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Effect of Chlorine and Silver Grafted Zeolite-LDPE Composite Bags Packaging on the Postharvest Quality of Banana

Palli Venkata Santhosh Kumar*, S. L. Jagadeesh, Netravati and M. D. Jameel Jhalegar

College of Horticulture, University of Horticultural Sciences, Bagalkot, Karnataka, India

**Corresponding author*

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A B S T R A C T

In this study, zeolite-LDPE composite bags with or without infusion of antimicrobial compound (chlorine or silver) were employed as novel packaging materials. The influence of packaging innovation on physico-chemical parameters and shelf life of banana fruits under cold storage condition was investigated. Banana fruits first packed in antimicrobial compound synergized zeolite-LDPE composite bags and then placed in corrugated fiber board (CFB) box showed significantly lower physiological loss in weight, respiration rate, total soluble solids (TSS), disease score and higher titratable acidity, firmness and more shelf-life than the banana fruits packed in corrugated fiber board (CFB) box alone. Our results suggest that zeolite-LDPE composite bags synergized with antimicrobial compounds could maintained the postharvest quality and increase the shelf-life of banana fruits.

Introduction

Banana fruits are classified under extremely high ethylene producers; they are highly perishable in nature, ripe quickly, lose moisture rapidly, spoiled faster and achieve senescence speedily after harvest (Singh *et al.*, 2017). The level of ethylene production in banana fruits increases slowly from the beginning of ripening and reaches its peak at 144 hours, followed by a decline (Selvaraj and Pal, 1984).

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 (Zhang *et al.*, 2012). 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 (Ernst, 2011). Effects of ethylene on quality attributes *viz.*, external appearance, texture, flavour and nutritive value of fruits have been extensively reported (Saltveit, 1999; Ernst, 2011). 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 is greater than ever.

Zeolite is a large and diverse class of volcanic aluminosilicate crystalline material which has many useful applications (Khosravi *et al.*, 2015). The use of zeolite as an adsorbent has started in 1930s followed by Milton, who used zeolite for air purification (Kamarudin, 2006). 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 (Khosravi *et al.*, 2015). 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 (Kamarudin, 2006). Moreover, the incorporation of antimicrobial compounds into zeolite-LDPE composite bags can further improve the physical, mechanical and biological properties of the bag (Lee *et al.*, 2017).

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* (Kim *et al.*, 2007; Lee *et al.*, 2009 and Yang *et al.*, 2009). 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 (Russel and Hugo, 1994). In this study, the effect of antimicrobial compounds synergized zeolite-LDPE composite bags packaging on the postharvest quality of banana fruits was evaluated and recorded for the first time.

Materials and Methods

Materials and treatments

The present investigation was undertaken in the Department of Post Harvest Technology, University of Horticultural Sciences, Bagalkot, Karnataka, India during the year 2018-19. Banana fruits (cv. Grand Naine) of uniform size and shape, free from any visible damage, scratches and decay were selectively harvested manually from a commercial orchard at proper maturity stage.

The fruits were brought to the laboratory in plastic crates. Soon, 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 zeolite-LDPE composite bags with or without outer CFB box *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 (per bag) and stored under refrigerated (13±1°C, 85-90% RH) conditions. A thermostat of the walk-in cold room maintained the set temperature. Relative humidity in the storage chamber was maintained by with the help of a humidifier.

Physiological loss in weight (%)

The banana 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 fruits 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.

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

Respiration rate (ml CO_2 $kg^{-1}h^{-1}$)

The rate of respiration was measured by static head space method using gas analyzer (Make: PBI, DANSENSOR, and CHECKMATE 2) and expressed as ml $CO_2kg^{-1}h^{-1}$. To carry out this method, four banana fruits were trapped in 3000 ml airtight containers having twist-top lid fitted with a silicone rubber septum at the center of lid. The containers were kept for an hour for accumulation of respiratory gases at the head space. After specified time, the head space gas was sucked to the sensor of the analyzer through the hypodermic hollow needle and the displayed value of evolution of CO_2 concentration (%) was recorded. Further, the rate of respiration was calculated on the basis of amount of CO_2 evolved from the fruit per unit weight per unit time using the following formula.

$$\text{Rate of respiration } (CO_2/\text{kg/h}) = \frac{CO_2 \text{ concentration (\%)} \times \text{Head space}}{100 \times \text{weight of fruit (kg)} \times \text{Time (hr)}}$$

Total Soluble Solids (TSS) (°B)

The juice extracted by squeezing the homogenized fruit pulp through muslin cloth was used to measure the TSS. It was determined by using digital refractometer (Make: Hanna Instruments, Romania) replicated three times and the mean was expressed in °Brix.

Titratable acidity (%)

Five grams of homogenized pulp was made up to 100 ml and filtered through muslin cloth. Then, 10 ml of the filtrate was taken for titration against 0.1 N NaOH solution using phenolphthalein as an indicator. The appearance of light pink colour was considered as end point. The acidity was calculated and expressed as per cent malic acid.

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

Firmness (Newtons)

Fruit firmness was determined with TAXT Plus Texture Analyzer (Make: Stable Micro Systems, UK, 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

Experimental design and data analysis

The 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. Randomly selected 8 fruits were taken to analyse physiological loss in weight, respiration rate, colour value of pulp (*L**, chroma and hue-angle), Total Soluble Solids (TSS), titratable acidity, 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 (Jangan and Thali, 2010). 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) (%)

Mean of PLW (%) of banana fruits on each day of observation increased (0.35 to 20.67 %) consecutively with the increase in duration of storage (Table 1). The differences among the treatments on each day were found to be statistically significant. Minimum PLW was observed in T_6 packaging treatment throughout the storage (3 DAS-0.35%; 6 DAS-1.13%; 9 DAS-2.77%; 12 DAS-5.11%; 15 DAS-8.06%; 18 DAS-10.02% and 21 DAS-12.91%). However, it was non-significantly followed by T_4 and T_5. Significantly maximum PLW over all the treatments under study was seen in T_8 at 3, 6, 9, 12, 15, 18 and 21 DAS (1.84%, 3.43%, 5.16%, 10.12%, 15.58%, 18.82% and 20.67% respectively).

Respiration rate (ml CO_2 /Kg/hr)

Initial respiration rate of banana fruits used in the study was 96.7 ml CO_2 /Kg/hr. However, the mean values indicate an increase respiration rate up to 15 DAS (3 DAS-101.50; 6 DAS-114.38; 9 DAS-130.11; 12 DAS-149.01; 15 DAS- 197.28 ml CO_2 /Kg/hr) and a decrease in the rate later at 18 and 21 DAS (187.05; 167.78 ml CO_2 /Kg/hr) (Table 2). The data revealed significant differences with respect to respiration rate of banana during storage of 18 days, but showed non-significant differences at 21 DAS. In comparison to all other treatments, the rate of respiration was found to be minimum in the treatment T_6 throughout the storage (3 DAS-98.4; 6 DAS-104.5; 9 DAS-118.5; 12 DAS-126.8; 15 DAS-183.8; 18 DAS-180.1 and 21 DAS-156.1 ml CO_2 /Kg/hr). However, this treatment had non-significant differences with T_3, T_4 and T_5 on all days of observation. On the contrary, a higher rate of respiration was noticed in T_8 (control) (3 DAS-105.2; 6 DAS-114.6; 9 DAS-141.0; 12 DAS-167.7; 15 DAS-212.3; 18 DAS-194.8 and 21 DAS-189.8 ml CO_2 /Kg/hr) all along the storage duration. However, the treatment T_8 was on par with T_7 throughout the storage period.

Total soluble solids (TSS) (°B)

The data on TSS revealed non-significant differences among the treatments on each day of observation during the storage period of 21 days. The TSS content was found to increase gradually along the period of storage of 21 days (Table 3). Minimum TSS was found in T_6 at all the days of observation (3 DAS-6.23 °B; 6 DAS-8.31°B; 9 DAS-14.18°B; 12 DAS-16.78°B; 15 DAS-18.44°B; 18 DAS-19.97°B and 21 DAS-21.87°B). On the other hand, maximum TSS was observed in T_8 (Control) in all the 7 observations taken during the study (3 DAS-7.53 °B; 6 DAS-9.93°B; 9 DAS-16.43°B; 12 DAS-18.60°B; 15 DAS-20.89°B; 18 DAS-22.37°B and 21 DAS-24.92°B).

Titratable acidity (%)

Significant differences were observed with respect to titratable acidity (%) of banana fruits during 21 days of refrigerated storage (Table 4). Titratable acidity (%) was found to increase from the initial value (0.16%) up to 3 DAS and thereafter declined in all the treatments during storage of banana. At all the days of observation, maximum acidity was associated with T_6 (3 DAS-0.63%; 6 DAS-0.60%; 9 DAS-0.57%; 12 DAS-0.53%; 15 DAS-0.49%; 18 DAS-0.47% and 21 DAS-0.42%). However, it was non-significantly followed by T_4 and T_5. The treatment T_8 showed significantly minimum titratable acidity (3 DAS-0.29%; 6 DAS-0.26%; 9 DAS-0.22%; 12 DAS-0.19%; 15 DAS-0.18%; 18 DAS-0.16% and 21 DAS-0.15%). However, the control treatment without any packaging (T_8) was on par with the packaging treatments T_2 and T_7 throughout the study duration.

Firmness (N)

The firmness (N) of banana 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 (10.15 N) and mean values observed at 3, 6, 9, 12, 15, 18 and 21 DAS (9.20 N, 8.55 N, 8.45 N, 8.12 N, 7.40 N, 6.93 N and 5.48 N respectively). Maximum firmness was seen in T_6 (3 DAS-9.71 N; 6 DAS-9.20 N; 9 DAS-9.09 N; 12 DAS-8.84 N; 15 DAS-8.02 N; 18 DAS-7.69 N and 21 DAS-6.12 N). However, the treatment T_6 was on par with T_4 throughout the storage period. Contrarily, the treatment T_8 showed significantly minimum firmness throughout the storage (3 DAS-8.67 N; 6 DAS-8.13 N; 9 DAS-7.92 N; 12 DAS-7.18 N; 15 DAS-6.50 N; 18 DAS-6.10 N and 21 DAS-4.62 N). The treatment T_8 had statistical similarity only with T_7 throughout the study and showed significant differences with rest of the treatments.

Disease score (%)

The data on scoring for disease (%) in banana fruits showed significant differences among the treatments during storage of 21 days (Table 6). The visual score for diseases increased with the increase in storage period. Bananas with no disease at the beginning were healthy up to 15 days; but showed an increase in score for disease from 18 DAS (28.99%) to 21 DAS (44.74%). The treatment T_6 witnessed significantly minimum disease score all along the study period (18 DAS-8.68% and 21 DAS-22.91%). It was however non-significant with T_1, T_3 and T_4 at 18 DAS and 21 DAS. Significantly maximum score for diseases was obtained by T_8 throughout the storage (18 DAS-52.96% and 21 DAS-71.63%). However, the treatment T_8 was statistically on par with T_7 at 18 DAS (44.58%) but differed significantly on 21 DAS (66.18%).

Physiological loss in weight (PLW) (%)

Zeolite has the property to adsorb gases like ethylene and oxygen from the storage environment (Khosravi *et al.,* 2015). Fruit respiration and transpiration in this study was therefore probably retarded resulting in minimum weight loss.

Table.1 Effect of zeolite-LDPE composite bags on physiological loss in weight (PLW) (%) of banana 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	0.80[cd]	2.15[cd]	3.34[bcd]	7.62[bcd]	12.46[bc]	13.85[bc]	15.95[cd]	**8.02**
T_2	0.83[c]	2.27[bc]	4.01[abc]	7.71[bc]	12.63[bc]	14.09[bc]	16.82[bc]	**8.33**
T_3	0.73[cd]	2.03[cde]	3.05[cd]	7.44[bcde]	11.97[cd]	13.67[bc]	15.54[cde]	**7.77**
T_4	0.52[de]	1.38[ef]	2.82[d]	5.33[de]	10.54[e]	11.31[c]	13.77[ef]	**6.52**
T_5	0.68[cd]	1.54[def]	2.95[cd]	5.76[cde]	10.98[de]	11.97[bc]	14.60[def]	**6.92**
T_6	0.35[c]	1.13[f]	2.77[d]	5.11[e]	8.06[f]	10.02[c]	12.91[f]	**5.76**
T_7	1.28[b]	2.96[ab]	4.25[ab]	8.63[ab]	13.36[b]	15.64[ab]	18.09[b]	**9.17**
T_8	1.84[a]	3.43[a]	5.16[a]	10.12[a]	15.58[a]	18.82[a]	20.67[a]	**10.80**
Mean	**0.87**	**2.11**	**3.54**	**7.21**	**11.94**	**13.67**	**16.04**	
S.Em±	0.11	0.23	0.39	0.78	0.39	1.37	0.62	
CD@1%	0.41	0.97	1.61	3.25	1.65	5.68	2.57	

T_1- Silver-zeolite-LDPE composite bag
T_2 - Zeolite-LDPE composite bag
T_3 - Chlorine-zeolite-LDPE composite bag
T_4 - Silver-zeolite-LDPE composite bag + CFB
T_5 - Zeolite-LDPE composite bag + CFB
T_6 - Chlorine-zeolite-LDPE composite bag + CFB
T_7 - Only CFB
T_8 - Control

Table.2 Effect of zeolite-LDPE composite bags on respiration rate (ml of CO_2 /Kg/hr) of banana fruits under refrigerated condition (13°C)

Treatments	Respiration rate (ml 0f CO_2 /Kg/hr)							
	3 DAS	6 DAS	9 DAS	12 DAS	15 DAS	18 DAS	21 DAS	Mean
Initial	96.7							
T_1	101.1^{bc}	109.7^{bcd}	132.2^{c}	151.6^{abc}	196.7^{bc}	187.0^{cd}	168.5	**149.54**
T_2	102.5^{b}	111.1^{abc}	135.3^{b}	158.8^{ab}	201.9^{ab}	189.5^{bc}	170.9	**152.85**
T_3	100.8^{bc}	108.2^{cde}	128.6^{c}	147.9^{bc}	194.4^{bc}	186.6^{cd}	164.4	**147.27**
T_4	99.4^{cd}	106.3^{de}	121.8^{e}	135.4^{cd}	188.6^{cd}	183.4^{d}	158.3	**141.88**
T_5	100.7^{bc}	107.9^{bcde}	125.1^{d}	142.3^{bcd}	192.6^{bcd}	184.4^{d}	161.7	**144.95**
T_6	98.4^{d}	104.5^{e}	118.5^{f}	126.8^{d}	183.8^{d}	180.1^{e}	156.1	**138.31**
T_7	103.9^{a}	112.8^{ab}	138.4^{ab}	161.6^{ab}	208.0^{a}	190.6^{b}	172.6	**155.41**
T_8	105.2^{a}	114.6^{a}	141.0^{a}	167.7^{a}	212.3^{a}	194.8^{a}	189.8	**160.77**
Mean	**101.50**	**109.38**	**130.11**	**149.01**	**197.28**	**187.05**	**167.78**	
S.Em±	0.57	1.50	1.04	6.50	2.19	1.39	14.00	
CD@1%	2.38	6.21	4.32	26.87	14.48	5.78	NS	

T_1- Silver-zeolite-LDPE composite bag
T_2 - Zeolite-LDPE composite bag
T_3 - Chlorine-zeolite-LDPE composite bag
T_4 - Silver-zeolite-LDPE composite bag + CFB
T_5 - Zeolite-LDPE composite bag + CFB
T_6 - Chlorine-zeolite-LDPE composite bag + CFB
T_7 - Only CFB
T_8 - Control

Table.3 Effect of zeolite-LDPE composite bags on TSS (°B) of banana fruits under refrigerated condition (13°C)

Treatments	TSS (°B)							
	3 DAS	**6 DAS**	**9 DAS**	**12 DAS**	**15 DAS**	**18 DAS**	**21 DAS**	**Mean**
Initial	5.9							
T_1	6.69	8.91	15.06	17.84	19.73	20.98	23.58	**16.11**
T_2	6.83	9.05	15.67	17.99	19.89	21.43	23.76	**16.37**
T_3	6.57	8.83	14.87	17.77	19.54	20.77	23.30	**15.95**
T_4	6.31	8.40	14.62	16.94	18.76	20.29	22.64	**15.42**
T_5	6.42	8.64	14.83	17.16	18.97	20.61	22.81	**15.63**
T_6	6.23	8.31	14.18	16.78	18.44	19.97	21.87	**15.11**
T_7	7.01	9.42	15.92	18.12	20.62	21.69	24.03	**16.68**
T_8	7.53	9.93	16.43	18.60	20.89	22.37	24.92	**17.23**
Mean	**6.69**	**8.93**	**15.19**	**17.65**	**19.60**	**21.01**	**23.36**	
S.Em±	0.73	0.97	1.66	1.93	2.14	2.30	2.55	
CD@5%	NS	NS	NS	NS	NS	NS	NS	

T_1- Silver-zeolite-LDPE composite bag
T_2 - Zeolite-LDPE composite bag
T_3 - Chlorine-zeolite-LDPE composite bag
T_4 - Silver-zeolite-LDPE composite bag + CFB
T_5 - Zeolite-LDPE composite bag + CFB
T_6 - Chlorine-zeolite-LDPE composite bag + CFB
T_7 - Only CFB
T_8 - Control

Table.4 Effect of zeolite-LDPE composite bags on titratable acidity (%) of banana fruits under refrigerated condition (13°C)

Treatments	Titratable acidity (%)							
	3 DAS	6 DAS	9 DAS	12 DAS	15 DAS	18 DAS	21 DAS	Mean
Initial	0.16							
T_1	0.43^{bcd}	0.40^{bc}	0.37^{cd}	0.34^{bcd}	0.31^{bcd}	0.30^{bc}	0.28^{bc}	**0.34**
T_2	0.39^{cd}	0.37^{bc}	0.34^{cde}	0.32^{cd}	0.30^{cde}	0.29^{bc}	0.26^{cd}	**0.32**
T_3	0.48^{abc}	0.44^{b}	0.41^{bc}	0.38^{bc}	0.35^{bc}	0.33^{b}	0.30^{bc}	**0.38**
T_4	0.56^{ab}	0.52^{ab}	0.50^{ab}	0.46^{ab}	0.43^{ab}	0.40^{ab}	0.38^{ab}	**0.46**
T_5	0.51^{abc}	0.49^{ab}	0.46^{abc}	0.43^{abc}	0.41^{abc}	0.39^{ab}	0.36^{abc}	**0.43**
T_6	0.63^{a}	0.60^{a}	0.57^{a}	0.53^{a}	0.49^{a}	0.47^{a}	0.42^{a}	**0.53**
T_7	0.32^{d}	0.29^{c}	0.27^{de}	0.24^{de}	0.22^{de}	0.20^{cd}	0.18^{de}	**0.24**
T_8	0.29^{d}	0.26^{c}	0.22^{e}	0.19^{e}	0.18^{e}	0.16^{d}	0.15^{e}	**0.20**
Mean	**0.45**	**0.42**	**0.39**	**0.36**	**0.33**	**0.31**	**0.29**	
S.Em±	0.03	0.04	0.03	0.04	0.05	0.02	0.04	
CD@1%	0.21	0.20	0.19	0.17	0.16	0.15	0.14	

T_1- Silver-zeolite-LDPE composite bag
T_2 - Zeolite-LDPE composite bag
T_3 - Chlorine-zeolite-LDPE composite bag
T_4 - Silver-zeolite-LDPE composite bag + CFB
T_5 - Zeolite-LDPE composite bag + CFB
T_6 - Chlorine-zeolite-LDPE composite bag + CFB
T_7 - Only CFB
T_8 – Control

Table.5 Effect of zeolite-LDPE composite bags on firmness (N) of banana 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	10.15							
T_1	9.22[bc]	8.45[bc]	8.31[b]	8.12[c]	7.41[c]	6.91[d]	5.47[e]	**7.70**
T_2	8.86[cd]	8.46[b]	8.51[ab]	7.94[d]	7.24[d]	6.75[g]	5.22[f]	**7.57**
T_3	9.27[abc]	8.49[bc]	8.39[ab]	8.24[c]	7.49[bc]	6.91[d]	5.66[d]	**7.78**
T_4	9.66[ab]	8.91[a]	8.81[ab]	8.61[ab]	7.89[a]	7.49[b]	5.98[b]	**8.19**
T_5	9.44[ab]	8.65[b]	8.58[ab]	8.44[b]	7.65[b]	7.10[c]	5.79[c]	**7.95**
T_6	9.71[a]	9.20[a]	9.09[a]	8.84[a]	8.02[a]	7.69[a]	6.12[a]	**8.38**
T_7	8.81[cd]	8.39[bc]	8.06[bc]	7.57[e]	6.97[e]	6.52[e]	5.03[g]	**7.33**
T_8	8.67[d]	8.13[c]	7.92[c]	7.18[f]	6.50[f]	6.10[f]	4.62[h]	**7.02**
Mean	**9.20**	**8.58**	**8.45**	**8.12**	**7.40**	**6.93**	**5.48**	
S.Em±	0.15	0.10	0.13	0.04	0.05	0.00	0.03	
CD@1%	0.64	0.45	0.53	0.22	0.23	0.16	0.16	

T_1- Silver-zeolite-LDPE composite bag
T_2 - Zeolite-LDPE composite bag
T_3 - Chlorine-zeolite-LDPE composite bag
T_4 - Silver-zeolite-LDPE composite bag + CFB
T_5 - Zeolite-LDPE composite bag + CFB
T_6 - Chlorine-zeolite-LDPE composite bag + CFB
T_7 - Only CFB
T_8 – Control

Table.6 Effect of zeolite-LDPE composite bags on disease score (%) of banana fruits under refrigerated condition (13°C)

Treatments	Disease score (%)		
	18 DAS	21 DAS	Mean
Initial	NIL		
T_1	23.02^{c}	37.58^{e}	**30.30**
T_2	37.78^{b}	53.73^{c}	**45.75**
T_3	20.52^{cd}	34.00^{e}	**27.26**
T_4	12.08^{cd}	28.07^{f}	**20.07**
T_5	32.33^{bc}	43.86^{d}	**38.09**
T_6	8.68^{d}	22.91^{g}	**15.79**
T_7	44.58^{ab}	66.18^{b}	**55.38**
T_8	52.96^{a}	71.63^{a}	**62.29**
Mean	**28.99**	**44.74**	
S.Em±	4.23	1.27	
CD@1%	17.50	5.26	

T_1 - Silver-zeolite-LDPE composite bag
T_2 - Zeolite-LDPE composite bag
T_3 - Chlorine-zeolite-LDPE composite bag
T_4 - Silver-zeolite-LDPE composite bag + CFB
T_5 - Zeolite-LDPE composite bag + CFB
T_6 - Chlorine-zeolite-LDPE composite bag + CFB
T_7 - Only CFB
T_8 - Control

However, 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 (Silver-zeolite-LDPE composite bag + CFB box), T_5 (Zeolite-LDPE composite bag + CFB box) and T_6 (Chlorine-zeolite-LDPE composite bag + CFB box) might have reduced the drive for removal of moisture from the fruits. Abhay *et al.*, (2015) 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. Banana fruits maintained without any packaging (T_8) followed by T_7 (Commercially used CFB) recorded higher PLW percentage throughout the storage period.

Respiration rate (ml CO_2 /Kg/hr)

In the present study, hurdle to respiration process was created by low temperature as well as zeolite composed package. Porous zeolite is effective in adsorbing gases such as oxygen, carbon dioxide and ethylene and water vapour, and thereby reducing respiration (Khosravi *et al.,* 2015). This is possibly due to biocidal effect of chlorine (Kim *et al.,* 2007; Lee *et al.,* 2009 and Yang *et al.,* 2009) leading to delay in fruit senescence. However, T_6 treatment had non-significant difference with T_3 (Chlorine-zeolite-LDPE composite bag), T_4 (Silver-zeolite-LDPE composite bag + CFB box) and T_5 (Zeolite-LDPE composite bag + CFB box) throughout the storage except at 12 DAS when T_6 differed significantly over all other treatments. Reduced respiration of fruits in zeolite-LDPE variants (with or without chlorine or silver) in CFB boxes (T_4, T_5, T_6) than those without CFB (T_1, T_2, T_3) could be due to beneficial synergistic effect of combined packages. Banana fruits kept open condition (T_8) had significantly higher respiration rate followed closely by T_7 (Commercially used CFB) throughout the storage period. This defends the beneficial effect of zeolite-LDPE bags.

Total soluble solids (TSS) (°B)

In the present study, TSS manifested no significant differences among the packaging treatments Although, TSS did not present statistical difference, a difference of 3-4^{o}B between the treatments practically has tremendous impact on taste, flavour and ripening of fruit. In climacteric fruits like banana the conversion of starch to sugars in the fruit is an important component of the ripening process, giving the fruit its distinctive sweet flavour as well as precursor for many of the aromatic flavour compounds (Kays, 1998). Zomoroid (2005) recorded minimum TSS in cut apples stored along with a pouch of zeolite (1 gm) for a period of 6 days. Zeolite has adsorbing property of oxygen, carbon dioxide and ethylene gases from storage environment thus checking the biochemical differentiation and metabolic reorganization leading to reduction in TSS (Khosravi *et al.,* 2015). Similar findings were reported by Reshmi *et al*., (2015), where control banana fruits showed maximum TSS (25.33°B) on 12th day and those kept in non-perforated LDPE and non-perforated HDPE along with $KMnO_4$ showed minimum TSS content of 23.33 and 23.83°B, respectively on the same day (12th day) of storage. During storage of custard apple fruits, total sugars significantly increased in all treatments, as the rate of respiration, transpiration and other metabolic changes increased with storage period (Pimpalpalle *et al.,* 2018).

Titratable acidity (%)

Titratable acidity (%) significantly varied among the treatments during storage. In banana significantly maximum titratable acidity was noticed in T_6 (Chlorine-zeolite-LDPE composite bag + CFB) and minimum was observed by T_8 (Control) One of the most important features of zeolite is effective adsorption of gases such as oxygen, carbon dioxide and ethylene and water vapour due to presence of pores in it, thus reducing respiration and advances of metabolism of fruits (Khosravi *et al.,* 2015). Reduction in metabolism could reduce the use of organic acids as substrates in respiration (Islam *et al.,* 1996), thus maintaining higher acidity in T_6 than in fruits without any package (T_8). Further, higher titratable acidity in zeolite-LDPE variants in CFB boxes (T_4, T_5, T_6) than those without CFB (T_1, T_2, T_3) could be due to beneficial synergistic effect of combined packages. Poor retention of acidity in fruits kept in CFB alone (T_7) on par with control strongly justifies the effect of zeolite-LDPE bags. These results are in accordance with the findings of Bhutia *et al.,* (2011) where sapota fruits treated with ethylene absorbent showed significantly high value of titratable acidity throughout the storage duration. Dhua *et al.,* (2006) revealed that sapota fruits packed along with ethylene absorbers showed marked retardation of ripening and also maintenance of higher acidity in those fruits in comparison to control fruits.

Firmness (N)

Firmness values showed significant differences among the treatments only under refrigerated storage. Significantly maximum firmness was registered in T_6 (Chlorine-zeolite-LDPE composite bag + CFB) under refrigerated storage (5.91 N). This could be due to the reduced weight loss resulting from reduced respiration or lower enzymatic activity as observed by Hailu *et al.*, (2012) in banana fruits packaged along with ethylene scrubbers ($KMnO_4$). Significantly minimum firmness was observed in T_8 under refrigerated storage (4.62 N) condition. Salunkhe and Desai (1984) 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 Kaur and Kaur (2018) 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, Elamin and Abu-Goukh (2010) 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 (%)

The disease infection appeared to be higher in packages with Zeolite-LDPE alone (T_2 and T_5) than in other variants of Zeolite-LDPE polybags (T_1, T_3, T_5 and T_6). The variant packages of Zeolite-LDPE polybags are synergized with silver (T_1, T_4) and chlorine (T_3, T_6). 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* (Kim *et al.,* 2007; Lee *et al.,* 2009 and Yang *et al.,* 2009). 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 (Russel and Hugo, 1994). 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 (Zeolite-LDPE chlorine) and T_6 (Zeolite-LDPE chlorine+CFB). Thus minimum disease score was recorded in T_6 than in fruits without any package (T_8).

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