Comparative effect of different individual wrappings on shelf life of guava (*Psidium guajava*)

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Abstract Being climacteric fruit the organoleptic quality of Guava deteriorates due to continuously occurring biochemical changes during the storage leading to heavy post harvest losses. The present research work was planned to depreciate the losses by assessing the effect of different individual packagings on the shelf life of the fruit. The individual wrapping of fruits were carried out in LDPE films by cling, shrink, vacuum and modified atmosphere packaging (MAP) and stored at room temperature (37 °C). Individual wrapping delayed the ripening process by slowing down the metabolic activities and reducing the magnitude of changes in physicochemical parameters. In control fruits significant compositional changes along with the total phenol content and ascorbic acid were observed with higher decay loss. However, wrapping of fruits maintained the natural freshness and helped in retaining the marketability of the fruits. Vacuum packing and MAP showed minimum PLW (3.5%), decay loss and ripening during storage. Cling wrapping and shrink wrapping were the best treatments that enhanced the shelf life of fruits by 4 days at room temperature.

Keywords Individual polythene packaging · ‘Hisar Safeda’ Guava · Polyphenol oxidase activity · Biochemical changes · Flesh firmness

Introduction

Guava (*Psidium guajava* L.) is a productive crop grown in tropical and subtropical zones of the world. In India, it is grown in plain areas of north and south regions like Haryana, Punjab, Uttar Pradesh, Karnataka and Kerala states. Guava is popular for its delicious flavour, unique fragrance, subtle aroma and sweet pulp with granular texture. Different Guava Cultivars has unique taste, flesh colour and usually available in different seasons of the year. Guava is superior among most other fruit crops being more productive, persist and versatile. Along with good organoleptic properties the fruit has distinguished nutritive value so commonly known as ‘apple of tropics’. The nutritive value of guava is high because of higher vitamin C content along with water soluble vitamins. The fruit has 80% moisture and 17% dry matter which consists of stellar amount of protein and dietary fibre along with the appreciable amount of minerals such as phosphorus, calcium and iron.

In India area under the cultivation of guava is 2.03 Lha producing 22.7MT (Indian Horticulture Database 2011). The well known Indian varieties of guava are Lucknow-46, Lucknow-49 (Sardar), Allahabadi safeda, Chittidar, Apple colour, Seedless guava, Red guava, Nasik, Hafsi, Harijha, Lalit, Nagpur seedless and Allahabad round etc. As Guava is highly perishable fruit, the nutritional and organoleptic quality declines rapidly. Quality deterioration mainly occurs due to respiration, transpiration and senescence associated with metabolic activities of the fruit (Pongener et al. 2011). The resulting heavy post harvest losses leads to high economic loss which requires depreciation. The post harvest technologies may have a profound effect on the shelf life of fruit (Gorris and Peppelenbos 2007). Understanding the biochemical changes during ripening

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and senescence is necessary to manipulate the ripening process, to extend the shelf life and to reduce the postharvest losses.

Packaging is the easy prospect to delay the persistently occurring physiological and biochemical changes in fruits which degrade the nutritive and organoleptic quality. The latest technique which is gaining ground in Indian food industry is individual wrapping. The potential benefits of individual packaging involves delay in ripening process, colour development, senescence, texture maintenance, reduction in decay loss and retention of nutrients (Risse 2001).

Polythene packaging modifies the atmospheric conditions inside the cover which results in reduced metabolic activities. Moreover, polythene packaging can be done in various ways depending on the type of packaging. Cling wrap is very thin polyethylene film that adheres to the surface of fruit and serves as an extra covering. Now-a-days cling wrap is regarded as an essential and cost-effective tool for food presentation. Cling film checks respiration and transpirational losses and thus decreases physiological loss in weight (Sehwag and Dass 2016). Shrink packaging uses shrinking property of thermoplastic films by applying heat. The greatest advantage of individual shrink wrapping is the control of moisture loss. Other benefits involve delay in senescence and metabolic activities as supported by lesser changes in soluble solids, sugars, acidity, respiration rate and ethylene production rate.

In vacuum packing, product is packed in a plastic bag which is evacuated in a vacuum chamber and sealed hermetically in order to provide total barrier against air and moisture. Vacuum packaging of fresh commodities eliminates the air in package by using a suction machine. This method reduces the level of O₂ and CO₂ in the package and thus prolongs the shelf life of fruits (Tapia et al. 2003). Modified atmosphere packaging is a technology to enhance the shelf life of fresh produce by utilizing basic principles of respiration and permeation simultaneously. Passive modified atmosphere is evolved inside the package as a consequence of commodity's respiration.

The packaging of perishable fruits in LDPE films by different methods depending on technique of wrapping offers better alternative to improve the shelf life and quality of guava. The polythene packs are commonly being used for packaging of a number of climacteric fruits. The purpose of the present study was to extend the shelf life of Guava fruits (cv. Hisar Safeda) at ambient conditions using plastic packaging materials.

Material and methods

Fruits

Guava (*Psidium guajava*) fruits of the cv. 'Hisar Safeda' were procured from a well maintained horticultural orchard situated at Hisar, district of Haryana, India. 'Hisar Safeda' is a summer season variety of Guava fruit. High room temperature in summer season led to higher respiratory and physiological losses which degrade the fruit quality and reduces the shelf life. The aim of present study was to reduce the impact of high temperature on summer season crop by packaging. Fruits were disinfected by immersing in 1% household bleach solution for one minute. The bleach solution was removed by rinsing fruits under tapwater by 30 s plunges.

Wrapping materials and treatments

The total numbers of fruits were divided in five sets. One set of fruits was not packed which served as control. Remaining four set of fruits were individually packed in polythene bags (LDPE) of 200 gauge thickness by four different methods. i.e. Vacuum packaging, Modified atmosphere packaging, Shrink and Cling wrapping, (1) vacuum pack: fruits were packed in sealed polybags by vacuum packaging machine. (2) Modified atmosphere pack: fruits were sealed in polybags individually. (3) Shrink wrap: fruits were packed in sealed polybags by shrink wrap machine. (4) Cling wrapping: fruits were wrapped manually in cling film (clean wrap). All five sets of fruits were stored at room temperature (37 °C) in corrugated fibre board boxes. Ten fruits were packed in one pack which served as one replicate. For each packaging treatment six replicates were packed and sampling was done on one day interval up to 8 days of storage.

Physical parameters

Physiological loss in weight (PLW) and decay loss

Packs of individually numbered fruit were weighed initially and at the end of particular interval of storage period. Three replicates were reweighed for each packaging treatment. The determined weight loss was expressed as percent loss from initial weight. The number of total rotted decayed fruit was assessed in terms of decay loss percentage.

% Respiration rate

At harvest and on particular date of observation, respiration rate of packaged guava fruits was measured with modified atmosphere packaging (MAP) testing machine (Quantek USA, Model 902D). To check the respiration rate, fruits were removed from the pack and kept in respiration jars for a period of 2 h. The needle of MAP testing machine was injected in jars and concentration of CO₂ was measured. The Concentration of CO₂ was expressed as μ mole of CO₂ evolved/hour/kilogram of fruit.

Flesh firmness, and hunter colour values

Cylindrical plunger of 11 mm diameter was fitted in Manual Pressure tester (Ogawa, Seiki, Japan) and firmness was measured at two opposite sides of fruit. Results were expressed as kg cm⁻².

To check the ripening occurring in fruits, the intensity of yellow to green colour was determined by Hunter colorimeter D25 optical sensor 173 (Hunter Associates Laboratory, Trestoa, VA, USA). Intensity of yellow to green colour was assessed in terms of three variables i.e. 'L', 'a', 'b' values. 'L' value signifies the lightness (100 for white and 0 for black), 'a' value represents greenness and redness (– 80 for green and 80 for red), while 'b' value signifies changes from blueness to yellowness (– 80 for blue and 80 for yellow). In particular, readings were taken on the opposite sides of visibly sound fruit and results were presented in terms of ΔE value (Licciardello and Muratore 2011).

Biochemical parameters

Fruit pulp was crushed and strained through muslin cloth to obtain juice for chemical analysis.

Titrateable acidity (TA) and total soluble solids (TSS)

To determine titrateable acidity, extracted juice was diluted four times and titrated against 0.5 N NaOH using phenolphthalein (1%) as an indicator to an endpoint of pink colour (A.O.A.C. 2005). Results were expressed as gm of citric acid per 100 gm of fruit pulp. The total soluble solid (TSS) of the fruit juice was determined using a hand refractometer and expressed as percent TSS.

Total phenols, ascorbic acid content and polyphenol oxidase activity

Flavour of guava is determined by types and amount of sugars, acids, phenolics and volatile compounds in fruits. With increase in softness of fruit, phenolic content

decreases during storage and reduces the shelf life (Bashir and Abu-Goukh 2003). Therefore total phenol content is measured as an important chemical parameter which affects the shelf life and flavor of fruit. The enzyme polyphenol oxidase catalyse the browning of fruit pericarp by rapidly degrading phenolic compounds (Zhang et al. 2005). Higher PPO level reduces the shelf life of fruit and thus control is required. So the effect of polythene packaging on polyphenoloxidase level was checked.

Total phenols were estimated by using Folin–Ciocalteu reagent (Amorium et al. 1997). Standard curve of tannic acid was prepared using different graded concentrations. Concentration of total phenols in test samples was expressed as mg of tannic acid equivalent/100g of fresh pulp weight.

Polyphenol oxidase assay was carried out by the method of Kaul and Farooq (1994). To prepare enzyme extract, 4 g fruit pulp was homogenized in cold 0.2 M tris–HCl buffer (pH = 7.5) having 0.1 M of cystine and 0.1 M EDTA. Homogenate was centrifuged at 15,000 rpm for 20 min at 4 °C. The obtained supernatant (0.5 ml) was further incubated at 30 °C for 20 min in 0.2 M phosphate buffer containing guaiacol (0.05 M). The reaction was terminated by adding chilled 10% TCA (1 ml) and optical density was read at 430 nm against the reagent blank. The enzyme activity was measured in units/g fruit wt h⁻¹. Under standard conditions one unit of enzyme represent increase in O.D. by one.

The ascorbic acid content varies from 60 to 100 mg/100 g in various guava cultivars. Vitamin C being sensitive to high temperature is liable to lose during storage, and thus retention of antioxidant activity is considered as an important quality parameter. The ascorbic acid was determined by the titration method using 2,6-dichlorophenol indophenol dye as described in A.O.A.C. (2005). Values were expressed in mg of ascorbic acid per 100 g of fresh pulp weight.

Organoleptic evaluation

The overall organoleptic rating of Guava samples was done by a panel of 20 semi-trained members of 25–55 years of age group on the basis of appearance of fruits, texture, taste, flavor and overall quality by 9 point hedonic scale (Narayana et al. 2002). After storage, guava samples from each treatment were given to judges. Fruits receiving a rating of 5 and above were considered marketable, while those rated less than 5 were considered unmarketable. The number of marketable fruits was used as a measure to calculate the percentage of marketable fruits during storage.

Statistical analysis

Statistical analysis of variance (ANOVA) technique was applied to the data obtained in present investigation using two factorial completely randomized designs (CRD). Single factorial CRD was also used for three parameters i.e. Physiological loss in weight, Decay loss % and Ripening %.

Results

Physiological loss in weight (PLW %)

The physiological loss in weight and decay loss of the fruits increased significantly with increased duration of storage at ambient conditions (Table 1). The unwrapped control fruits had maximum PLW 35.5% by 8th day of storage, whereas it was lower than 15% in other treatments. No decay loss was observed by 2nd day of storage in all the treatments. However, at later storage periods, the control fruits started showing decay loss which increased to 90% by 8th day of storage. Individual packaging reduced the PLW and decay loss significantly. Among all packaging treatments minimum reduction in PLW was found in cling wrapped (14.9%) followed by shrink wrapped (2.3%), modified atmosphere (1.7%) and vacuum packed (1.3%) fruits. Similarly higher decay loss was observed in Cling and shrink wrap by 6th day being 30% and 20% respectively, which increased up to 50 and 40% respectively by 8th day. Vacuum and modified atmosphere packed fruits did not show any decay loss even by 8th day of storage.

Ripening %, flesh firmness and Hunter colour values

The ripening of fruits increased progressively resulting in decreased flesh firmness with increasing period of storage (Table 1). The unwrapped control fruits attained 100% ripening with minimum firmness (2.6 kg cm^{-2}), whereas wrapped fruits had still lower ripening % (< 76%) with

firmness in range of $4\text{--}8 \text{ kg cm}^{-2}$ by 8th day of storage. With ripening %, Hunter color Lab values also varied and increased with increasing duration of storage. The delta E value of control fruit increased and was maximum by 8th day of storage while in wrapped fruits it was less than control. Individual wrapping slowed down the changes in Hunter Lab values by reducing the ripening % and thus firmness significantly. Vacuum packed fruits and modified atmosphere packed fruits showed no ripening, as maximum firmness was maintained in vacuum (8.5 kg cm^{-2}) and modified atmosphere (8.2 kg cm^{-2}) packed fruits. Shrink (6.9 kg cm^{-2}) and cling wrapped (6.0 kg cm^{-2}) fruits showed 60 and 75% ripening respectively, at the end of storage. Similarly minimum changes in delta E values were observed in vacuum and modified atmosphere packed fruits followed by shrink and cling film wrapped fruits, respectively (Fig. 1a). The Vacuum and modified atmosphere packing were equally effective in maintaining the firmness and colour values of fruits. The cling film wrapping was least effective in delaying the ripening of fruits.

Respiration rate

Respiration rate of fruits increased progressively with increasing period of storage. The unwrapped control fruits attained maximum value ($30.3 \text{ ml h}^{-1} \text{ kg}^{-1}$) of CO_2 concentration by 6th day which decreased to $25.3 \text{ ml h}^{-1} \text{ kg}^{-1}$ by 8th day (Fig. 1b). However, in individually wrapped fruits, CO_2 concentration was below $23.5 \text{ ml h}^{-1} \text{ kg}^{-1}$ by 8th day of storage. Individual wrapping reduced the respiration rate significantly. Minimum respiration rate was observed in vacuum packed followed by modified atmosphere packed, shrink and cling film wrapped fruits.

Total soluble solids and acidity

The similar trend of progressive increase in TSS of fruits was observed with increase in duration of storage. The control fruits had maximum TSS (10.4%) by 6th day while individually wrapped fruits had maximum TSS in range of

Table 1 Effect of individual wrapping on physiological loss in weight (%) and ripening % at different storage period

Treatments	Period of storage (days)							
	PLW (%)				Ripening (%)			
	2	4	6	8	2	4	6	8
Control	7.2 ^a	15.8 ^a	24.9 ^a	36.4 ^a	25	80	100	100
Cling wrap	1.7 ^b	4.6 ^b	9.0 ^b	14.9 ^b	15	40	60	75
Shrink wrap	0.3 ^c	0.9 ^c	1.4 ^c	2.3 ^c	10	30	50	60
Vacuum pack	0.2 ^c	0.6 ^c	1.0 ^c	1.7 ^c	–	–	–	–
Modified atmosphere pack	0.2 ^c	0.4 ^c	0.8 ^c	1.5 ^c	–	–	–	–

Means with different superscripts (a, b) in column differ significantly ($P < 0.05$) from each other

Fig. 1 Physiological change in
a delta E values of colour.
b Respiration activity in
 individually wrapped guava
 fruits stored at room
 temperature for 8 days. Bars
 followed by different letters are
 significantly different at
 $P < 0.05$

Fig. 2 Trend of Total soluble
 solid (%) in individually
 wrapped guava fruits stored at
 room temperature for 8 days.
 Bars followed by different
 letters are significantly different
 at $P < 0.05$

5–9.5% by 8th day of storage (Fig. 2). The acidity of fruits decreased due to ripening during storage. Control fruits had minimum acidity of 0.22% by 4th day as compared to 0.28% on 8th day in individually wrapped fruits. Individual wrapping slowed down the rise in TSS and reduction in acidity of fruits significantly. Among all wrapping treatments, vacuum and modified atmosphere packed fruits exhibited minimum rise in TSS followed by shrink and cling film wrapped fruits. Differences were found to be non-significant among vacuum and modified atmosphere packagings but significant with respect to shrink and cling wrap. However, in case of acidity all wrapping treatments showed non significant differences among themselves.

Ascorbic acid

Ascorbic acid content of fruit decreased with increasing period of storage at room temperature (Table 2). The individually wrapped fruits retained higher ascorbic acid content (30 mg/100 g) by 8th day of storage as compared to control fruits (19.3 mg/100 g). Individual wrapping of fruits helped in retention of higher ascorbic acid in fruits during storage. At room temperature, maximum ascorbic acid was retained in vacuum packed fruits (45.0 mg/100 g) followed by modified atmosphere packed fruits (44.6 mg/100 g), shrink (42.5 mg/100 g) and cling film wrapped fruits (41.0 mg/100 g).

Total phenols and polyphenol oxidase activity

Total phenolic content of fruit decreased while PPO activity increased with increasing period of storage at room temperature (Fig. 3). By 8th day of storage, phenolic content was higher in individually wrapped fruits (25 mg/100 g) fruits as compared to control fruits (16.2 mg/100 g) (Table 2). Activity of PPO was maximum in control fruits (0.53 units) while individually wrapped fruits had 0.34–0.45 enzyme units by 8th day of storage. Individual wrapping of fruits reduced the rate of decrease in phenolic content during storage. Among all wrapping methods,

vacuum packed (48.4 mg/100 g) fruits had higher phenolics followed by modified atmosphere (46.4 mg/100 g) packed, shrink (44.2 mg/100 g) and cling (42.3 mg/100 g) wrapped fruits. In case of PPO activity trend was just reverse. Vacuum and modified atmosphere packed fruits had lowest PPO activity and were equally effective in slowing down the increase in activity of PPO. Shrink and cling wrapped fruits had higher PPO activity with insignificant difference among them but significant with respect to control.

Organoleptic evaluation

The data revealed that storage at room temperature had significant effect on aroma and taste of fruits. Aroma as well as taste score of fruits increased slightly and decreased thereafter (Table 3). The taste score of unwrapped control fruits was maximum by 2nd day and decreased to 3.5 by 6th day which was below the acceptable sensory score of '5', and thus turned out to be unacceptable. Among wrapped fruits, cling film and shrink wrapped fruits had highest aroma and taste score followed by modified and vacuum packed fruits by 2nd day which decreased with storage period. Thus cling and shrink wrapped fruits remained acceptable with respect to aroma and taste score while modified and vacuum packed fruits became unacceptable by 8th day of storage. Cling film wrapped fruits received the highest mean score for the taste. Similar trend was observed for texture of guava fruits. Shrink wrapped fruits received the highest mean score for texture. Increased texture score of guava fruits could be associated with the ripening. At room temperature modified and vacuum packed fruits had highest texture score. In the present investigation, all wrapped fruits remained organoleptically acceptable with regard to the texture at room temperature. The texture score followed the pattern similar to flesh firmness of fruits. However, the decrease in flesh firmness as compared to the texture was of higher magnitude during initial storage periods of 2 days.

Table 2 Effect of individual wrapping on total phenol content (mg of tannic acid equivalent/100 g fruit pulp) and ascorbic acid content (mg/100 g fruit pulp) at different storage period

Treatments	Period of storage (days)									
	Total phenols (mg/100 g)					Ascorbic acid (mg/100 g)				
	0	2	4	6	8	0	2	4	6	8
Control	58.2	45.5 ^a	36.7 ^a	27.8 ^a	16.2 ^a	50	40 ^a	34.1 ^a	25.7 ^a	19.3 ^a
Cling wrap	58.2	50.9 ^b	42.4 ^b	34.5 ^b	25.5 ^b	50	44.5 ^b	41.5 ^b	36.3 ^b	33.6 ^b
Shrink wrap	58.2	54.5 ^c	45.1 ^c	36 ^c	27.3 ^c	50	48.4 ^c	43.6 ^c	35.6 ^c	34.3 ^c
Vacuum pack	58.2	52.7 ^c	49.1 ^d	37.5 ^d	34.5 ^d	50	46.9 ^d	43 ^d	42.2 ^d	41.3 ^d
Modified atmosphere pack	58.2	55.5 ^d	50 ^d	42.2 ^e	36 ^e	50	47 ^e	44.6 ^e	42.2 ^d	41.1 ^d

Means with different superscript are different from each other

Fig. 3 Polyphenol oxidase activity in individually wrapped guava fruits stored at room temperature for 8 days. Bars followed by different letters are significantly different at $P < 0.05$. *(1 unit = Change in 1.0 O.D/g/h under standard conditions for enzyme polyphenol oxidase at 430 nm)

Table 3 Effect of different packaging materials on organoleptic characteristics of guava fruits stored at room temperature

Treatments	Aroma					Taste				Texture				Overall acceptability			
	0	2	4	6	8	2	4	6	8	2	4	6	8	2	4	6	8
Control	7	8 ^a	5.5 ^b	–	–	8 ^a	5.5 ^b	–	–	7.8 ^a	5.2 ^b	–	–	7.6 ^a	5.6 ^b	–	–
Cling film	7	7.4 ^a	7 ^b	6.5 ^c	5.9 ^d	7.4 ^a	7 ^b	6.5 ^c	5.9 ^d	7.5 ^a	6.5 ^b	6 ^c	5.3 ^d	7.4 ^a	6.9 ^b	6.6 ^c	5.9 ^d
Shrink wrap	7	7.4 ^a	7 ^b	6.5 ^c	5.5 ^d	7.4 ^a	7 ^b	6.5 ^c	5.5 ^d	7.5 ^a	6.8 ^b	6.2 ^c	5.6 ^d	7.4 ^a	7 ^b	6.3 ^c	5.7 ^d
Modified atmosphere pack	7	7.2 ^a	6.5 ^b	5.2 ^c	4.8 ^d	7.2 ^a	6.5 ^b	5.2 ^c	4.8 ^d	7.1 ^a	7.5 ^b	7.2 ^c	6.6 ^d	7.2 ^a	6.8 ^b	6.2 ^c	5.5 ^d
Vacuum pack	7	7 ^a	6.4 ^b	5 ^c	4.6 ^d	7 ^a	6.4 ^b	5 ^c	4.6 ^d	7.2 ^a	7.8 ^b	7.4 ^c	6.8 ^d	7.1 ^a	6.6 ^b	6 ^c	5.3 ^d

Means with different superscripts (a, b) in row differ significantly ($P < 0.05$) from each other

The organoleptic quality of wrapped fruits improved initially while at later storage period decreased significantly. For unwrapped control fruits, the overall acceptability of control fruits was below the acceptable limit by 6th day of storage. Cling and shrink wrapped fruits had highest score of 7.4 by 2nd day, which then decreased to 5.8 and 5.7 by 8th day. Acceptability of MAP and vacuum packed fruit was not significantly affected by 2nd day and decreased to 5.5 and 5.3 by 8th day of storage.

Percent marketability

The control guava lost its marketability by 4th day. At 6th day the marketability of cling and shrink wrapped fruit reduced to 50 and 60% respectively but still organoleptically acceptable by judges. Vacuum packed and MAP

samples maintained marketability (75 and 80%) up to 6th day of storage but became organoleptically unacceptable at 8th day of storage due to anaerobic respiration.

Discussion

As observed in the present study, remarkable reduction in PLW in individual polythene packed banana fruits had also been reported by Hailu et al. (2014). The direct contact of control fruits with atmosphere led to higher respiration and evapo-transpiration rates. Polythene wrapping formed an extra covering by adhering to the surface of fruit, completely isolates fruits from each other and thus act as a barrier for pathogens to spread. It reduced respirational and evapo-transpirational losses, maintained turgidity and

modified the atmospheric composition around the fruit (O_2 depletion and CO_2 accumulation) resulting in reduced respiration rate and lower PLW (Rai et al. 2011).

Relatively higher decay loss was observed in individually cling wrapped chilli fruits as compared to PVC wrapped chilli fruits at ambient temperature (25–30 °C) (Brar et al. 2000) as observed in present study. No decay loss was observed in vacuum packed and modified atmosphere packed fruits which may be due to the prevention of dust and other microbial contamination (Nath et al. 2012). Left out spaces in cling film wrapped fruits and uneven thickness in shrink wrapped fruits led to direct exchange of gases (Sehwag and Das 2016). Shrink wrapped cucumber were reported to have lower decay incidence, well retained physico-chemical attributes and lower respiration rate as compared to unwrapped cucumber (Dhall et al. 2012).

Due to climacteric nature of fruits, the rise in respiration rate takes place during storage when harvested at green mature stage. Sahoo et al. (2015) had reported increased respiration rate in guava fruit cvs. ‘Allahabad Safeda’ during room temperature storage. A number of previous studies support our finding of reduction in respiration rate in polythene packed fruit to the extent which can delay the climacteric ripening. Patel et al. (2009) and Singh et al. (2015) reported reduction in respiration rate in passion fruits packed in Polythene terephthalate (PET) stored at ambient (18–23 °C, 58–77% RH) conditions and in individually wrapped pomegranate fruits in polythene bags as compared to control respectively. Vacuum packed fruits had lowest respiration rate and PLW followed by modified atmosphere packed fruits, probably because of reduced O_2 concentration and removal of ethylene from the intercellular spaces (Porat et al. 2009). In a previous study, vacuum packed sapota fruits were also reported to have lowest respiration rate as compared to LDPE packed fruit stored at 15 °C (Siddiqui et al. 2014). Control fruits showed decrease in respiration rate probably due to the post climacteric decline and skin dryness which possibly prevented the exchange of gases.

Lower turgidity of cells due to moisture loss and degradative changes in cell wall structure and composition by breakdown of insoluble protopectin to soluble pectin decreased the firmness of guava. Further conversion of dark green colour to light green or yellowish colour increased the lightness, ‘L’, ‘a’ and ‘b’ values. Individual wrapping significantly reduced the decrease in flesh firmness and change in Hunter ‘L’, ‘a’ and ‘b’ values of fruits during storage by modifying the atmospheric composition which is inhibitory to the ripening process. MAP retained the green color of skin, which means that yellow visual perception delayed and preserved the colour characteristic up to 60 and 90 days for ‘Rocha’ and ‘Packham’ pears, respectively (Zucoloto et al. 2017). As a result, ripening

rate was higher in control fruits only. Remarkable reduction in ripening in individually wrapped guava fruits by LDPE of thickness 150 gauge has also been reported by Sahoo et al. (2014).

According to the present study maximum firmness and delta E values were retained in Vacuum packed fruits followed by MAP, shrink and cling wrapped fruits due to the above described reasons. Higher maintenance of the flesh firmness in shrink packed fruits under MAP was also recorded in pear during storage (Mahajan et al. 2015). Vacuum packaging of Sapota in polyethylene bags (200 gauge thickness) stored at 15 °C maintained texture and increased the shelf life up to three weeks (Siddiqui et al. 2014). Decrease in the Hunter Lab values of control fruits has indicated darkening or decay loss and zero value of ‘a’ indicates grayness as the fruit started decaying. The decreased Hunter Lab value thus indicated over-ripening.

With the advancement of storage rise in TSS of fruits and decrease in acid content was reported in sapota (Jindal et al. 2005) stored at ambient (30–35 °C, 40–60% RH) conditions. The progressive decrease in acidity could be due to the conversion of acids into sugars during ripening process. Individual wrapping slowed down the rise in TSS and reduction in acidity by modifying the gaseous composition of pack which reduced the metabolic activities and thus delayed the ripening process. The results of present investigation are in accordance with the previously reported results. Sharma et al. (2012) reported a delayed and sustained increase in total soluble solids of shrink film packed kiwi fruits. Delayed increase in TSS in individually seal packed ‘kinnow’ by HDPE of 0.1 µm thickness as compared to unwrapped fruits has also been reported by Randhawa et al. (2009).

Decrease in ascorbic acid with the increasing duration of storage was also reported in bell pepper stored at 27 °C and 65% RH (Sahoo and Matche 2006) and waxed apples at 27 and 10 °C (Wu 2000). Loss of ascorbic acid during storage was due to the oxidation by ascorbic acid oxidase enzyme. The results obtained in the present investigation are in accordance with the previous findings of Nath et al. (2012), where higher retention of ascorbic acid had been reported in 150 gauge polypropylene packed pear fruits as compared to control fruits stored at room temperature.

With the advancement of storage total phenol content decreases due to increased activity of polyphenol oxidase enzyme which is responsible for the oxidation of phenols. Similar increase in activity of PPO with the advancement of storage was reported in guava cv. ‘Hisar Safeda’ stored at low temperature (Rana et al. 2015, 2018). Individual wrapping retained the phenol content during storage by delaying the ripening process and reducing the extent of increase in PPO activity. Similarly, lower decrease in tannin content as compared to control fruits in 100 gauge

LDPE packed litchi stored at 27 °C and 65% RH has been reported by Neog and Saikia (2010). Higher phenol content in vacuum and modified atmosphere packed fruits is due to atmospheric composition in polytene pack which is inhibitory to ripening process.

The slightly increased taste scores of guava fruits could be associated with the increased sugar content. At later storage periods, decrease in taste could be attributed to undesirable aroma development. In the present investigation, wrapped guava fruits except MA and vacuum packed remained organoleptically acceptable with respect to taste even by the end of storage period. The development of off flavour with accumulation of ethanol and acetic acid were the main factors responsible for the reduction in organoleptic score of Modified Atmosphere and vacuum packed fruit. Due to optimum ripening and desirable texture cling and shrink wrapped fruits remained acceptable at the end of storage. The hardening of fruits in MAP and vacuum pack could be possible due to gelling behaviour of water soluble pectins, which reconstitute to form protopectin and lead to flesh hardening on prolonged storage.

The low density polyethylene film was efficient in maintaining the skin colour, pulp texture and overall quality (Jacomino et al. 2001). Our results are in agreement with Sahoo et al. (2015) that better results were obtained under ambient storage with LDPE and PP where the marketability was reduced to 80 and 82% respectively in 4 days of storage. Organoleptic score of fruits first increased and then decreased in all treatments due to ripening during the storage. Amongst the various wrapping methods, vacuum packing and MAP though showed minimum PLW, decay loss and ripening but suffered from the drawback that fruits remained hard and scored low organoleptically. Cling wrapping and shrink wrapping were the best treatments that enhanced the shelf life of fruits by 4 days at room temperature.

Conclusion

It can be concluded from the present investigation that the unwrapped control fruits had the shelf life of about 4 days at room temperature. Under various packaging conditions, the PLW remained lesser than 15% even by 8th day of storage. Amongst the various wrapping methods, vacuum packing and MA though showed minimum PLW, decay loss and ripening but suffered from the drawback that fruits remained hard and unripened and scored low organoleptically. Cling wrapping and shrink wrapping were the best treatments that enhanced the shelf life of fruits by 4 days at room temperature.

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