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ORIGINAL ARTICLE

Effect of packaging materials and storage environment on postharvest quality of papaya fruit

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Abstract This experiment was conducted to assess the effects of packaging materials and storage environments on shelf life of papaya fruit (*Carica papaya L.*). A factorial combination of five packaging materials and two storage environments using randomized complete block design with three replications were used. The papaya fruits were evaluated for weight loss, percentage marketability, firmness, total soluble solids, pH, titratable acidity, ascorbic acid, reducing sugar and total sugar content. The packaged and cooled fruits remained firmer than unpackaged and evaporatively cooled fruits. Higher chemical compositions were recorded in the control fruits stored under ambient conditions during the earlier times of storage. Packaging and cooling maintained the chemical quality of papaya fruits better than the control sample fruits towards the end of storage periods. The evaporatively cooled storage combined with packaging improved the shelf life of papaya fruits by more than two fold. The polyethylene bag packaging combined with evaporatively cooled storage maintained the superior quality of papaya fruit for a period of 21 days. This integrated agro-technology is recommended for postharvest loss reduction biotechnology in hot regions.

Keyword Papaya · Packaging · Evaporative cooling · Quality · Storage

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Introduction

In spite of the great potential for production of papaya in Ethiopia, the fruit industry has not been contributing much to the economy of the country. Partly due to this reason, the production and the consumption of fruits is relatively lower in developing countries (Emana and Gebremedhin 2007). Postharvest technologies have not been developed for most of the major fruit crops. Marketing of fruits and vegetables in Ethiopia is complicated by high postharvest losses which are estimated to be as high as 25–35% (Tadesse 1991). It has also been estimated by the FAO (2005) that the postharvest loss of perishable commodities in Ethiopia is as high as 50%. This high loss has been attributed to several factors among which lack of packaging and storage facilities and poor means of transportation are the major ones (Kebede 1991; Wolde 1991). In spite of this, very little emphasis was given to research on postharvest handling of perishable produce (Tadesse 1991). The postharvest losses could discourage farmers from producing and marketing fresh produce and limit the urban consumption of fresh fruits and vegetables. Hence, development of postharvest technologies is believed to make great contribution to improve quality and use of these crops.

Reduction of the losses in a systematic way requires knowledge of postharvest physiology, its applied technical aspect, handling and the appreciation of its biological limitation represented as storage potential (Nakasone and Paull 1999). Packaging and handling systems have been developed in many countries to move products from farm to consumer expeditiously in order to minimize quality degradation. Procedures include lowering temperature to slow respiration and senescence, maintaining optimal relative humidity to reduce water loss without accelerating decay, adding chemical preservatives to reduce physiological and microbial losses, and maintaining an optimal gaseous environment to slow respiration and senescence (Wills et al. 1989; Tigist et al. 2011; Workneh et al. 2011a,b; Awole et al. 2011). Packaging fruits is one of the most commonly used postharvest practice that puts them into unitized volumes which are easy to handle while also protecting them from hazards of transportation and storage (Burdon 2001). Modified atmosphere packaging for storage and transportation of fruits and vegetables is commonly achieved by packing them in plastic films. Storage in plastic films with different kinds of combinations of materials, perforation and inclusions of chemicals and individual seal packaging are types of modified atmosphere storage (Burdon 2001; Irtwange 2006).

The root cause of postharvest deterioration that needs to be inhibited is enhanced metabolism, whether due to natural senescence physiology or biotic or abiotic stress, with the main technological interventions involving control of temperature and humidity of the atmosphere around the produce (Wills et al. 1989). It is essential to control storage temperature and relative humidity during storage as they are the main causes of fruit and vegetable deterioration during ripening and storage. Temperature of the produce and surrounding air can be reduced by forced air-cooling, hydro cooling, vacuum cooling, ice cooling, and evaporative cooling (Thompson et al. 1998; Awole et al. 2011). The evaporatively cooled environment is suggested to be a good alternative for the small-scale peasant farmers, retailers, and wholesalers in Ethiopia, as it require low initial and running cost compared to other cooling methods (Workneh and Woldetsadik 2004; Tigist et al. 2011; Workneh et al. 2011a,b).

In developing countries, considerable quantity of papaya is wasted before it reaches the target markets due to limited shelf life of the fruit and poor postharvest handling (Emana and Gebremedhin 2007, Ignacio et al. 2011). Papaya fruits are produced mainly for local markets while some percentage is also exported to neighboring countries such as Djibouti and Somaliland. Similar to other exported fresh produces, papaya marketing lacks standardization formalities such as grading system and packaging. Hence, information on papaya shelf life and methods of mitigating postharvest losses can be of high value for growers, distributors and exporters. So far research on this crop has been limited; few postharvest researches have been undertaken in spite of the high postharvest loss incurred at the various marketing levels between production and consumption. Therefore, the present study was initiated with the main aim of shelf life improvement. The specific objectives of the study are to evaluate the effect of different packaging materials on the shelf life of papaya and to compare the impact of evaporative cooling and ambient storage environments on the shelf life and quality of papaya.

Material and methods

Experimental site The experiment was conducted at Dire Dawa farm of Haramaya University during the period from August 2007 to March 2008. The site is located at 9°27–9° 49′N latitude and 41°38′–42°9′E longitude and at an altitude of 1160 m above sea level. The mean annual precipitations is 520 mm. and mean maximum and minimum temperatures range from 28.1 to 34.6 °C and 14.5 °C to 21.6 °C, respectively. The texture of the soil is sandy loam with an average pH of 8.54.

Treatments and experimental design A factorial combination of five packaging materials: perforated high density polyethylene (HDPE) film, perforated low density polyethylene (LDPE) film, dried banana leaves (BL), newspaper (NP) and control (only wooden crates); and two storage environments (evaporatively cooled storage and ambient storage) with three replications were used in the study. The treatments were arranged in a randomized complete block design with three replications.

Experimental procedures Papaya (*Carica papaya* L. cv. Solo) fruits were obtained from Haramaya University fruit and vegetable farm in Dire Dawa. Based on visual maturity determination, green mature papayas with about 25% yellowed skin were harvested with the aid of experienced personnel (Paull and Chen 1997). Harvesting was carried out manually with maximum care to minimize mechanical damage. Fruits were selected for uniformity of color, size, shape and freedom from defects. Immediately after selection, fruits were washed with tap water containing 2% sodium hypochlorite solution to remove field heat, soil particles and to reduce microbial population.

After surface drying with cheese cloth, the fruits were subdivided and packed with the different packaging materials in wooden boxes and stored in evaporative cooler (EC) and at ambient (AM) conditions with three replications. Each treatment per replication consisted of 30 fruits. Hence, a total of 900 fruits were kept under the two storage conditions in which 450 fruits were under evaporative cooler and 450 fruits at ambient temperature. A modified version of the ventilated evaporative cooler designed by Workneh and Woldetsadik (2004) was used in this investigation as one of the storage environments.

Data collection Samples of nine fruits per treatment were taken to Horticultural Laboratory of the Department of Plant Science at Haramaya University for chemical analysis every third day. Nine fruits kept for non-destructive evaluation per treatment, were used on times corresponding to 0, 3, 6, 9, 12, 15, 18 and 21 days after storage.

The storage air temperature and relative humidity were recorded throughout the storage period using digital psychrometer units (Jenway-digital psychrometer 5105, UK). The readings were made at two hours intervals during the daytime from 6:00 h over the study period.

The physiological weight loss (WL) was determined using the methods described by Mohammed et al. (1999). Weight loss of fruits was calculated from the initial weight of nine individual papaya fruit per treatment and at each storage interval during the 21 days storage period. Marketability of the fruits was subjectively assessed according to the procedure described by Mohammed et al. (1999). The descriptive quality attributes were determined by observing the level of decay, color, surface defects, and shriveling. A 1–9 rating, with 1 = unusable, 3 = unsalable, 5 = fair, 7 = good, and 9 = excellent, was used to evaluate the fruit quality. 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. The firmness of fruit was measured manually using a digital penetrometer (model FT 011; 0–11 lbs). Each fruit was dissected vertically, each half placed on a table with the cut area facing up, and the plunger vertically pressed in to the flesh along the cut surface. The average readings (kg cm^{-2}) were recorded for firmness determination.

The total soluble solids (TSS) were determined after the peel, placenta and seeds were removed, and the flesh of papaya halves from the fruit was homogenized in a laboratory blender using an aliquot of the juice. Two drops of clear juice was placed on the prism of digital hand held refractrometer (Palm Abbe™) with a range of 0 to 32°Brix and resolution of 0.2°Brix. Between samples the prism of the refractrometer was washed with distilled water and dried with tissue paper before use. The referactrometer was standardized against distilled water (0%TSS). For pH and titratable acidity (TA) determination, papaya juice was extracted from the sample with a juice extractor and filtered with filter paper. Clear juice was used for the analysis of TA as the methods described by Maul et al. (2000). The pH value of the papaya juice was measured with a pH meter (Jenway model 3320). The TA expressed as percent citric acid, was obtained by titrating 10 ml of papaya juice to pH 8.2 with 0.1 N NaOH. The ascorbic acid (AA) content of papayas was determined by the 2, 6-dichlorophenol indophenol method (AOAC 1970). An aliquot of 10 g papaya puree was diluted to 50 ml with 3% metaphosphoric acid in a 50 ml volumetric flask. The aliquot was then centrifuged for 15 min and titrated with 2, 6-dichlorophenol indo-phenol dye to a pink endpoint (persisting for 15 s).

Reducing and total sugars were estimated using the techniques of Somogyi (1952). Macerated tissue of papaya (10 g) was added to 15 ml of 80% ethanol, mixed and heated in a boiling water bath until the ethanol odor went off. After extraction, 1 ml of saturated Pb $(CH_3COO)_2.3H_2O$ and 1.5 ml of Na_2HPO_4 was added and the contents was mixed by gentle shaking. After filtration, the extract was made up to 50 ml with distilled water. An aliquot of 1 ml extract was diluted to 25 ml with distilled water. Then, 1 ml aliquot mixed with 1 ml copper reagent in a test tube was heated for 20 min in a boiling water bath. After heating, the contents were cooled under running tap water without shaking. Arsenomolybdate color reagent (1 ml) was added, mixed, made up to 10 ml with distilled water and left for about 10 min to allow color development, after which the absorbance was determined by a spectrophotometer at 540 nm in a milton ROY spectronic model 20D spectrophotometer. For total sugar determination, sugar was first hydrolyzed with 1 N HCl by heating at 70 °C for 30 min. After hydrolysis, total sugar was determined following the same procedure employed for the reducing sugar. A blank was prepared using distilled water and the reducing or total sugar was calculated.

Statistical analysis Difference between the treatments was determined by analysis of variance (ANOVA) for factorial experiment in randomized complete block design with three replications using SAS statistical software and comparison of the treatment means was made by LSD test.

Results and discussion

Temperature and relative humidity During the 21 days of storage period, the ambient dry bulb temperature varied between 16.8 °C and 34.0 °C with the average being 27.7 °C. However, the dry bulb temperature inside the evaporative cooler varied between 12.4 and 19.7 °C with the average being 16.8 °C. The relative humidity ranged between 28.5% and 68.6% under the ambient conditions, with the average being 43.0% and between 71.4% and 90.7% in evaporative cooler with the average of 78.8%. For the same location, Workneh and Woldetsadik (2004) reported that the evaporatively cooled chamber maintained the range of temperature varying from 17–26 °C and relative humidity between 43–98%. A report by Tefera et al. (2007) also gives a range of temperature between 14.3 and 19.2 °C and relative humidity from 70 to 82.4% in evaporative cooler. Similarly, Getenit et al. (2008) reported range of 14–19 °C temperature and 82–96% RH for the same evaporative cooler.

In the present study, the average difference in dry bulb temperature between ambient and evaporative cooler conditons was 10.9 °C and that of relative humidity was 35.8%. The minimum differences in temperature (4.3 °C) were found at 6:0, where as the maximum (14.4 °C) difference was recorded at 14:0. Similarly, the minimum (22.1%) difference in relative humidity was recorded at 6:00, while the maximum (45.4%) was obtained at 14:00. The higher rate of evaporation of water from the wet cooling pad at higher environmental temperature could be the reason for such differences (Workneh and Woldetsadik 2004).

There was little fluctuation in temperature and relative humidity in the evaporative cooler during the storage period as compared to the wide fluctuation at ambient condition. This is important from point of view of safe and effective storage of perishable commodities (Burdon 2001; Kundan et al. 2011). However, fruits stored under ambient conditions could be exposed to harsh conditions at 14:00 hr because of high temperature and low relative humidity. It has been previously reported that exposure of papaya fruit to excessively hot temperatures during handling resulted in accelerated ripening, contributing to the depletion of organic acids and sugars due to an increase in the respiration rate, which was normally observed in fruit stored above the optimum temperature (Lam 1990). The evaporative cooler was effective in minimizing the extremes of temperature and RH which is in agreement with the previous reports by Workneh and Woldetsadik (2004), Tefera et al. (2007) and Getenit et al. (2008).

Weight loss Highly significant ($P \leq 0.001$) difference in weight loss of papaya fruits was observed due to the interaction effect of packaging and storage environment during most part of the storage period (Table 1). The weight loss values varied between 0.5 to 14.6% in the evaporative cooler and from 0.76% to 18.3% under ambient condition. The highest weight loss was recorded for control (non packaged) papaya fruits stored under ambient conditions, whereas the lowest was for fruits packaged with high density polyethylene (HDPE) bags and stored in the evaporative cooler.

In general, weight loss of papaya fruits progressively increased during the storage period both under the evaporative cooler and ambient (AM) storage conditions. On day 6 of the storage period, weight loss of non packaged fruits stored at ambient conditions was 8.4% which was significantly ($P \leq 0.001$) higher than weight loss of papaya fruits subjected to all other treatments on the same date. The HDPE packaged fruits had about 78% lower weight loss at ambient and 90% lower in the evaporative cooler storage compared to the loss in non packaged fruits stored at ambient conditions. Fruits packaged with news paper (NP) and banana leaf (BL) and stored at ambient conditions had a relatively higher weight loss next to non packaged ones.

On day 9, maximum weight loss (18.3%) was noticed in non packaged fruits stored at ambient condition which was higher than the weight loss of fruits packaged in HDPE and LDPE bags stored in the evaporative cooler after 21 days of storage. Whereas, fruits packaged with HDPE bags had the lowest weight loss both under ambient storage and in the evaporative cooler compared to other packaging materials and the control in the respective storage environments.

Table 1 The interaction effect of packaging materials and storage environment on the percentage weight loss (%) of papaya fruit during 21 days of storage period

Treatments	Storage periods (days)						
	3	6	9	12	15	18	21
Evaporative cooler							
High density polyethylene	0.51^{i}	0.81^{i}	1.85^{h}	3.98^{c}	6.04^{d}	9.14^{c}	11.48
Low density polyethylene	0.71^{h}	1.06^{h}	2.78^{gh}	4.56^{c}	7.57^{c}	9.66^{c}	12.76
News paper	1.68^{d}	2.65^{d}	3.90^{fg}	6.44^{ab}	9.23^{b}	13.33^{b}	–
Banana leaf	1.13^{f}	1.63^{g}	3.62^{fg}	5.33^{bc}	8.85^{b}	12.52^{b}	–
Control	1.27^{e}	2.03^{e}	4.36^{ef}	7.66^{a}	11.35^{a}	14.61^{a}	–
Ambient condition							
High density polyethylene	0.76^{h}	1.82^{f}	5.34^{de}	–	–	–	–
Low density polyethylene	0.96^{g}	2.08^{e}	6.15^{d}	–	–	–	–
News paper	2.39^{c}	4.45^{c}	11.16^{c}	–	–	–	–
Banana leaf	2.59^{b}	5.77^{b}	14.73^{b}	–	–	–	–
Control	3.46^{a}	8.40^{a}	18.32^{a}	–	–	–	–
CV (%)	4.39	2.81	9.65	12.82	7.18	4.40	8.37
SE	0.04	0.05	0.40	0.41	0.36	0.30	0.59
LSD (5%)	0.12	0.14	1.19	1.35	1.17	0.98	NS
Significance							
Packaging (A)	***	***	***	**	***	***	NS
Storage (B)	***	***	***	–	–	–	–
A*B	***	***	***	–	–	–	–

(n=3)

The data from day 12 onwards is meant for the EC storage only. All fruits stored at ambient were discarded on day 12. NS, **, *** indicate non-significant or significant difference at $P \leq 0.01$ or 0.001, respectively; different letters in a column indicate significant differences at P=0.001.

Banana leaf and newspaper packaged fruits had a weight loss which was significantly lower than the weight loss of non-packaged fruits under respective storage environments. The LDPE packaged fruits which had weight loss similar to those packaged with HDPE also showed significantly lower weight loss compared to news paper and banana leaf packaged fruits under respective storage environments during most part of the storage period. After day 9, however, nearly all papaya fruits stored at ambient conditions were unmarketable while those fruits in evaporative cooler kept well for 18–21 days.

After 18 days of storage in the evaporative cooler, weight loss of papaya fruits packaged in HDPE and LDPE bags were found to be less by 37% and 33.9% when compared with the weight loss of the control fruits, respectively. Similarly, papaya fruits packaged in news paper and banana leaf had 9% and 14.3% less weight loss compared to the weight loss of control fruits, respectively. After 21 days of storage in the evaporative cooler, the weight loss of fruits packaged using HDPE and LDPE packaging materials did not show significant differences.

The control fruits stored under ambient conditions recorded weight loss of 8.4% which is close to the acceptable weight loss threshold level (10%) (Wills et al. 1989) on day 6, whereas those fruits stored in the evaporative cooler approached the threshold after 12 days of storage period. The banana leaf and news paper packaged fruits stored under ambient condition already passed the threshold level on day 9 while those stored in the evaporative cooler reached similar threshold level after 15 days of storage. Similarly, HDPE and LDPE packaged fruits stored in the evaporative cooler reached the threshold level after 18 days of storage.

Generally, the weight loss of fruits was higher under ambient storage condition than in the evaporative cooler. Weight loss of control fruits was significantly ($P \leq 0.01$) higher during most part of the storage period than the packaged fruits both under ambient conditions and in the evaporative cooler. HDPE packaged fruits had the lowest WL throughout the storage period under both storage conditions, LDPE bags maintained better weight compared to other packaging materials. Similarly, the weight losses of news paper and banana leaf packaged fruits were relatively lower than the control fruits in most parts of the storage period.

The weight loss differences among the treatments in this study appear to be due to differences in temperature and relative humidity among the storage environments. Hence, reduced rate of respiration and transpiration at lower temperature and higher relative (RH) humidity could be the reason for such a reduced rate of weight loss of fruits in the evaporative cooler storage (Lam 1990). The difference in water vapor transmission rate of the packaging materials could also play a significant role for the variation of the time to reach the threshold level. About 10.0% physiological loss in weight is considered as an index of termination of shelf life (threshold level) of commodities (Pal et al. 1997). According to Paull et al. (1997) and Proulx et al. (2005), loss of about 8.0% of weight from papaya results in unmarketable fruit as a result of rubbery and low-gloss appearance.

According to Paull and Chen (1989), loss of weight and development of symptoms resulting from water loss, i.e., loss of glossy appearance, softness, shriveling, and dryness of the peel, in papaya fruits are greatly influenced by the relative humidity and temperature of the storage area (Nunes et al. 2006) which is in agreement with the present results. High storage temperature leads to accelerated water loss and subsequently to shriveling and softening of the fruit (Proulx et al. 2005). In the present study, the average RH and temperature of the evaporative cooler were 16.8 °C and 78.8%, respectively, compared to 25.7 °C and 43.0% at the ambient condition. This might have contributed to the high weight loss of papayas in the later storage condition which is associated with faster metabolism and ripening at higher temperature, increased cell wall degradation and higher membrane permeability leading to exposure of cell water for easy evaporation (Lee et al. 1995).

Furthermore, lower weight loss of fruits in the package could be due to slow rate of ripening and prevention of excessive moisture loss. Similar results were also presented by Gonzalez et al. (1990), Lazan et al. (1990), Workneh and Woldetsadik (2004) and Nath et al. (2011). The relatively lower water vapor transmission rate of HDPE plastic may also contribute for the development of relatively higher humidity inside the package (Thompson 2001; Farber et al. 2003; Mathooko 2003). According to Ben-Yehoshua (1985), the main function of packaging is to reduce respiration rate and water loss by transpiration, and injurious atmosphere inside the package, which could affect the fruits metabolism. Higher water vapor transmission rate of the banana leaf and news paper may contribute for the relatively higher weight loss of fruits than the plastic packaged ones.

Percentage marketability Packaging and storage conditions had significant ($P \leq 0.01$) interaction effect on the percentage marketability of papaya fruits (Table 2). The percentage marketability of papaya fruits decreased from 100.0% to about 25.0% in the evaporative cooler after 21 days of storage while under ambient conditions after 9 days of storage all fruits were unmarketable.

On day 3, all papayas in the evaporative cooler and those packaged with perforated plastic film and stored at ambient temperature were in a marketable status. However, the percentage marketability of the control and banana leaf packaged fruits stored at ambient conditions on the same date dropped to 94.0% and 97.0%, respectively. Polyethylene

Table 2 The interaction effect of packaging materials and storage environment on the marketability (%) of papaya fruit during 21 days of storage period

Treatments	Storage periods (days)						
	3	6	9	12	15	18	21
Evaporative cooler							
High density polyethylene	100.0[a]	100.0[a]	94.4[a]	87.3[a]	68.5[a]	48.9[a]	25.0
Low density polyethylene	100.0[a]	100.0[a]	94.4[a]	87.3[a]	70.4[a]	53.3[a]	29.2
News paper	100.0[a]	95.1[b]	84.7[b]	72.8[b]	51.9[b]	22.2[b]	–
Banana leaf	100.0[a]	93.8[b]	83.3[b]	74.5[b]	50.0[b]	22.0[b]	–
Control	100.0[a]	87.7[c]	76.4[c]	63.5[c]	40.7[c]	20.0[b]	–
Ambient condition							
High density polyethylene	100.0[a]	74.07[e]	51.39[e]	–	–	–	–
Low density polyethylene	100.0[a]	79.01[d]	54.17[d]	–	–	–	–
News paper	98.7[ab]	67.90[f]	37.50[f]	–	–	–	–
Banana leaf	97.3[b]	65.43[f]	36.11[f]	–	–	–	–
Control	94.0[c]	58.03[g]	26.39[g]	–	–	–	–
CV (%)	1.2	2.2	2.5	3.9	3.4	8.6	18.8
SE	0.7	1.0	0.9	1.7	1.1	1.7	3.0
LSD (5%)	2.1	3.1	2.7	5.6	3.6	5.4	NS
Significance							
Packaging (A)	**	***	***	***	***	***	NS
Storage (B)	***	***	***	–	–	–	–
A*B	**	**	**	–	–	–	–

(n=3)

Initial (0 day) marketable fruits were 100 percent and the data from day 12 onwards is meant for the EC storage only. All fruits stored at ambient were discarded on day 12. NS, **, *** indicate non-significant or significant difference at $P \leq 0.01$ or 0.001, respectively; different letters in a column indicate significant differences at $P=0.01$.

film packaged fruits stored in the evaporative cooler were intact and 100.0% marketable up to day 6 of the storage period. On the 9th day, only polyethylene film packaged fruits stored in the evaporative cooler had marketability of more than 90.0% while fruits stored under ambient conditions had marketability values ranging from 26.4% (control) to 54.2% (LDPE package).

The termination of shelf life of papayas stored at ambient environment was determined by shriveling, over ripening, discoloration and mould growth. Shriveling and mould growth were predominant on the control fruits and polyethylene packaged fruits, respectively, with mould growth being more in HDPE plastics. Faster transpiration rate at relatively higher temperature may result in shriveling of non packaged fruits. Furthermore, higher respiration rate at higher temperature may lead to senescence because the stored food reserve which provides energy could be exhausted (Paull 1993). On the other hand, condensation of water vapor, which may lead to the buildup of mould growth, may occur in the polyethylene bag due to the lower permeability of the film to water vapor (Thompson 2001).

Papayas stored in the evaporative cooler remained fresh and firm for reasonable period of time. They looked shiny and had attractive color compared to those stored at ambient conditions. This might be attributed to reduced rate of respiration and transpiration of fruits due to relatively lower temperature and higher RH inside the evaporative cooler. Since a higher rate of respiration decreases shelf life (Lee et al. 1995), the use of low temperature is indicated to be the most important means of extending the storage life of postharvest produce (Exama et al., 1993). Generally, the percentage marketability of papayas stored in the evaporative cooler was higher than those stored under ambient condition. Similar results were reported for mango by Workneh and Woldetsadik (2004) and Tefera et al. (2007) and for tomato by Getenit et al. (2008).

Packaged fruits had more number of marketable fruits than the control under both storage conditions. LDPE film packaging had more percent marketable fruits than other package treatments while the control fruits were having the lowest percentage marketability during the storage period. Also, banana leaf and news paper packaging had more number of marketable fruits compared to the control. These beneficial effects can be explained by the modified atmosphere created inside the package as well as the reduction in water loss (González et al. 2003). Lower respiration and ethylene production rates, reduced ethylene action, delayed ripening and senescence, retarding the growth of decay causing pathogens and insects due to modification of the gas atmosphere inside the package could be possible reason to extend the storage life of fruits (Exama et al. 1993; Kader and Rolle 2004).

Firmness Packaging had highly significant ($P \leq 0.001$) effect on firmness of papaya fruits during storage except on day 9. Firmness of papaya fruits during the storage period varied between 1.2 to 9.0 kg cm^{-2} (Table 3). All fruits lost their firmness and became soft after 9 days of storage. On day 3, fruits packaged with HDPE and LDPE bags were relatively firmer than those packaged with newspaper, banana leaf and the control. The control fruits were the least firm than the packaged fruits, those fruits packaged with NP and BL were firmer than the control. On the 6th day storage, there was a significant difference in firmness of fruits packaged with the different materials. HDPE bag packaged fruits were the most firm. Similarly, LDPE bags maintained fruits firmness better next to HDPE bag. Fruits packaged with newspaper, banana leaf and the control lost firmness after 6 days. While, polyethylene bag packaged fruits remained relatively firm till 9 days of the storage period in the evaporative cooler.

Generally, there was softening of fruits as the storage time progressed which could be due to texture modification through degradation of polysaccharides such as pectins, cellulose and hemicellulose that take place during ripening (Irtwange 2006). It has been well established that texture changes in fruits are consequences of modifications by component polysaccharides that, in turn, give rise to disassembly of primary cell wall and middle lamella structures due to enzyme activity on carbohydrate polymers (Manrique and Lajolo 2004). Hence, the differences in decrease of firmness of papaya fruits in the different treatments could partly be explained by differences in rate of respiration that affect solubility and depolimerization of pectins during ripening (Lazan et al. 1995).

Table 3 Effect of packaging materials and storage environment on the firmness (kg cm^{-2}) of papaya fruit during 9 days of storage period

Treatments	Storage periods (days)		
	3	6	9
Packaging (A)			
High density polyethylene	9.0^{a}	3.5 ^{a}	1.4
Low density polyethylene	8.1^{b}	3.0^{b}	1.2
News paper	6.4^{c}	2.6 ^{c}	–
Banana leaf	6.4^{c}	2.2^{d}	–
Control	5.9^{c}	1.7^{e}	–
SE	0.2	0.1	0.1
LSD (5%)	0.6	0.3	Ns
Storage (B)			
Evaporative cooler	7.9^{a}	3.1^{a}	1.3
Ambient condition	6.5^{b}	2.1^{b}	–
SE	0.10	0.10	0.10
LSD (5%)	0.40	0.20	–
CV (%)	6.94	8.70	9.2
Significance			
A	***	***	NS
B	***	***	–
AxB	Ns	**	–

(n=3)

Initial (0 day) firmness was 9.864 kg cm^{-2} and the data from day 9 onwards is meant for the EC storage only. NS, **, *** indicate non-significant or significant difference at $p \leq 0.01$ or 0.001, respectively; different letters in a column indicate significant differences at P=0.001.

Both HDPE and LDPE bags maintained firmness of papaya better than other packaging materials. Similar findings for papaya were reported by Lazan et al. (1993). The newspaper and banana leaf package also maintained firmness of papaya fruits better than the control. These effects of packaging materials may be attributed to their retardation effects of ripening and reduction of water loss (Yamashital et al. 2002; Manrique and Lajolo 2004).

The storage environment affected firmness of papaya fruits significantly ($P \leq 0.001$). Fruits stored in evaporative cooler were firmer till day 9, while those stored in ambient condition were less firm and became soft after 6 days of storage. The relatively higher firmness of fruits in evaporative cooler might be due to the presence of higher relative humidity and lower temperature which will retard the respiration and transpiration rate of the fruits. According to Lazan et al. (1993), the rapid loss in firmness of papaya during ripening at ambient (25 °C) temperature is associated closely with increase in activity of polygalacturonase, pectinmethyl esterase and β-galactosidase as well as with depolymerisation of cell wall pectins.

Total soluble solids The changes in total soluble solids (TSS) content of papaya fruits during the 21 days of storage are displayed in Table 4. There was significant ($P \leq 0.001$) interaction effect of storage environment and packaging materials on the TSS values of fruits which varied between 8.867–11.5°Brix in the evaporative cooler and from 8.3–12.5°Brix under ambient conditions. Camara et al. (1993) reported a range of 8–12°Brix for Solo papayas, which is in agreement with the present result. The values commonly obtained for TSS of papaya ranges from 7.4–19.0°Brix (Wills and Widjanarko 1995; Paull et al. 1997; Wall, 2006; Zaman et al. 2006).

On day 3 and 6, papaya fruits stored under the ambient conditions had more TSS content compared with fruits stored in the evaporative cooler. Under both storage environments, packaged fruits had lower TSS content compared to their respective control treatments while control fruits stored at ambient conditions had more total soluble solid than others. This could be due to accelerated ripening because of higher temperature at ambient conditions and free access of the non packaged fruits to O_2 which increases respiration rates, resulting in faster conversion of starch to soluble sugars (Wills et al. 1989; Lam 1990). There could

Table 4 The interaction effect of packaging materials and storage environment on total soluble solid (°Brix) content of papaya fruit during 21 days of storage period

Treatments	Storage periods (days)						
	3	6	9	12	15	18	21
Evaporative cooler+Packaging							
High density polyethylene	10.0	10.2^{e}	10.6^{c}	10.9^{b}	11.1^{a}	10.7^{a}	10.5
Low density polyethylene	10.1	10.1^{e}	10.7^{bc}	10.9^{b}	11.1^{ab}	10.7^{a}	10.6
News paper	10.3	10.6^{d}	10.7^{bc}	11.5^{a}	11.1^{ab}	9.8^{b}	–
Banana leaf	10.2	10.5^{d}	10.9^{b}	11.3^{a}	10.9^{ab}	9.8^{b}	–
Control	10.4	10.8^{c}	11.4^{a}	11.0^{b}	9.3^{c}	8.9^{c}	–
Ambient condition+packaging							
High density polyethylene	10.6	10.8^{c}	10.2^{d}	–	–	–	–
Low density polyethylene	10.7	10.9^{c}	10.1^{d}	–	–	–	–
News paper	10.9	11.5^{b}	9.4^{e}	–	–	–	–
Banana leaf	10.9	11.5^{b}	9.6^{e}	–	–	–	–
Control	11.3	12.5^{a}	8.3^{f}	–	–	–	–
CV (%)	1.779	1.170	1.224	0.987	1.109	1.208	0.668
SE	0.108	0.074	0.072	0.06	0.068	0.069	0.041
LSD (5%)	ns	0.217	0.217	0.206	0.221	0.227	NS
Significance							
Packaging (A)	**	***	***	***	**	***	NS
Storage (B)	***	***	***	–	–	–	–
A*B	ns	***	***	–	–	–	–

(n=3)

Initial (0 day) TSS value was 10.0 °Brix and the data from day 12 onwards is meant for the EC storage only. All fruits stored at ambient were discarded on day 12. NS, **, *** indicate non-significant or significant difference at $p \leq 0.01$ or 0.001, respectively; different letters in a column indicate significant differences at P=0.001.

also be a concentration effect due to higher water loss in control fruits partially under ambient conditions.

On day 9, control fruits stored in the evaporative cooler attained the highest TSS content (11.4°Brix) while the control fruits stored at ambient conditions had the lowest TSS value (8.3°Brix), which was even lower than the value of papaya fruts subjected to polyethylene package after 21 days storage in the evaporative cooler. HDPE and LDPE bag packaged fruits followed by news paper and banana leaf packaged ones maintained their TSS content better than the control under ambient conditions.

The TSS content of fruits packaged with LDPE and HDPE bags and stored in the evaporative cooler increased slowly and reached their maximum on 15th day of storage and followed by a decreasing trend. Those fruits packaged using news paper and banana leaf and stored under the same storage conditions attained their maximum TSS content on day 12. On the other hand, both packaged and control papayas stored at ambient conditions reached their maximum TSS content on day 6 and then decreased afterwards. The decline of TSS of the fruits at ambient storage is most likely due to the use of the soluble sugars as respiration substrate which is promoted by higher temperature (Lam 1990; Irtwange 2006). High temperature enhances climacteric respiration, which leads to shorter shelf life of fruits (Pinto et al. 2004; Irtwange 2006).

Slight initial rises followed by fall in the TSS levels were observed under both evaporative cooler and ambient storage conditions regardless of the packaging materials. However, the TSS of papaya fruits was maintained at lower level in the evaporative cooler than under ambient storage. These results are similar to those described by Wills and Widjanarko (1995) and Gomez et al. (2002). The slow change in TSS content of fruits stored in the evaporative cooler is in agreement with the findings of Tefera et al. (2007) for mango and Getenit et al. (2008) for tomato. This may be partly attributed to lower temperature and higher relative humidity maintained in the evaporative cooler that could have resulted in slow conversion of starch in to water soluble sugars (Irtwange 2006).

Generally, packaging papaya fruits in polyethylene bags, news paper and banana leaf combined with evaporative cooler storage showed better maintenance of the TSS content towards the end of storage time with relatively higher TSS value for plastic packaged ones. The possible atmospheric modification, that is, reduced O_2 and increased CO_2 created in the package, combined with lower temperature in the evaporative cooler might have delayed ripening of the fruits as a result of reduced respiration rate (Mathooko 2003). Hence, packaged fruits do not rapidly deplete their soluble solids as those of the control fruits as observed in this study.

pH values Table 5 displays the pH values of papaya fruits subjected to different packaging and storage treatments for 21 days. The pH values of papaya fruits varied from 5.0–5.8

Table 5 The interaction effect of packaging materials and storage environment on pH value of papaya fruit during 21 days of storage period

Treatments	Storage periods (days)						
	3	6	9	12	15	18	21
Evaporative cooler+Packaging							
High density polyethylene	5.8	5.6^{a}	5.5^{bc}	5.1^{b}	5.1^{c}	5.2^{c}	5.4
Low density polyethylene	5.7	5.6^{a}	5.3^{d}	5.1^{b}	5.2^{bc}	5.4^{b}	5.4
News paper	5.7	5.6^{a}	5.2^{e}	5.1^{b}	5.4^{a}	5.5^{b}	–
Banana leaf	5.6	5.6^{a}	5.1^{ef}	5.1^{b}	5.3^{ab}	5.4^{b}	–
Control	5.6	5.4^{ab}	5.0^{f}	5.3^{a}	5.2^{bc}	5.8^{a}	–
Ambient condition+							
High density polyethylene	5.6	5.6^{a}	5.4^{c}	–	–	–	–
Low density polyethylene	5.6	5.4^{ab}	5.5^{c}	–	–	–	–
News paper	5.6	5.2^{c}	5.5^{bc}	–	–	–	–
Banana leaf	5.5	5.3^{bc}	5.6^{ab}	–	–	–	–
Control	5.4	5.0^{d}	5.7^{a}	–	–	–	–
CV (%)	1.157	2.062	1.368	1.457	1.323	1.696	1.139
SE	0.037	0.065	0.042	0.043	0.039	0.053	0.036
LSD (5%)	ns	0.196	0.121	0.141	0.130	0.174	NS
Significance							
Packaging (A)	*	**	*	*	*	**	NS
Storage (B)	***	***	***	–	–	–	–
A*B	NS	*	***	–	–	–	–

(n=3)

Initial (0 day) pH value was 5.70 and the data from day 12 onwards is meant for the EC storage only. All fruits stored at ambient were discarded on day 12. NS, *, **, *** indicate non-significant or significant difference at $P \leq 0.05$, 0.01 or 0.001, respectively; different letters in a column indicate significant differences at P=0.05.

when stored in the evaporative cooler and from 5.003–5.670 when stored under ambient conditions, which are comparable to the values reported earlier by Wills and Widjanarko (1995) and Proulx et al. (2005).

On day 3 and 6, pH values of papaya fruits stored in the evaporative cooler were higher than that of fruits stored under ambient condition. Under both storage environments, packaged fruits had higher pH values compared to their respective control treatments. Similar difference in pH value of fruits stored in the evaporative cooler and under ambient conditions was reported for Mango (Tefera et al. 2007). The lower pH of fruits under ambient storage conditions could be associated with the production of acids from catabolism of sugar at faster rate under ambient condition than in the evaporative cooler. High storage temperature leads to faster respiration rate which is responsible for acid production of the fruits (Wills et al. 1989). Hence, lowering the storage temperature can reduce respiration rate and delay senescence of papaya fruits. On the other hand, the higher pH values of packaged fruits could be explained by the relatively reduced respiration rate in the package than in the control fruits. Reduced O_2 and increased CO_2 which could be created as a result of produce respiration could delay the rate of respiration in the package (Mathooko 2003).

On day 9 of the storage period, the pH value of papaya fruits stored under ambient conditions was higher than the pH values of those stored under evaporative cooler. Control fruits stored under ambient condition had the highest value of pH (5.7) while control fruits in the evaporative cooler had the lowest (5.0) pH value compared to that of the packaged fruits under respective storages. The rate of use of acids as respiratory substrates may increase at higher temperature and result in depletion of acid content of fruits stored at ambient condition (Wills et al. 1989). From day 12 onwards, control fruits stored in the evaporative cooler had higher pH value compared with the packaged ones. News paper and banana leaf packaged fruits attained their minimum pH value on day 12 whereas fruits packaged with HDPE and LDPE bags attained their minimum after 15 days storage.

The pH values of papaya, generally, decreased with ripening of the fruits; however a tendency of increase in the pH value was observed towards the end of the storage time and this could be attributed to the fact that fruits at the time proceeding the ripening process is going to diminish its predominant malic acid (Selvaraj et al. 1982). The decreasing trend followed by an increase in pH value of papaya with advance in storage time is in agreement with the previous findings by Camara et al. (1993) and Wills and Widjanarko (1995).

Titratable acidity The interaction between packaging materials and storage environment had significant ($P \leq 0.001$) effect on the titratable acidity of papaya fruits (Table 6). In this study, the TA value varied from 0.30% to 0.48% in the evaporative cooler and 0.36% to 0.54% under ambient storage conditions respectively. Other authors also reported

Table 6 The interaction effect of packaging materials and storage environment on the titratable acidity (%) of papaya fruit during 21 days of storage period

Treatments	Storage periods (days)						
	3	6	9	12	15	18	21
Evaporative cooler+packaging							
High density polyethylene	0.477[de]	0.379[e]	0.387[e]	0.403[bc]	0.483[a]	0.367[a]	0.350
Low density polyethylene	0.370[e]	0.377[e]	0.388[e]	0.397[c]	0.480[a]	0.363[a]	0.353
News paper	0.383[cde]	0.397[d]	0.410[cd]	0.437[a]	0.363[bc]	0.350[ab]	–
Banana leaf	0.387[cde]	0.400[d]	0.417[bcd]	0.447[a]	0.373[b]	0.343[b]	–
Control	0.389[cd]	0.427[c]	0.473[a]	0.424[ab]	0.350[c]	0.300[c]	–
Ambient condition+packaging							
High density polyethylene	0.397[c]	0.456[b]	0.433[b]	–	–	–	–
Low density polyethylene	0.380[cde]	0.383[de]	0.400[de]	–	–	–	–
News paper	0.433[b]	0.467[b]	0.423[bc]	–	–	–	–
Banana leaf	0.432[b]	0.470[b]	0.420[bc]	–	–	–	–
Control	0.457[a]	0.537[a]	0.357[f]	–	–	–	–
CV (%)	1.879	2.187	2.278	3.154	2.044	2.727	1.161
SE	0.004	0.003	0.004	0.008	0.005	0.005	0.002
LSD (5%)	0.017	0.017	0.017	0.025	0.016	0.018	Ns
Significance							
Packaging (A)	***	***	***	**	***	***	NS
Storage (B)	***	***	***	–	–	–	–
A*B	***	***	***	–	–	–	–

(*n*=3)

Initial (0 day) TA value was 0.37% and the data from day 12 onwards is meant for the EC storage only. All fruits stored at ambient were discarded on day 12. NS, **, *** indicate non-significant or significant difference at $P \leq 0.01$ or 0.001, respectively; different letters in a column indicate significant differences at $P=0.001$.

similar TA values of papaya fruits with a range varying from 0.20% to 1.0% (Camara et al. 1993).

Generally, TA of papaya fruits showed a trend of an initial increase followed by a decrease. This trend is in agreement with the findings of Lazan et al. (1989) and Bron and Jacomino (2006) which showed increased TA content of papaya towards ripening and then followed by a decrease which could be due to its use by the cells as a respiration substrate (Selvaraj et al. 1982).

On day 6 of storage, the TA of control fruits stored at ambient condition was 0.54% which was significantly higher than TA values in all other treatments. LDPE packaged fruits had 0.38% TA in the evaporative cooler and 0.383% at ambient conditions, values were significantly ($P \leq 0.001$) lower than in fruits packaged with paper, banana leaf and the control under both storage environments. However, the control fruits under ambient storage had the lowest TA value (0.36%) on day 9. On day 12, papaya fruits packaged in banana leaf and news paper and stored in the evaporative cooler had higher TA content. Fruits packaged with plastics showed higher value of TA towards the end of the storage period, which was followed by those packaged using banana leaf and paper.

The lower TA value of polyethylene bag packaged fruits in the evaporative cooler could be explained by the reduced rate of respiration which results in slow production of acids as a result of carbohydrate catabolism. On the other hand, the higher loss of TA in control fruits could be due to depletion of organic acids as a result of relatively faster respiration and ripening rate of fruits at ambient storage (Wills et al. 1989). The atmospheric modification created when fruits are packaged with polyethylene bags may delay respiration and as a direct effect, the consumption of respiration substrates such as organic acids and sugars is retarded. Consequently, as the fruit respires, the O_2 level could decrease and the CO_2 level increases in the bags (Kader 1985). Under these atmospheric conditions, the respiration rate of the fruit decrease which is helpful since high acidity in fruit has been suggested to contribute in part to the flavor retention of ripened fruit (Bron and Jacomino 2006).

In general, the TA value of papaya fruits was maintained at relatively lower level in the evaporative cooler than at ambient storage. Evaporative cooler maintained lower temperature and higher relative humidity than ambient storage. Lower TA in fruits at high relative humidity and in the package during earlier periods of storage may be due to reduced rate of acid production from carbohydrates as a result of slow respiration rate (Wills et al. 1989). Furthermore, slow respiration as well as transpiration rate may contribute for higher retention of water in fruits (Mathooko 2003). Therefore, the concentration effect caused by water loss may be reflected on TA values of fruits.

Ascorbic acid The interaction effect of packaging materials and storage environment on the ascorbic acid (AA) content of papaya fruits was significant ($P \leq 0.05$) except on day 3 of the storage period (Table 7). The AA content of papaya fruits in this study varied from 39.690–50.0 mg100^{-1} g which is an agreement with the literature. A range of 36.3–67.8 mg100^{-1} g AA content of papaya fruit was reported by Wills and Widjanarko (1995) and Wall (2006).

On day 3 and 6, the AA content of fruits stored at ambient condition was higher than in the evaporative cooler. During these periods, the control fruits recorded significantly higher AA than all other treatments. However, polyethylene packaged fruits tended to have the lowest AA value at both days of storage while banana leaf and news paper packaged fruits had higher AA content next to the control.

After 9 days storage, control fruits in the evaporative cooler had the highest AA value and the lowest at ambient storage condition. Whereas, after 12 days storage, NP and BL packaged fruits attained their maximum AA value, polyethylene packaged fruits reached their maximum AA content after 15 days of storage which remained higher than in fruits packaged with banana leaf, news paper and the control. Especially, papaya fruits packaged with polyethylene bags had consistently higher AA content than in fruits with other packaging treatments. Similar results were presented by Singh and Rao (2005).

As a general trend, AA content of papaya fruits increased with ripening under both storage conditions and showed a decline there after. This trend was in agreement with the previous reports by Wills and Widjanarko (1995) and Bron and Jacomino (2006) which indicated that AA content increased with stage of ripening and decreased once the fruit reached full ripe stage. The authors reported that cell wall degradation during ripening provides substrates for AA synthesis, explaining the AA increase of papayas with advance in ripening (Bron and Jacomino 2006).

AA content increased rapidly and was higher under ambient storage than in the evaporative cooler, being higher for control fruits than the packaged ones. As storage time advanced, the trend was changed. Fruits stored in the evaporative cooler showed higher AA content than those stored under ambient conditions. Similarly, packaged fruits showed more AA content than the control papayas. This could be due to the reduced rate of respiration at low temperature and in the polyethylene bags that retards aging as well as depletion of acids. On the other hand, high temperature increased enzymatic catalysis that leads to biochemical breakdown of compounds in the fruits (Yeshida et al. 1984). Furthermore, possible reduction in internal O_2 and a decrease in ethylene concentration might explain the presence of higher value of AA in packaged fruits through delay in respiration and ripening of the packaged fruit (Kader 1985).

Reducing sugar Table 8 displays the effect of storage environment and packaging material on reducing sugar content of papaya fruit during the 21 days of storage period. The reducing sugar concentration varied from 6.2–8.9 mg100^{-1} g of fresh weight. A range of 3.4% to 6.9% reducing sugar, which

Table 7 The interaction effect of packaging materials and storage environment on the ascorbic acid content (mg 100 g^{-1}) of papaya fruit during 21 days of storage period

Treatments	Storage periods (days)						
	3	6	9	12	15	18	21
Evaporative cooler+Packaging							
High density polyethylene	41.1	42.5^{fg}	44.0^{cd}	45.9^{b}	47.0^{a}	43.5^{b}	40.9
Low density polyethylene	41.0	42.4^{g}	45.0^{bc}	46.3^{b}	48.2^{a}	45.6^{a}	41.1
News paper	41.8	44.0^{def}	46.3^{b}	49.0^{a}	44.9^{b}	40.8^{c}	–
Banana leaf	41.9	43.5^{efg}	45.7^{bc}	48.7^{a}	44.4^{bc}	40.7^{c}	–
Control	43.1	45.2^{cd}	48.8^{a}	47.4^{ab}	43.1^{c}	40.6^{c}	–
Ambient condition+Packaging							
High density polyethylene	42.3	43.7^{defg}	41.0^{ef}	–	–	–	–
Low density polyethylene	42.1	44.8^{cde}	42.0^{de}	–	–	–	–
News paper	43.8	46.3^{c}	40.6^{ef}	–	–	–	–
Banana leaf	43.2	47.9^{b}	41.2^{ef}	–	–	–	–
Control	45.1	50.0^{a}	39.7^{f}	–	–	–	–
CV (%)	1.629	2.021	2.709	2.067	1.812	2.443	2.606
SE	0.400	0.526	0.679	0.567	0.476	0.596	0.616
LSD (5%)	ns	1.562	2.018	1.847	1.553	1.943	3.751
Significance							
Packaging (A)	***	***	ns	*	***	**	NS
Storage (B)	***	***	***	–	–	–	–
A*B	ns	*	**	–	–	–	–

(*n*=3)

Initial (0 day) AA was 40.98 mg100^{-1} g and the data from day 12 onwards is meant for the EC storage only. All fruits stored at ambient were discarded on day 12. NS, *, **, *** indicate non-significant or significant difference at $p \leq 0.05$, 0.01 or 0.001, respectively; different letters in a column indicate significant differences at $P=0.05$.

Table 8 Effect of packaging materials and storage environment on the reducing sugar content (mg 100 g^{-1}) of papaya fruit during 21 days of storage period

Treatments	Storage periods (days)						
	3	6	9	12	15	18	21
Packaging (A)							
High density polyethylene	7.0	7.3^{bc}	7.3^{d}	7.7^{b}	8.9^{a}	7.5^{a}	7.1
Low density polyethylene	6.9	7.2^{c}	7.4^{cd}	7.6^{b}	8.0^{a}	7.6^{a}	7.4
News paper	7.3	7.7^{ab}	7.8^{b}	8.7^{a}	7.3^{bc}	7.4^{a}	–
Banana leaf	7.0	7.4^{bc}	7.6^{bc}	8.8^{a}	7.4^{b}	7.4^{a}	–
Control	7.4	8.0^{a}	8.2^{a}	7.0^{b}	6.5^{c}	6.2^{b}	–
SE	0.247	0.173	0.111	0.302	0.3	0.231	0.179
LSD (5%)	ns	0.513	0.331	0.986	0.8	0.753	ns
Storage (B)							
Evaporative cooler	7.2	7.2^{b}	8.0^{a}	8.0	7.8	7.2	7.3
Ambient condition	7.0	7.8^{a}	7.3^{b}	–	–	–	–
SE	0.156	0.109	0.070	0.135	0.115	0.103	0.126
LSD (5%)	ns	0.325	0.209	–	–	–	–
CV (%)	8.489	5.641	3.572	6.570	5.660	5.559	4.268
Significance							
A	ns	*	***	*	**	*	NS
B	ns	**	***	–	–	–	–
AxB	ns	ns	**	–	–	–	–

(n=3)

Initial (0 day) reducing sugar content was 6.915 mg100^{-1} g and the data from day 12 onwards is meant for the EC storage only. All fruits stored at ambient were discarded on day 12. NS, *, **, *** indicate non-significant or significant difference at P<0.05, 0.01 or 0.001, respectively; different letters in a column indicate significant differences at P=0.05.

is lower than the findings of the present study, was reported by Zaman et al. (2006). This could be attributed to variation in growing conditions and variety.

Packaging had significant ($P\leq0.05$) effect on the reducing sugar content of papaya fruits during most parts of the storage period. Up to day 9, control fruits had higher reducing sugar content compared with the packaged ones while the later seemed to maintain higher reducing sugar towards the end of the storage time. Fruits packaged with NP and BL had higher reducing sugar content on day 12, whereas those packaged with HDPE and LDPE bags attained maximum reducing sugar content on day 15 and onwards. This can be explained by the beneficial effect of packaging materials in increasing shelf life of perishable commodities by retardation of ripening and senescence processes partially through reduction of O_2 and increase of CO_2 concentrations in the packaging head space (Ben-Yehoshua 1985; Irtwange 2006). Low O_2 and high CO_2 in the head space reduce respiration and the production of ethylene during storage in passive MAP, which in turn reduces physiological, chemical and chemical changes responsible for the fruits quality deterioration (Mathooko 2003; Irtwange 2006).

Storage temperature significantly ($P\leq0.01$) affected the reducing sugar content of papaya fruits from day 6 onwards. Considerable increase and then decrease in the reducing sugar content was observed in papayas stored under ambient conditions compared to those stored in the evaporative cooler. Under the later storage, the sugar content of the fruits was maintained for relatively longer duration.

On the 9th day of storage, fruits stored in the evaporative cooler had significantly (P 0.001) higher reducing sugar content than those stored under ambient conditions. Similar results were presented by Tefera et al. (2007) for tomato and mango, respectively. This could be as a result of reduced temperature in the evaporative cooler that reduces fruit metabolism, particularly respiratory activity which delays the ripening process and increasing fruit shelf life. Since reducing sugars such as glucose and fructose are the main substrates in the respiratory process, their utilization is high at relatively higher temperature (Willey 1994) which may explain the lower reducing sugar content of fruits during later storage period.

The interaction effect of packaging and storage environment on reducing sugar content of papaya was not significant except on day 9 of the storage period.

Total sugar The total sugar (TS) content of papayas in the present study varied from 11.023–14.998 mg100^{-1} g of fresh weight (Table 9) which is similar to the ranges reported in the literature (Camara et al. 1993; Gomez et al. 2002; Zaman et al. 2006). The fruits exhibited a slight increase of total sugars towards ripening and decrease afterwards. Similar trend was reported by Gomez et al. (2002).

Packaging had significant ($P\leq0.05$) effect on TS concentration of papaya fruits except on day 3 and day 21 of the storage period. It maintained higher TS during the later period of the storage than in the control papaya fruits. However, the control fruits were found to contain higher

Table 9 Effect of packaging materials and storage environment on total sugar content (mg 100 g^{-1}) of papaya fruit during 21 days of storage period

Treatments	Storage periods (days)						
	3	6	9	12	15	18	21
Packaging (A)							
High density polyethylene	11.8	12.2^{c}	13.0^{c}	14.1^{ab}	14.9^{a}	13.5^{a}	11.9
Low density polyethylene	12.0	13.0^{b}	13.7^{bc}	14.3^{ab}	14.6^{a}	14.3^{a}	12.6
News paper	12.4	13.1^{b}	14.3^{ab}	15.0^{a}	12.6^{b}	12.0^{b}	–
Banana leaf	12.1	13.3^{ab}	14.2^{ab}	15.0^{a}	13.8^{ab}	11.0^{b}	–
Control	12.6	13.8^{a}	15.0^{a}	13.0^{b}	12.3^{b}	11.8^{b}	–
SE	0.309	0.200	0.298	0.442	0.469	0.435	0.258
LSD (5%)	ns	0.594	0.887	1.349	1.531	1.419	ns
Storage (B)							
Evaporative cooler	11.4^{b}	12.6^{b}	15.1^{a}	14.3	13.6	12.5	12.2
Ambient condition	13.0^{a}	13.6^{a}	13.0^{b}	–	–	–	–
SE	0.195	0.126	0.188	0.185	0.210	0.195	0.183
LSD (5%)	0.582	0.376	0.560	–	–	–	–
CV (%)	6.223	3.747	5.204	5.025	5.966	6.02	3.655
Significance							
A	NS	**	*	*	*	**	NS
B	***	***	***	–	–	–	–
AxB	NS	*	NS	–	–	–	–

(*n*=3)

Initial (0 day) total sugar content was 11.7 mg100^{-1} g and the data from day 12 onwards is meant for the EC storage only. All fruits stored at ambient were discarded on day 12. NS, *, **, *** indicate non-significant or significant difference at $P \leq 0.05$, 0.01 or 0.001, respectively; different letters in a column indicate significant differences at $P=0.05$.

TS content on day 3 and day 6 when compared with papaya fruits subjected to different packaging treatments. Papaya fruits packaged with HDPE and LDPE bags retained their TS concentration better than those packaged with NP, BL and the control at later time of storage. The higher TS concentration of packaged fruits may be explained by the beneficial effects of MAP. When fruits are packaged with polyethylene bags, a modified atmosphere is created, where the O_2 level decreases and the CO_2 level increases in the bags as the fruit ripen (Kader 1985). Under this atmospheric condition, the consumption of respiratory substrates such as sugars is retarded and fresh fruit can maintain its quality (Chachin et al. 2002) which could partly explain the result in this study.

Storage environment significantly ($P \leq 0.001$) affected the TS content of papaya fruits during the storage period. The TS content of the fruits at ambient conditions was higher than the TS concentration of papayas stored in the evaporative cooler up to day 6. On day 9, papayas stored in evaporative cooler had higher TS concentration when compared with the TS concentration of those stored under ambient conditions. This could be associated with the higher rates of respiration and metabolic activity resulting in rapid hydrolysis of sugar under ambient temperature (Wills et al. 1989, Ramakrishnan et al. 2010). Higher temperature favors faster utilization of sugars as substrate in the respiration process (Willey 1994). Whereas the relatively lower temperature in the evaporative cooler helped to preserve the TS of the fruits possibly through retarding respiration and thus delaying ripening (Wang 1989).

Interaction of packaging and storage temperature did not have significant effect on TS of papaya fruit during the storage period.

Conclusion

Packaging and storage environments had significant ($P \leq 0.05$) interaction effects on the shelf life and most of the physiological and chemical qualities of papaya fruits. In this experiment, the evaporative cooler maintained temperature between 12.4 and 19.7 °C and relative humidity between 71.4 and 90.7% which is close to ranges considered to be adequate for storage of papaya. Weight loss of papaya fruits was reduced in packages compared to the control under both storage conditions. Fruits packaged with HDPE bag in the evaporatively cooled storage maintain better fresh weight during the storage period. Packaging combined with the evaporatively cooled storage best maintained the fresh weight than when combined with ambient storage. As the storage time advanced, packaged fruits stored in the evaporative cooler had shown more TSS, AA, TA, reducing and total sugar content and lower pH values. Polyethylene bag with evaporatively cooled storage were generally more effective compared to news paper and banana leaf packaging materials and the control in maintaining the quality of the fruit. The reducing and total sugar content of control fruits were higher up to day six compared to the packaged ones. However, packaged fruits maintain their sugar content better than the control towards the end of the storage period. Similarly, as the storage time advanced, fruits stored in the evaporative cooler maintained their sugar better than the control. Over all, packaging combined with evaporative cooler storage maintained the freshness and improved the shelf life of papaya fruits. Polyethylene bag packaging with evaporative cooler storage were more effective compared to news paper, banana leaf and the control fruits in maintaining the quality as well as prolonging shelf life and marketability of papaya fruits.

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