Research Article

Effect of Antimicrobial Compound (Chlorine & Silver) Grafted Zeolite-LDPE Composite Bags Packaging On the Physical Properties of Sapota Fruits

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Abstract

In this study, antimicrobial compounds grafted zeolite-LDPE composite bags were used as a novel packaging material for extend the shelf life of sapota (*Manilkaraachras*, Family: Sapotaceae) fruits. Effect of antimicrobial compounds synergized zeolite-LDPE composite bags on the physico-chemical parameters of *M. achras* fruits during cold storage was investigated. As compared to sapota fruits packed in corrugated fiber board (CFB) boxes along with antimicrobial compounds synergized zeolite-LDPE composite bags and commercially used corrugated fiber board (CFB) boxes, sapota fruits packed in corrugated fiber board (CFB) boxes along with antimicrobial compounds synergized zeolite-LDPE composite bags showed significantly lower physiological loss in weight, disease score and higher colour (*L**, chroma and hue-angle) values for pulp, firmness and more shelf-life. Our results suggested antimicrobial compounds synergized zeolite-LDPE composite bags packaging could increase the shelf-life of *M. achras*, which in turn maintained the postharvest quality of sapota fruits.

Keywords: Zeolite, *Manilkaraachras*, LDPE (Low Density Poly Ethylene), Days after storage (DAS)

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Introduction

The sapota (*Manilkaraachras*) is highly delicious, nutritive fruit valued for its mellow and sweet pulp with granular texture and pleasant aroma. It is native of southern parts of Mexico and now it has been adopted in many countries of tropical and subtropical climate. The fruit is a fleshy berry, ellipsoidal, conical, or oval and contains one or two shiny black seeds. It weighs about 70-300 g, has a dull brown color and thin skin with yellowish, light brown or red pulp. The fruit is commonly known as chikku in India and mainly cultivated for its fruit value; while in some countries like Southeast Mexico, Guatemala, it is commercially grown for the production of chuckle that is coagulated milky latex obtained from the bark of sapota tree [1]. The chuckle is used as the principal ingredient of chewing gum. India is the leading producer of sapota in the world with an annual production of 350.33 thousand metric tons [2]. The popularity of the crop is increasing due to high production per unit area and continuous fruiting throughout the year.

From nutritional point of view, sapota is the cheapest source of sugars. Every 100 g of sapota flesh contains 73.7 % water, 1.1 % fat, 0.7 % protein, 21.4 g carbohydrate, 28 mg calcium, 27 mg phosphorus, 2 mg iron and 6 mg ascorbic acid [6]. Sapota, when fully ripe, is delicious and is eaten as dessert fruit. It is also made into sherbet and halwa[26]. The dried sapota pieces could be made into edible powder and the powder could be utilized for making milk shake and sweets (burfi) [12].

As sapota fruits classified under extremely high ethylene producers, they are highly perishable in nature, ripe quickly, lose moisture rapidly, spoiled faster and achieve senescence rapidly after harvest [27].The level of ethylene production in sapota fruits increased slowly from the beginning of ripening and reached its peak at 144 hours, which was followed by a decline [25].

Ethylene is a gaseous plant hormone that plays a major role in the regulation of the metabolism of harvested horticultural crops at very low concentrations [32]. The post-harvest life of both climacteric and non-climacteric fruits can be influenced by ethylene. This hormone affects their quality attributes, the development of physiological disorders and post-harvest diseases [10]. Effects of ethylene on quality attributes *viz.*, external appearance, texture, flavour and nutritive value of fruits have been extensively reported [10]. Any closed environment such as truck trailer, shipping container, warehouses, cold rooms and consumer size package results in increase in concentration of ethylene. Therefore, the need to control ethylene activity to extend the post-harvest life of fruits through improvement in packaging, introducing anti-ethylene substances like zeolite is greater than ever.

Zeolite is a large and diverse class of volcanic aluminosilicate crystalline material which has many useful applications [16]. The use of zeolite as an adsorbent has started in 1930s followed by Milton, who used zeolite for air purification [13]. Zeolite is a nanoporous crystalline alumina silicate having trihedral and tetrahedral structure. It contains large vacant spaces or cages in its structure that provide space for adsorption of cations or large molecules such as water and ethylene [16]. It has a rigid, three dimensional crystalline structure consisting of a network of interconnected channels and cages. Water moves freely in and out of these pores, but the zeolite framework remains rigid [13]. Moreover, the incorporation of antimicrobial compounds into zeolite-LDPE composite bags can further improve the physical, mechanical and biological properties of the bag[19].

Among inorganic antimicrobial agents, chlorine and silver compounds could highly inhibit microbial growth and show strong biocidal effects on many species of bacteria including *Escherichia coli* [17,19 and 31]. The interaction of chlorine and silver ions with microbial cytoplasmic components and nucleic acids can inhibit the respiratory chain enzymes and interferes with the membrane permeability, limiting the development of bacteria, fungi and yeast [24]. In this study, the effect of antimicrobial compounds synergized zeolite-LDPE composite bags packaging on the postharvest quality of *M. achras* fruits was evaluated for the first time.

Materials and Methods

Materials and treatments

Sapota fruits (cv. Kalipatti) of uniform size and shape, free from any visible damage, scratches and decay were selectively harvested manually at right maturity stage and brought to the laboratory. Then, the plastic crates containing fruits were placed in the cold room for pre-cooling by room cooling method at 13^{o}C for 12 hours. Then fruits were packed in antimicrobial compounds synergized zeolite-LDPE composite bags*viz.,* Silver-zeolite-LDPE composite bag (T_1), Zeolite-LDPE composite bag (T_2), Chlorine-zeolite-LDPE composite bag (T_3), Silver-zeolite-LDPE composite bag + CFB box (T_4), Zeolite-LDPE composite bag + CFB box (T_5), Chlorine-zeolite-LDPE composite bag + CFB box (T_6), Commercially used CFB (T_7) and Control (without any package) (T_8)@ 6 fruits/treatment and stored under refrigerated (13°C) conditions.

Preparation of antimicrobial compounds synergized zeolite-LDPE composite bags

In the production of the composite bags, finely ground natural zeolite was combined with commercial polyethylene. Polyethylene was purchased from the market (Mumbai, Maharashtra) as polyethylene beads. Zeolite (Na_2O. Al_2O_2. $2SiO_2$. $5H_2O$) was received from Asian Pacific zeolite molecular sieve market region in an unprocessed form. The zeolite mineral was in the form of large pieces about 20 x 18 x 8 cm in dimension as received from the region. These were crushed in a hammer mill (Laboratory Mill Model 4, Arthur H. Thomas Company, USA). Chlorine and silver powders was received from Kudaim Industries, Goa. Polyethylene beads were dissolved in a solvent and zeolite and antimicrobial compounds were added to this solution. The solvent used was xylene as it is the most suitable for polyethylene. Polyethylene in the form of beeds was put into xylene in 1:10 ratio and the mixture was kept at 75°C for 1 hour while mixing the solution intermittently. Upon obtaining a homogeneous solution, the solution was divided into three groups. First group solution was added with silver and zeolite powder @ 1 part of polyethylene, second group was added with chlorinr and zeolite powder @ 1 part of polyethylene and third group was added with only zeolite powder @ 1 part of polyethylene. Then the mixture formed was poured as a thin film in a petri dish and dried in a hot air oven at 80°C until all xylene evaporated leaving a thick and brittle film as a residue. Finally, the obtained film was cut into very small pieces, i.e., 0.02 m x 0.05 m rectangular strips, placed between heat stable and non-sticking papers and hot pressed at 130°C for 5 min to obtain the sheet. Then the sheets were carved into bags by sealing the ends.

Then fruits were packed in those bags. Each pack of fruits was kept undisturbed until the scheduled date of observation. Thus, there were so many numbers of packs under each treatment as the number of times the fruits were observed at scheduled interval. Sapota fruits were observed for 8 times for each treatment. There were 8 packs each containing 6 fruits for each treatment. All the fruit-packs removed from storage condition on scheduled day of observation were used to record different observations. Thus, each pack in the storage condition passed through the storage time undisturbed until it was finally taken out to observe for different parameters.

Physiological loss in weight (%)

The sapota fruits in each treatment were weighed at the beginning of storage and recorded as initial weight. On the subsequent dates of observation during storage, the hands were weighed and the weight was recorded as final weight on each date of observation. The cumulative loss in weight of fruits was calculated and expressed as per cent

physiological loss in weight using the formula given below.

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

Colour value of pulp (L*, chroma and hue-angle)

Colour of the fruit peel was measured using Colour Flex EZ colorimeter (Model: CFEZ 1919, Hunter associates laboratory. Inc., Reston) fitted with 45 mm diameter aperture. The instrument was calibrated using black and white tiles provided. Colour was expressed in terms of *L** (lightness/darkness), chroma or saturation(*C**) is the relation of a colour to a neutral gray of the same lightness. Hue-angle is the index or purity of the colour and it shows the brightness of fruits.

Firmness (Newtons)

Fruit firmness was determined with TAXT Plus Texture Analyzer (Make: Stable Micro System, Model: Texture Export Version 1.22). The force with the samples got pierced was recorded in the graph and the peak force value in the graph was taken as the firmness value in terms of Newton force (N). The following instrument settings were used during the experiment.

Type of probe used	: Piercing probe
Test option	: Return to start
Test speed	: 5.0 mm/s
Post-test speed	: 10.0 mm/s
Distance	: 50mm
Load cell	: 5kg

Disease score (%)

Disease occurrence on fruits was scored by visual inspection of fruits during storage. For the disease sore, damage caused by fungi or bacteria was considered based on the scale mentioned below. Finally, disease scoring was calculated with the following formula.

$$\text{Disease score(\%)} = \frac{\text{Sum of all disease rating}}{\text{Total number of rating} \times \text{Maximum disease grade}} \times 100$$

Disease scale:

0. No lesions
1. 5% to < 15% lesions
2. 15 to < 25% lesions
3. 25 to < 50% lesions
4. 50 to < 75% lesions
5. 75 to 100% lesions

Shelf life (days)

The number of shelf life days was decided based on physiological loss in weight (PLW). A PLW of 10% was considered as the upper limit for determination of shelf life.

Experimental design and data analysis

The first experiment was carried out with 3 replicate fruits and the experiment was repeated 3 times and pooled data was subjected to statistical analysis. Fruits were arranged in Complete Randomised Design. The second experiment was carried out for 3 replicate fruits and repeated 3 times. Randomly selected 8 fruits were taken to analyse physiological loss in weight, colour value of pulp (*L**, chroma and hue-angle), firmness, disease score and shelf life and all the experiments were repeated 3 times. The data of experiment was analyzed as applicable to completely randomized design (CRD). Statistical analyses of experiments were performed using Web Agri Stat Package (WASP)

Version 2. The level of significance used in 'F' and 't' was p=0.01 and also p=0.05 for some parameters. Critical difference values were calculated whenever F-test was found significant.

Results and Discussion

Physiological loss in weight (PLW) (%)

The most abundant constituent of sapota fruits is water. Ripening increases the water concentration of pulp from 69 to 80% in sapota[30]. Fruits continuously lose moisture through transpiration and evaporation thus accounts for loss of weight during storage [28]. Stover and Simmonds (1987) reported that climacteric fruits lose weight due to respiration and transpiration by which the fruits lose water and cause the weight loss. Respiration causes a weight reduction because a carbon atom is lost from the fruit each time a carbon-dioxide molecule is produced from an absorbed oxygen molecule and evolved into atmosphere. The loss in weight of produce owing to physiological processes is known as physiological loss in weight (PLW).

As seen from mean of PLW on the day observed, physiological loss in weight (%) of sapota fruits increased (1.46% at 3 DAS to 17.67 % at 21 DAS) with the increase in duration of storage (**Table 1**). The differences among the treatments on each observed day were found to be statistically significant. Minimum PLW was noted in T_6 packaging treatment throughout the storage (3 DAS-0.98%; 6 DAS-1.23%; 9 DAS-2.81%; 12 DAS-5.30%; 15 DAS-7.03%; 18 DAS-10.42% and 21 DAS-12.05%). However, it was non-significantly followed by T_4 and T_5. Significantly maximum PLW was seen in T_8 at 3, 6, 9, 12, 15, 18 and 21 DAS (2.04%, 4.47%, 8.59%, 13.03%, 16.12%, 18.41% and 23.96% respectively). The treatment T_8 was at parity with the treatment T_7 at 3, 12, 15 and 21 DAS and also with T_2 only at 12 DAS.

Table 1 Effect of antimicrobial compounds synergized zeolite-LDPE composite bags on physiological loss in weight (PLW) (%) of sapota fruits under refrigerated condition (13°C)

Treatments	Physiological loss in weight (PLW) (%)							
	3 DAS	6 DAS	9 DAS	12 DAS	15 DAS	18 DAS	21 DAS	Mean
T_1	1.49^{cd}	3.87^{ab}	4.85^{bc}	8.98^{bc}	11.18^{bc}	14.68^{bc}	17.90^{bcd}	8.99
T_2	1.66^{bc}	2.09^{bc}	6.07^{b}	10.21^{ab}	11.91^{bc}	16.11^{b}	19.58^{bc}	9.66
T_3	1.41^{cd}	3.82^{ab}	4.64^{bcd}	8.86^{bc}	10.78^{bc}	14.34^{bc}	17.52^{cd}	8.76
T_4	1.07^{e}	1.49^{c}	3.09^{cd}	6.49^{cd}	8.55^{cd}	12.10^{de}	13.25^{e}	6.57
T_5	1.25^{de}	3.62^{ab}	4.38^{bcd}	8.52^{bcd}	10.15^{cd}	12.93^{cd}	15.47^{de}	8.04
T_6	0.98^{e}	1.23^{c}	2.81^{d}	5.30^{d}	7.03^{d}	10.42^{e}	12.05^{e}	5.68
T_7	1.83^{ab}	2.26^{bc}	6.38^{b}	11.37^{ab}	14.00^{ab}	16.28^{b}	21.64^{ab}	10.53
T_8	2.04^{a}	4.47^{a}	8.59^{a}	13.03^{a}	16.12^{a}	18.41^{a}	23.96^{a}	12.37
Mean	1.46	2.85	5.10	9.09	11.21	14.40	17.67	
S.Em±	0.08	0.61	0.67	1.11	1.15	0.67	1.30	
CD@1%	0.39	2.52	2.79	4.61	4.76	2.79	5.39	

*DAS- Days After Storage

According to [22] respiration and transpiration by which the fruit losses water and cause the weight loss are advanced by the gases like ethylene and oxygen that raise breathing (respiration). Zeolite has the property to adsorb gases like ethylene and oxygen from the storage environment [16]. In this study, packages involving antimicrobial compounds synergized zeolite-LDPE bags (T_1 to T_6) therefore probably fruit respiration and transpiration was retarded resulting in minimum weight loss. However, antimicrobial compounds synergized zeolite-LDPE variant packages combined with CFB boxes (T_4, T_5, T_6) exhibited better performance over their counterparts without the combination of CFB (T_1, T_2, T_3). The humid microclimate created within CFB in T_4, T_5 and T_6 might have reduced the drive for removal of moisture from the fruits. Similarly, [1] recorded minimum physiological loss in weight in Dwarf Cavendish fruits packed in ventilated polyethylene bag along with $KMnO_4$ up to 18 days of storage. Physiological loss in weight increased considerably in all the treatments with progress of storage period but control bananas recorded higher PLW percentage throughout the storage period.

Colour value of pulp (L, chroma and hue-angle)*

Flesh colour of sapota fruits changes from pale yellow or pale pink to orange or dark brown colour upon repining [20]. Orange colour is due to the synthesis of carotenoids and brown colour is due to synthesis of phenols during ripening (Casas Alencaster, 1977). In this present study, instrumental colour values (*L**, Chroma and Hue-angle) of sapota pulp gradually decreased during storage under both ambient and refrigerated (13°C)

conditions (Table 2, 3 and 4). This might be due to browning of pulp associated with the high concentrations of phenols in ripe fruits [31].

Instrumental colour *L** values of sapota fruit pulp revealed significant differences at 3 DAS to 15 DAS, but they showed no significant differences among the treatments during storage period of 18 and 21 DAS (**Table 2**). Significantly maximum *L** value was observed in T_6 at 3, 6, 9, 12 and 15 days of storage (70.4, 69.9, 61.7, 57.8 and 53.9 respectively) and remained on par with all other treatments at 18 and 21 DAS (49.8 and 45.6). However, the treatment T_6 was on par with T_1, T_3, T_4 and T_5 at 3 DAS, with T_4 and T_5 at 6 and 15 DAS and only with T_4 at 12 DAS. On the other hand, minimum *L** value was seen in T_8 at 3, 6, 9, 12, 15 18 and 21 days after storage (64.5, 59.4, 49.1, 47.0, 43.3, 38.0 and 37.4 respectively). Nevertheless, the treatment T_8 had statistical similarity only with T_7 at 3, 6, 9, 12 and 15 DAS.

Table 2 Effect of antimicrobial compounds synergized zeolite-LDPE composite bags on *L** colour value of pulp of sapota fruits under refrigerated condition (13°C)

Treatments	*L** value							
	3 DAS	6 DAS	9 DAS	12 DAS	15 DAS	18 DAS	21 DAS	Mean
Initial	70.4							
T_1	70.4^{a}	63.4^{bc}	55.0^{bcd}	51.5^{bc}	47.0^{bcd}	42.8	39.8	52.84
T_2	68.7^{ab}	61.1^{c}	53.8^{cde}	49.3^{cd}	45.8^{cd}	40.5	38.9	51.15
T_3	70.4^{a}	63.7^{bc}	55.3^{a}	51.7^{bc}	47.2^{bcd}	42.6	39.2	52.87
T_4	70.4^{a}	67.6^{ab}	59.2^{ab}	55.2^{ab}	51.7^{ab}	46.2	43.3	56.22
T_5	70.4^{a}	65.0^{abc}	57.8^{abc}	53.9^{b}	49.4^{abc}	44.9	41.5	54.70
T_6	70.4^{a}	69.9^{a}	61.7^{a}	57.8^{a}	53.9^{a}	49.8	45.6	58.44
T_7	66.3^{bc}	59.8^{c}	51.4^{de}	47.3^{d}	43.5^{d}	38.3	37.8	49.20
T_8	64.5^{c}	59.4^{c}	49.1^{e}	47.0^{d}	43.3^{d}	38.0	37.4	48.38
Mean	68.93	63.73	55.41	51.71	47.72	42.88	40.43	
S.Em±	1.03	1.98	1.60	1.25	1.80	2.28	1.25	
CD@1%	4.29	5.96	6.63	5.19	7.44	NS	NS	

*DAS- Days After Storage

Instrumental colour chroma values of sapota fruit pulp revealed significant differences at 3 DAS to 15 DAS, but they showed non-significant differences among the treatments at 18 and 21 DAS (**Table 3**). Significantly maximum chroma value was observed in T_6 at 3, 6, 9, 12, 15, 18 and 21 DAS (44.2, 43.9, 41.9, 38.6, 35.5, 32.1 and 27.8 respectively). However, the treatment T_6 was on par with T_4 at 3 and 6 DAS, and with T_3 and T_4 at 9, 12 and 15 DAS. On the other hand, significantly minimum chroma value was seen in T_8 at 3, 6, 9, 12 and 15 days of storage (37.4, 33.5, 31.8, 26.3, 23.5, 20.6 and 16.1 respectively). The treatment T_8 had statistical similarity with T_7 at 3 DAS, with T_1, T_2 and T_7 at 9 DAS, with T_1, T_2, T_3 and T_7 12 DAS, and with T_2 and T_7 at15 DAS.

Instrumental hue angle values of sapota fruit pulp revealed significant at 3, 6, 12, 18 and 21 DAS, but non-significant differences among the treatments at 9 and 15 DAS (**Table 4**). Significantly maximum hue angle value was observed in T_6 at 3, 6, 12, 18 and 21 days of storage (57.6, 53.9, 49.1, 42.5 and 39.1 respectively). However, the treatment T_6 was on par with T_4 and T_5 at 3, 6 and 12 DAS, with T_1, T_3, T_4 and T_5 at 18 DAS, and with T_3, T_4 and T_5 at 21 DAS. Maximum hue angle value recorded in T_6 at 9 and 15 DAS (50.8 and 47.0) had no significant difference with other treatments in the study.On the other hand, significantly minimum hue angle value throughout the storage was seen in T_8 (3 DAS-47.0, 6 DAS-43.3, 9 DAS-38.0, 12 DAS-33.8, 15 DAS-31.5, 18 DAS-28.3, 21 DAS-24.0). The treatment T_8 had statistical similarity with T_1, T_2, T_3 and T_7 at 3, 6 and 18 DAS, only with T_7 at 12 and 21 DAS.

Comparatively higher *L**, chroma and hue-angle colour values in fruits packed in antimicrobial compounds synergized zeolite-LDPE bags (T_1 to T_6) could be reasoned to ethylene adsorbing capacity of zeolite. Porous zeolite is effective in adsorbing ethylene thereby reducing carotenoids and phenols synthesis in fruits [16]. Hence, the presence of higher ethylene around fruits in T_7 and T_8 and reduced presence of ethylene around fruits in antimicrobial compounds synergized zeolite-LDPE bags could be responsible for lower and higher *L**, chroma and hue-angle value in those treatments respectively. Additional modification of atmosphere caused by CFB in T_4, T_5 and T_6 might have contributed to higher *L**, chroma and hue-angle value in comparison to those antimicrobial compounds synergized zeolite-LDPE variants without CFB boxes (T_1, T_2 and T_3). The antimicrobial effect of silver in T_4 and chlorine in T_6 might be the reason for still higher *L**, chroma and hue-angle value as microbial contribution to enhancing ethylene in the package is minimized.

Table 3 Effect of antimicrobial compounds synergized zeolite-LDPE composite bags on chroma colour value of pulp of sapota fruits under refrigerated condition (13°C)

Treatments	Chroma							
	3 DAS	6 DAS	9 DAS	12 DAS	15 DAS	18 DAS	21 DAS	Mean
Initial	44.2							
T_1	39.2^{cd}	39.4^{c}	37.1^{cde}	32.1^{abcd}	29.6^{bcd}	26.4	23.5	32.47
T_2	38.9^{cd}	37.0^{d}	35.2^{def}	30.6^{bcd}	27.1^{cde}	24.5	21.9	30.74
T_3	39.8^{c}	39.7^{c}	37.8^{bcd}	32.5^{abcd}	29.9^{bcd}	26.8	24.7	33.02
T_4	43.3^{a}	43.1^{a}	41.6^{ab}	36.2^{ab}	33.4^{ab}	30.2	26.6	36.34
T_5	41.5^{b}	41.2^{b}	39.4^{abc}	34.4^{abc}	31.8^{abc}	28.7	25.4	34.62
T_6	44.2^{a}	43.9^{a}	41.9^{a}	38.6^{a}	35.5^{a}	32.1	27.8	37.71
T_7	37.8^{de}	35.8^{d}	33.5^{ef}	28.9^{cd}	25.9^{de}	22.4	20.6	29.27
T_8	37.4^{e}	33.5^{e}	31.8^{f}	26.3^{d}	23.5^{e}	20.6	16.1	27.02
Mean	40.26	39.20	37.28	32.45	29.58	26.46	23.32	
S.Em±	0.55	0.40	1.32	2.31	1.76	3.06	2.80	
CD@1%	2.28	1.68	5.46	6.95	7.30	NS	NS	

*DAS- Days After Storage

Table 4 Effect of antimicrobial compounds synergized zeolite-LDPE composite bags on hue angle colour value of pulp of sapota fruits under refrigerated condition (13°C)

Treatments	Hue angle							
	3 DAS	6 DAS	9 DAS	12 DAS	15 DAS	18 DAS	21 DAS	Mean
Initial	57.6							
T_1	51.5^{bcd}	47.0^{bcd}	44.8	42.0^{bc}	40.5	36.5^{abcd}	32.8^{bcd}	42.15
T_2	49.3^{cd}	45.8^{cd}	42.5	39.5^{cd}	36.2	33.2^{bcd}	29.6^{cde}	39.44
T_3	51.7^{bcd}	47.2^{bcd}	44.6	42.9^{bc}	40.9	36.7^{abcd}	33.7^{abc}	42.52
T_4	55.2^{ab}	51.7^{ab}	48.2	47.2^{a}	45.6	40.7^{ab}	37.8^{ab}	46.62
T_5	53.9^{abc}	49.4^{abc}	46.9	45.7^{ab}	43.8	38.8^{abc}	35.9^{ab}	44.91
T_6	57.6^{a}	53.9^{a}	50.8	49.1^{a}	47.0	42.5^{a}	39.1^{a}	48.57
T_7	47.3^{d}	43.5^{d}	40.3	36.2^{de}	33.9	30.1^{cd}	27.3^{de}	36.94
T_8	47.0^{d}	43.3^{d}	38.0	33.8^{e}	31.5	28.3^{d}	24.0^{e}	35.12
Mean	51.68	47.72	44.51	42.05	39.92	35.85	32.52	
S.Em±	1.93	1.59	3.37	1.35	3.51	2.97	2.07	
CD@5%	5.81	4.77	NS	4.05	NS	8.93	6.21	

*DAS- Days After Storage

Firmness (Newtons)

The fruit firmness is considered as one of the key quality attributes which limits the fruit shelf-life, especially in the case of climacteric fruits. Because when the fruits are suitable for consumption, they are very soft and this change in the firmness makes them very susceptible to mechanical damage and pathogen attack [8]. Fruit ripening is a highly coordinated, genetically programmed and an irreversible phenomenon involving a series of physiological, biochemical, and organoleptic changes that finally lead to the development of a soft edible ripe fruit [14].In the present study irrespective of the treatments, firmness (N) of fruits in this study decreased along the period of storage (**Table 5**). The steady reduction in fruit firmness during the storage period is a natural process of ripening of almost all fleshy fruits as a result of biochemical changes in the cellular structure [7]. Depletion of fruit firmness during ripening is apparently a result of the cell wall hydrolysis mechanism, which is related to increased activity of endogenous enzymes like pectinase and pectin methylesterase which break down pectin material, or the reduction of turgor pressure, which diminishes with loss of water or dehydration caused by tissue perspiration during storage [8]. Decreased turgor pressure of cells due to water loss has been suggested as a cause of tissue softening [5].

Thefirmness (N) of sapota fruits showed significant differences among the treatments during storage period (Table 5). Firmness (N) was found to decrease gradually along the period of storage of 21 days. This is witnessed by initial value (9.87 N) and means values recorded at 3, 6, 9, 12, 15, 18 and 21 DAS (8.99 N, 8.54 N, 8.35 N, 7.76 N, 7.19 N, 6.74 N and 5.28 N respectively). Maximum firmness was observed in T_6(3 DAS-9.50 N; 6 DAS-9.14 N; 9 DAS-8.93 N; 12 DAS-8.69 N; 15 DAS-7.82 N; 18 DAS-7.42 N and 21 DAS-5.91 N). However, the treatment T_6 was on par with T_4 and T_5 throughout the storage period except for 12 DAS where T_5 showed significant difference. The treatment T_8 showed significantly minimum firmness throughout the storage (3 DAS-8.45 N; 6

DAS-7.95 N; 9 DAS-7.77 N; 12 DAS-6.97 N; 15 DAS-6.30 N; 18 DAS-5.97 N and 21 DAS-4.42 N). The treatment T_8 showed non-significant difference with T_7 throughout the study period. The treatment T_1 also on par with T_8 only at 3 DAS.

Table 5 Effect of antimicrobial compounds synergized zeolite-LDPE composite bags on firmness (N) of sapota fruits under refrigerated condition (13°C)

Treatments	Firmness (N)							
	3 DAS	6 DAS	9 DAS	12 DAS	15 DAS	18 DAS	21 DAS	Mean
Initial	9.87							
T_1	9.02^{bcd}	8.52^{cd}	8.38^{bc}	7.55^{cd}	7.21^{ab}	6.72^{cd}	5.27^{cd}	7.52
T_2	8.69^{cd}	8.32^{de}	8.12^{cd}	7.33^{cde}	7.04^{cd}	6.55^{cd}	5.02^{de}	7.29
T_3	9.01^{bcd}	8.59^{bcd}	8.37^{bc}	7.73^{c}	7.29^{bc}	6.71^{cd}	5.46^{bc}	7.59
T_4	9.42^{ab}	8.92^{ab}	8.70^{ab}	8.43^{ab}	7.69^{ab}	7.29^{ab}	5.78^{ab}	8.03
T_5	9.26^{abc}	8.78^{abc}	8.58^{ab}	8.22^{b}	7.45^{abc}	6.93^{bc}	5.59^{abc}	7.83
T_6	9.50^{a}	9.14^{a}	8.93^{a}	8.69^{a}	7.82^{a}	7.42^{a}	5.91^{a}	8.20
T_7	8.61^{d}	8.11^{e}	7.97^{d}	7.16^{de}	6.72^{de}	6.38^{de}	4.80^{e}	7.10
T_8	8.45^{d}	7.95^{e}	7.77^{d}	6.97^{e}	6.30^{e}	5.97^{e}	4.42^{f}	6.83
Mean	8.99	8.54	8.35	7.76	7.19	6.74	5.28	
S.Em±	0.20	0.12	0.12	0.14	0.14	0.14	0.12	
CD@1%	0.84	0.51	0.52	0.59	0.60	0.58	0.49	

*DAS-Days After Storage

This could be due to the reduced weight loss resulting from reduced respiration or lower enzymatic activity as observed by [11] in banana fruits packaged along with ethylene scrubbers ($KMnO_4$). Significantly minimum firmness was observed in T_8 under refrigerated storage (banana-4.62 N and sapota-4.42 N at 21 DAS) condition. [24] reported that controlled atmosphere storage or modified atmosphere packaging inhibits the breakdown of pectin substances, which retains fruit texture and remains firmer for a longer period. These results are in conformity with the findings of [15] where they observed maximum firmness (7.48 kg/cm^2) in the banana fruits packed in polybag with $KMnO_4$ after 8 days of storage. Similarly, [9] reported that bananas packed along with $KMnO_4$ showed more delay in climacteric peak and more firmness (8.23 Kg/cm^2) compared to the fruits packed without $KMnO_4$.

Disease score (%)

Fruits lose quality after harvest due to environmental stress and pathogeninfection [18]. Lipid oxidation and microbial contamination are the primary variables that determine the loss of fruit quality and shelf life [23]. The existence of spoilage microorganisms in fruits and vegetables is the consequence of contamination of their surfaces; therefore contamination must be reduced by ensuring that fruit and vegetables are sanitized [21]. Blue mould, black mould and Internal rot is the main post harvest disease in sapota[4]. [29] emphasize the need for good hygiene in the plantation and the packaging shed to manage these diseases.

Sapota fruits showed significant differences among the treatments for disease scoring (%) during storage of 21 days (**Table 6**). The visual score for diseases increased with the increase in storage period. Sapota with no disease at the beginning were healthy up to 15 days; but showed an increase in score for disease from 18 DAS (32.12%) to 21 DAS (47.83%). The treatment T_6 witnessed significantly minimum disease score (18 DAS-11.19% and 21 DAS-24.29%). However, it had significant differences with rest of the treatments throughout the storage period. Significantly maximum score for diseases over all other treatments was obtained by T_8 both at 18 DAS (57.36%) and 21 DAS (78.67%).

Among inorganic antimicrobial agents, silver and chlorine could effectively inhibit microbial growth and show strong biocidal effects on many species of bacteria including *Escherichia coli* [17; 19 and 31]. The interaction of silver and chlorine ions with microbial cytoplasmic components and nucleic acids can inhibit the respiratory chain enzymes and interfere with the membrane permeability, limiting the development of bacteria, fungi and yeast [24]. In general, all variants of polybags performed better when combined with CFB boxes (T_4, T_5, T_6) than if they were employed alone (T_1, T_2, T_3). Additional modification of atmosphere caused by CFB in T_4, T_5 and T_6 might have caused less proliferation of diseases. Further between the two antimicrobial agents used in the package, chlorine appeared to be more effective than silver. Between T_3 (Chlorine zeolite-LDPE composite bag) and T_6 (Chlorine zeolite-LDPE composite bag+CFB), Chlorine is the most commonly used sanitizer due to its efficacy, cost-

effectiveness ratio and simple use [16]. Washing raw produce with water containing sodium hypochlorite (NaOCl) is the most commonly used method for removing pathogens from the surfaces of vegetables [3]. Thus minimum disease score was recorded in T_6 than in fruits without any package (T_8).

Table 6 Effect of zeolite-LDPE composite bags on disease score (%) and shelf life (days) of sapota fruits under refrigerated condition (13°C)

Treatments	Disease score (%)			Shelf life (days)
	18 DAS	21 DAS	Mean	
Initial	NIL			
T_1	26.85^{d}	39.17^{e}	33.01	13.33^{d}
T_2	39.37^{c}	55.91^{c}	47.64	11.66^{e}
T_3	22.00^{e}	37.48^{e}	29.74	13.66^{d}
T_4	14.70^{f}	31.25^{f}	22.97	16.00^{b}
T_5	36.68^{c}	46.51^{d}	41.59	14.66^{c}
T_6	11.19^{f}	24.29^{g}	17.74	17.66^{a}
T_7	48.81^{b}	69.38^{b}	59.09	11.33^{e}
T_8	57.36^{a}	78.67^{a}	68.01	9.66^{f}
Mean	32.12	47.83		13.49
S.Em±	1.56	1.33		0.30
CD@1%	6.47	5.52		1.28
*DAS-Days After St				

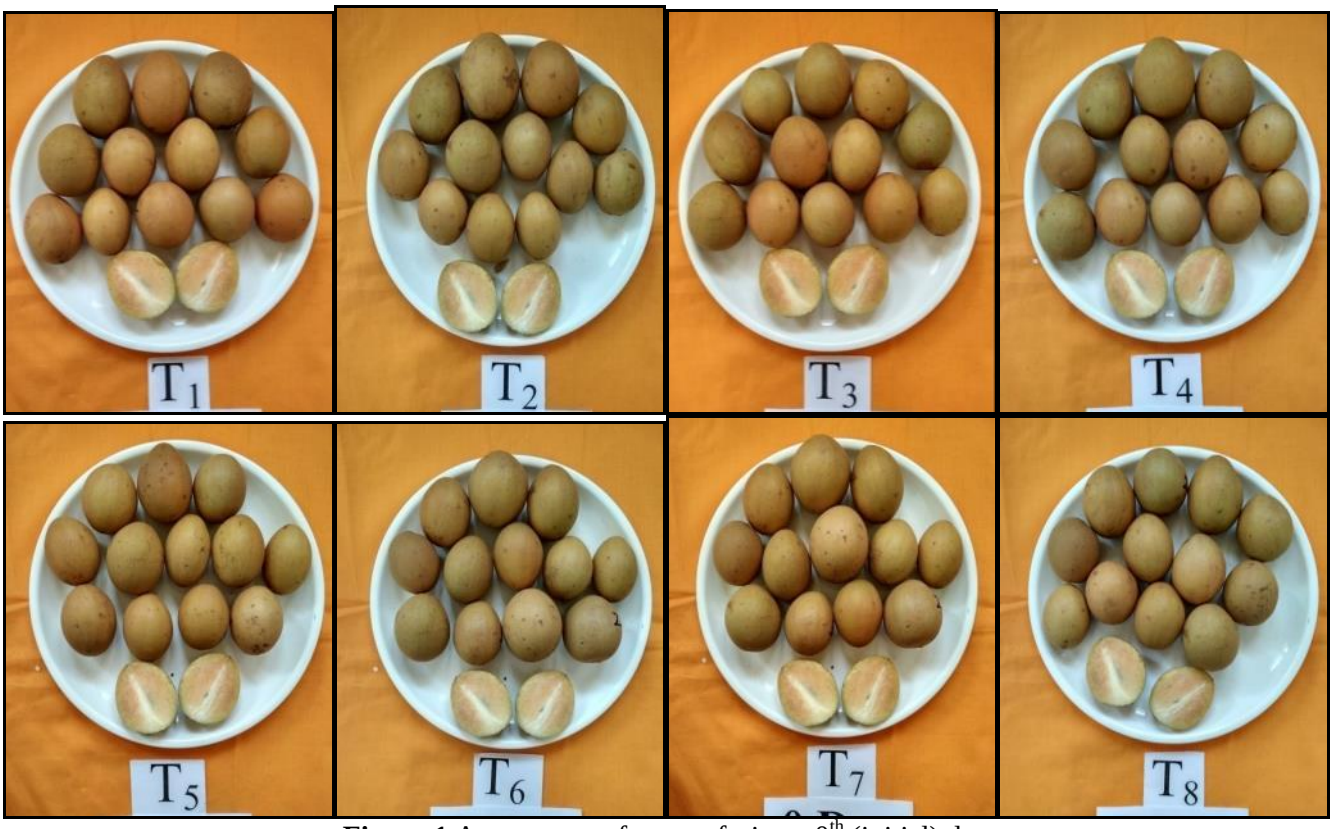

Figure 1 Appearance of sapota fruits at 0th (initial) day

Shelf –life (days)

The data on shelf life (days)of sapota fruits showed significant differences among the treatments during storage of 6 days(Table 6). Significantly maximum shelf life (days)was recorded in T_6 (17.66 days) (Fig. 1&2). It was however non-significant with T_1, T_2, T_3 and T_4. Significantly minimum shelf life (days) was recorded in T_8 (12.00 days) (Fig. 1&2). However, the treatment T_8 was on par with T_7 (9.66 days).

Figure 2 Appearance of sapota fruits at 21 days after storage as influenced by the packaging treatments

Sapota fruits exhibited significantly maximum shelf life of 17.66 days in the treatment T_6 (Chlorine-zeolite-LDPE composite bag + CFB) over all other treatments in the study (Fig. 1&2). The packaging yielded an extra shelf-life of 8 days over control (T_8) and 6.33 days over T_7. The treatment T_4 performed closer to T_6, but it differed significantly. The extra cost and energy involved in packaging has added more life to sapota fruits in T_6. Slow rate of ripening of sapota fruits in T_6 is documented in terms of slow reduction in fruit firmness, reduced respiration rate, physiological loss in weight and disease score. Realization of more shelf life in T_6 was mainly due to retarding ethylene effect on ripening process and due to effect of chlorine on post harvest decay. Beneficial micro-environment provided by CFB box in T_6 added cushioning benefit to support health and wholesomeness of sapota fruits.

Conclusion

Our results have shown that antimicrobial compounds synergized zeolite-LDPE composite bags packaging has a positive effect on maintaining the postharvest quality of *M. achras* fruits (Fig. 1&2). The preservation effect of antimicrobial compounds synergized zeolite-LDPE composite bags could be attributed to its intrinsic ethylene adsorbing property as well as antimicrobial property. Thus sapota fruits packaged with antimicrobial compounds synergized zeolite-LDPE composite bags showed lower physiological loss in weight, disease score and higher color (*L**, chromaand hue-angle) values for pulp, firmness and more shelf-life (Fig. 1&2). These indicated that antimicrobial compounds synergized zeolite-LDPE composite bags could be explored as a novel active packaging material for the postharvest storage of sapota fruits. In future, the preservation effect of antimicrobial compounds synergized zeolite-LDPE composite bags on other fruits can be also evaluated.

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