a}	6.11^{a}
T_5	7.33^{a}	6.83^{b}	6.68^{d}	6.50^{c}	6.35^{c}	6.22^{a}	5.84^{c}	5.63^{c}
Mean	**7.23**	**6.99**	**6.80**	**6.62**	**6.49**	**6.35**	**6.09**	**5.95**
S. Em±	0.08	0.03	0.02	0.02	0.04	0.02	0.05	0.02
CD at 1%	NS	0.13	0.05	0.07	0.16	0.07	0.20	0.08
Initial value:7.56								

Similar alphabets within the column represent non-significant differences at ($p<0.01$).
Treatments: T_1- Gunny bag T_3- HDPE bag T_5- Open crates; T_2- Nylon Net bags T_4- LDPE Bags

Table 3. Effect of packaging materials on pH of acid lime fruits stored at ambient storage.

Treatments	pH							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	2.07^{bc}	2.18^{bc}	2.24^{bc}	2.32^{bc}	2.37^{bc}	2.43^{bc}	2.50^{b}	2.56^{b}
T_2	2.19^{a}	2.23^{ab}	2.27^{ab}	2.36^{ab}	2.43^{ab}	2.47^{b}	2.54^{b}	2.59^{b}
T_3	2.03^{cc}	2.10^{c}	2.18^{c}	2.25^{d}	2.26^{d}	2.33^{d}	2.38^{d}	2.43^{d}
T_4	2.02^{c}	2.14^{bc}	2.20^{c}	2.28^{cd}	2.34^{c}	2.39^{c}	2.45^{c}	2.50^{c}
T_5	2.14^{ab}	2.33^{a}	2.31^{a}	2.39^{a}	2.47^{a}	2.56^{a}	2.62^{a}	2.69^{a}
Mean	**2.09**	**2.19**	**2.24**	**2.32**	**2.37**	**2.44**	**2.50**	**2.55**
S. Em±	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
CD at 1%	0.08	0.11	0.07	0.07	0.07	0.06	0.05	0.06
Initial value:1.98								

Table 4: Effect of packaging materials on Brix/Acid ratio of acid lime fruits stored at ambient storage.

Treatments	Brix /Acid ratio (%)							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	1.00^{a}	1.04^{b}	1.08^{abc}	1.12^{ab}	1.15^{ab}	1.19^{b}	1.25^{bc}	1.28^{bc}
T_2	1.01^{a}	1.06^{ab}	1.09^{ab}	1.13^{ab}	1.16^{ab}	1.20^{ab}	1.26^{b}	1.30^{b}
T_3	0.98^{a}	1.01^{b}	1.04^{b}	1.07^{c}	1.09^{c}	1.12^{c}	1.17^{d}	1.20^{d}
T_4	1.00^{a}	1.03^{b}	1.07^{bc}	1.10^{bc}	1.13^{bc}	1.16^{bc}	1.20^{cd}	1.23^{cd}
T_5	1.02^{a}	1.10^{a}	1.13^{a}	1.17^{a}	1.21^{a}	1.24^{a}	1.33^{a}	1.40^{a}
Mean	**1.00**	**1.05**	**1.08**	**1.12**	**1.15**	**1.18**	**1.24**	**1.28**
S. Em±	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
CD at 1%	NS	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Initial value: 0.92								

Similar alphabets within the column represent non-significant differences at ($p<0.01$).
Treatments: T_1- Gunny bag T_3- HDPE bag T_5- Open crates; T_2- Nylon Net bags T_4- LDPE Bags

Table 5: Effect of packaging materials on physiological loss in weight of acid lime fruits stored at ambient storage.

Treatments	Physiological loss in weight (%)							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	7.44^{c}	11.75^{c}	15.75^{c}	19.35^{c}	23.25^{c}	27.35^{c}	31.60^{c}	34.25^{c}
T_2	8.20^{b}	13.44^{b}	17.56^{b}	22.00^{b}	25.85^{b}	30.25^{b}	34.24^{b}	38.25^{b}
T_3	5.76^{d}	8.25^{e}	11.08^{e}	13.93^{e}	17.95^{d}	20.96^{e}	24.18^{d}	27.38^{d}
T_4	6.04^{d}	8.84^{d}	12.36^{d}	15.05^{d}	18.25^{d}	21.75^{d}	24.38^{d}	27.88^{d}
T_5	9.50^{a}	14.65^{a}	19.48^{a}	24.75^{a}	27.99^{a}	32.50^{a}	36.65^{a}	42.69^{a}
Mean	7.39	11.39	15.25	19.02	22.66	26.56	30.21	34.09
S. Em±	0.09	0.14	0.23	0.17	0.19	0.11	0.15	0.16
CD at 1%	0.40	0.58	0.94	0.70	0.81	0.47	0.65	0.66

Table 6: Effect of packaging materials on juice per cent of acid lime fruits stored at ambient storage.

Treatments	Juice per cent (%)							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	49.26^{ab}	47.29^{ab}	46.11^{a}	45.20^{a}	42.72^{ab}	39.80^{bc}	36.39^{ab}	31.62^{bc}
T_2	49.10^{ab}	46.41^{b}	44.62^{b}	44.45^{ab}	41.32^{b}	38.52^{bc}	33.50^{b}	30.32^{c}
T_3	50.14^{a}	48.82^{a}	47.31^{a}	45.52^{a}	44.76^{a}	42.63^{a}	39.52^{a}	36.11^{a}
T_4	49.83^{a}	48.00^{ab}	47.04^{a}	46.00^{a}	44.45^{a}	40.64^{ab}	37.16^{ab}	34.41^{ab}
T_5	48.40^{b}	46.78^{ab}	43.76^{b}	43.46^{b}	41.50^{b}	37.60^{c}	33.91^{b}	29.29^{c}
Mean	**49.34**	**47.46**	**45.76**	**44.93**	**42.95**	**39.84**	**36.10**	**32.35**
S. Em±	0.31	0.47	0.39	0.39	0.49	0.57	1.06	0.75
CD at 1%	NS	NS	1.64	1.60	2.05	2.93	4.42	3.14
Initial value: 52								

Similar alphabets within the column represent non-significant differences at ($p<0.01$).
Treatments: T_1- Gunny bag T_3- HDPE bag T_5- Open crates; T_2- Nylon Net bags T_4- LDPE Bags

Table 7: Effect of packaging materials on firmness of acid lime fruits stored at ambient storage.

Treatments	Firmness (N)							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	26.35^{b}	27.70^{a}	28.25^{c}	28.53^{c}	29.04^{c}	29.51^{c}	29.93^{c}	30.38^{c}
T_2	26.38^{b}	27.77^{a}	28.51^{b}	28.99^{b}	29.29^{b}	29.89^{b}	30.26^{b}	30.83^{b}
T_3	26.33^{b}	27.38^{c}	27.91^{e}	28.32^{d}	28.71^{d}	29.03^{e}	29.53^{e}	29.97^{e}
T_4	26.31^{b}	27.55^{b}	28.06^{d}	28.46^{c}	28.94^{c}	29.24^{d}	29.78^{d}	30.24^{d}
T_5	26.47^{a}	27.83^{a}	28.94^{a}	29.69^{a}	30.05^{a}	30.76^{a}	31.98^{a}	33.94^{a}
Mean	**26.37**	**27.64**	**28.33**	**28.80**	**29.21**	**29.68**	**30.29**	**31.07**
S. Em±	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.02
CD at 1%	0.07	0.13	0.07	0.08	0.12	0.09	0.06	0.08
Initial: 26.30								

Table 8: Effect of packaging materials on fruit decay percentage of acid lime fruits stored at ambient storage.

Treatments	Fruit decay (%)				
	Days after storage				
	20	25	30	35	40
T_1	0.0	2.5^{a}	6.3^{ab}	26.3^{ab}	28.8^{b}
T_2	0.0	2.5^{a}	6.3^{ab}	21.3^{b}	35.0^{a}
T_3	0.0	0.0	3.8^{b}	7.5^{c}	15.0^{c}
T_4	0.0	0.0	6.3^{ab}	8.8^{c}	16.3^{c}
T_5	1.3^{a}	5.0^{a}	11.3^{a}	31.3^{a}	40.0^{a}
Mean	**0.3**	**2.0**	**6.8**	**19.0**	**27.0**
S. Em±	0.6	1.6	1.6	1.3	1.2
CD at 1%	NS	NS	NS	5.3	5.0

Similar alphabets within the column represent non-significant differences at ($p<0.01$).
Treatments: T_1- Gunny bag ; T_2- Nylon Net bags ; T_3- HDPE bag ; T_4- LDPE Bags; T_5- Open crates

Table 9: Effect of packaging materials on fruit colour and appearance of acid lime fruits stored at ambient storage (5-point hedonic scale).

Treatments	Colour/ appearance							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	4.74^c	4.40^c	4.27^c	4.14^c	4.00^c	3.66^c	3.32^c	3.16^a
T_2	4.63^d	4.27^d	4.12^d	4.00^d	3.83^d	3.52^d	3.14^d	2.99^a
T_3	5.00^a	4.81^a	4.56^a	4.41^a	4.26^a	3.95^a	3.64^a	3.40^a
T_4	4.90^b	4.67^b	4.36^b	4.23^b	4.13^b	3.81^b	3.48^b	3.27^a
T_5	4.53^e	4.18^d	3.99^e	3.79^e	3.64^e	3.29^e	2.81^e	1.07^b
Mean	4.76	4.46	4.26	4.11	3.97	3.65	3.28	2.78
S. Em±	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.28
CD at 1%	0.07	0.13	0.07	0.05	0.08	0.05	0.13	1.16

Table 10: Effect of packaging materials on fruit flavour of acid lime fruits stored at ambient storage (5-point hedonic scale).

Treatments	Flavour							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	4.67^b	4.48^c	4.18^c	3.97^c	3.72^e	3.35^c	3.00^c	2.61^c
T_2	4.58^c	4.30^d	4.03^d	3.80^d	3.63^c	3.26^c	2.83^d	2.32^d
T_3	4.95^a	4.70^a	4.52^a	4.25^a	3.97^a	3.77^a	3.61^a	2.96^a
T_4	4.75^b	4.58^b	4.27^b	4.14^b	3.83^b	3.57^b	3.25^b	2.76^b
T_5	4.50^c	4.18^e	3.96^e	3.64^e	3.53^d	3.16^d	2.66^e	1.94^e
Mean	4.69	4.45	4.19	3.96	3.74	3.42	3.07	2.52
S. Em±	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04
CD at 1%	0.10	0.09	0.06	0.07	0.09	0.09	0.14	0.14

Similar alphabets within the column represent non-significant differences at ($p<0.01$).
Treatments: T_1- Gunny bag; T_2- Nylon Net bags; T_3- HDPE bag; T_4- LDPE Bags; T_5- Open crates

Table 11: Effect of packaging materials on firmness of acid lime fruits stored at ambient storage (5-point hedonic scale).

Treatments	Firmness							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	4.63^{ab}	4.30^c	4.18^c	4.07^c	3.93^c	3.70^c	3.48^c	2.89^{bc}
T_2	4.47^b	4.21^d	4.04^d	3.91^d	3.69^d	3.47^d	3.35^d	2.87^{bc}
T_3	4.95^a	4.65^a	4.45^a	4.35^a	4.22^a	4.12^a	3.95^a	3.23^a
T_4	4.88^a	4.44^b	4.31^b	4.15^b	4.01^b	3.84^b	3.75^b	3.06^{ab}
T_5	4.33^b	4.09^e	3.97^d	3.83^e	3.53^e	3.27^e	2.89^e	2.69^c
Mean	4.65	4.34	4.19	4.06	3.88	3.68	3.48	2.95
S. Em±	0.08	0.02	0.02	0.02	0.02	0.02	0.03	0.05
CD at 1%	0.35	0.06	0.07	0.07	0.06	0.05	0.12	0.20

Table 12: Effect of packaging materials on overall acceptability of acid lime fruits stored at ambient storage (5-point hedonic scale).

Treatments	Overall acceptability							
	Days after storage							
	5	10	15	20	25	30	35	40
T_1	4.68^c	4.39^c	4.21^c	4.06^c	3.88^c	3.57^c	3.26^c	2.89^{ab}
T_2	4.56^d	4.26^d	4.06^d	3.90^d	3.72^d	3.42^d	3.08^d	2.73^b
T_3	4.97a	4.72^a	4.51^a	4.34^a	4.15^a	3.95^a	3.73^a	3.19^a
T_4	4.84^b	4.56^b	4.32^b	4.18^b	3.99^b	3.74^b	3.49^b	3.03^{ab}
T_5	4.45d	4.15^e	3.96^e	3.75^e	3.57^e	3.24^c	2.78^e	1.90^c
Mean	4.70	4.42	4.21	4.05	3.86	3.58	3.27	2.75
S. Em±	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.09
CD at 1%	0.12	0.05	0.05	0.08	0.05	0.10	0.08	0.38

Similar alphabets within the column represent non-significant differences at ($p<0.01$).
Treatments: T_1- Gunny bag; T_2- Nylon Net bags; T_3- HDPE bag; T_4- LDPE Bags; T_5- Open crates

CONCLUSIONS

HDPE packaging films significantly reduced physiological loss in weight reported least fruit decay percent, TSS, Brix/acid ratio and pH, maintain the better firmness and retained the significantly highest content of titratable acidity, juice and better sensory attributes in ambient stored acid lime fruit up to 40 days.

FUTURE SCOPE

— Large scale trials involving the best treatments of the present experiments can be tried to confirm the results. Combined effect of post harvest treatments on shelf life of acid lime fruits at different stages of maturity can be tried.

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