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ORIGINAL ARTICLE

Effect of packaging materials on shelf life and quality of banana cultivars (*Musa spp.*)

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Abstract This study was carried out to evaluate the effect of packaging materials on the shelf life of three banana cultivars. Four packaging materials, namely, perforated low density polyethylene bag, perforated high density polyethylene bag, dried banana leaf, *teff* straw and no packaging materials (control) were used with three banana cultivars, locally known as, *Poyo*, *Giant Cavendish* and *Williams I*. The experiment was carried out in Randomized Complete Block Design in a factorial combination with three replications. Physical parameters including weight loss, peel colour, peel thickness, pulp thickness, pulp to peel ratio, pulp firmness, pulp dry matter, decay, loss percent of marketability were assessed every 3 days. Banana remained marketable for 36 days in the high density polyethylene and low density polyethylene bags, and for 18 days in banana leaf and *teff* straw packaging treatments. Unpackaged fruits remained marketable for 15 days only. Fruits that were not packaged lost their weight by 24.0 % whereas fruits packaged in banana leaf and *teff* straw became unmarketable with final weight loss of 19.8 % and 20.9 %, respectively. Packaged fruits remained well until 36th days of storage with final weight loss of only 8.2 % and 9.20 %, respectively. Starting from green mature stage, the colour of the banana peel changed to yellow and this process was found to be fast for unpackaged fruits. Packaging maintained the peel and the pulp thickness, firmness, dry matter and pulp to peel ratio was kept lower. Decay loss for unpackaged banana fruits was16 % at the end of date 15, whereas the decay loss of fruits packaged using high density and low density polyethylene bags were 43.0 % and 41.2 %, respectively at the end of the 36th day of the experiment. It can, thus, be concluded that packaging of banana fruits in high density and low density polyethylene bags resulted in longer shelf life and improved quality of the produce followed by packaging in dried banana leaf and *teff* straw.

Keywords Banana · Packaging · *Teff* straw · Colour · Peel thickness · Physical quality · Flexible film

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Introduction

Banana, cooking banana and plantain (*Musa spp*.) are major starch staple crops of considerable importance in the developing world. They are consumed both as an energy yielding food and as a dessert (Dadzie and Orchard 1997). Most edible-fruited bananas, are seedless, belong to the species *Musa acuminata* Colla. *Musa balbisiana* Colla of southern Asia and the East Indies bears a seedy fruit but the plant is valued for its disease-resistance and therefore plays an important role as a “parent” in the breeding of edible bananas (Morton 1987). Bananas and plantains are today grown in every humid tropical region and constitute the 4th largest food crop of the world after rice, wheat and maize (Shamebo 1999; Arias et al. 2003). Furthermore, with increasing urbanization, bananas and plantains are becoming more and more important as cash crops, in some cases providing the sole source of income to rural populations, thus playing an important role in poverty alleviation. Bananas and plantains can be a very cheap food to buy and are hence an important food for low-income families (Shamebo 1999).

Bananas and plantains will also grow in a range of environments and will produce fruit year-round, thus providing a source of energy during the “hungry-period” between crop harvests. They are particularly suited to intercropping systems and to mixed farming with livestock and they are also popular as a backyard crop with urban populations. When grown in perennial production systems, they maintain soil cover throughout the year and if their biomass is used for mulch, soil fertility and organic matter remain stable. In mixed farming systems, bananas are used as a ground shade and nurse-crop for a range of shade-loving crops including cocoa, coffee, black pepper and nutmeg (Shamebo 1999).

Ethiopia lies in the tropics where vast areas are suitable for banana growing. Banana production in Ethiopia ranges from homestead to large commercial plantations. At present, bananas are the leading fruit crops produced in the country both in terms of area coverage (28,695 ha) and production (1,245,615.60 q year^{-1}) (Central Statistics Authority 2004). Due to its relatively little requirement of land preparation, care, maintenance, and a comparatively high yield per given area and time, bananas are well suited to traditional agricultural systems. It is recently reported that bananas are replacing other fruit crops such as lime and mango and the most important food crops like maize and sweet potato in some parts of the southern areas of the country (Seifu 1999).

In Ethiopia, banana was started in early 1970s at major research centers, and cultivar development was being the major research activity. From introduced and locally collected varieties, Dwarf Cavendish, *Poyo*, *Giant Cavendish* and Ducasse hybrid were recommended for production (Seifu 1999). Even though theses preharvest practices are compulsory they must be coupled with the postharvest management practices because postharvest loses are of major concerns in many developing countries (Tadesse 1991). On the other hand, there is potential for export, being located close to important markets, such as Saudi Arabia, Djibouti, Somalia, etc (Workneh et al. 2011a, b and c). Despite these facts, marketing of fresh produce including bananas is complicated by postharvest losses both in terms of quantity and quality between harvest and consumption. Both the fresh market and processing plants for fruits are located in towns away from farms and producers in rural areas. The quality of the fresh and processed fruit depends on the postharvest handling during harvesting, transportation, and storage, and should be monitored effectively to keep the best quality of fruit at harvest. Because of a rain-fed farming system, lack of storage facilities, limited access to transportation, and risk of high losses, growers in Ethiopia are often forced to dispose off their produce over a short period of time (Haidar and Demisse 1999; Tigist et al. 2011) which causes an economic loss of horticultural crops in general and fruits in particular.

Overall, there is no proper means of postharvest handling of fruits and vegetables at the retail and wholesale levels, which results in poor quality of banana at the consumer level. Although the country is experiencing huge postharvest losses of banana very little or no emphasis is given to postharvest handling of the fruit (Tadesse 1991; Workneh et al. 2011a and b).

For the fresh bananas to reach the consumer in the right condition, it must be marketed properly, bearing in mind the application of most suitable temperature and humidity as well as appropriate packaging and handling methods. Good handling during harvesting can minimize mechanical damage and reduce subsequent wastage due to microbial attack (Wills et al. 1989). Low temperature handling and storage are the most important physical method of postharvest management (Johnson et al. 1997). The traditional packaging method for banana is nested packaging in which dried banana leaf and straw of *teff* are used but the effectiveness of these packaging materials has not yet been investigated and reported.

Modified atmosphere packaging (MAP) of fresh banana refers to the technique of sealing actively respiring banana in polymeric film packages to modify the O_2 and CO_2 levels within the package atmosphere. It is often desirable to generate an atmosphere low in O_2 and/or high in CO_2 to influence the metabolism of the product being packaged or the activity of decay-causing organisms to increase storability and/or shelf life (Workneh et al. 2009). In addition to atmosphere modification, MAP vastly improves moisture retention, which can have a greater influence on preserving quality. Furthermore, packaging isolates the product from the external environment and helps to ensure conditions that, if not sterile, at least reduce exposure to pathogens and contaminants there extends the shelf life of the produce (Beaudry 2000). The loss of banana can be kept minimum by improving postharvest handling techniques through the use of different locally available packaging materials. Therefore, this study was aimed at the investigation of the effectiveness of different packaging materials in extending the shelf life of banana. The specific objective of the study was to evaluate the effect of packaging materials on physical quality of three banana cultivars.

Materials and methods

Experimental site The experiment was conducted at the Central Laboratory of Haramaya University. Haramaya University is located at an altitude of 1,980 m.a.s.l., latitude of 9° 26′ N and longitude of 42° 03′ E. The rainfall of the area is bimodal type with an average annual rainfall of 790 mm. The mean annual temperature is 17 °C with minimum and maximum temperatures of 3.8 °C and 25 °C respectively. The mean relative humidity is 50 %, varying from 20 to 80 % and the soil tyoe is well-drained deep clay loam type. Daily temperature and relative humidity of the room was recorded throughout the storage period. The temperature ranged from 15.9 °C to 17.7 °C during the ripening period.

The maximum temperature was attained in the afternoon around 3:00 pm and the lowest temperature was observed in the morning. The relative humidity (RH) varied from 27.9 % to 45.7 % and the maximum was attained during the morning while the minimum was recorded during midday.

Experimental materials The experimental materials consisted of three banana (*Musa spp.*) cultivars named *Williams I*, *Giant Cavendish* and *Poyo*. They were obtained from Werer Agricultural Research Center (WARC) which is located 256 km far from Addis Ababa in the easterly direction. The area has an altitude of 740 m above sea level, and is characterizes by low and erratic rainfall with an average of 560 mm per annum, with the peaks in July and August. The mean temperature of the center is 34 °C (WARC 2007).

Sample preparation Green mature dessert banana fruits of three varieties (*Williams I*, *Giant Cavendish* and *Poyo*) which were collected from WARC were used in this study. Fruits were harvested when the fingers of the first hand on the bunch showed signs of ripening or yellowing and the fingers changed to circular (Dadzie and Orchard 1997). Harvesting was carried out manually with great care to avoid mechanical damage. Harvested fruits were transported to Haramaya university by vehicle covering with dried banana leaf and then by providing cushion with *teff* straw underneath. Transportation was done during the night to avoid light and heat damage. The samples were then graded by size and colour and fruits with defects were discarded. Then unblemished uniform fruits were washed with tap water to remove field heat, to reduce microbial population and to get rid of soil particles on the surface of fruits. Perforated high density polyethylene (HDPE) bags (0.0375 mm thick), perforated low density polyethylene (LDPE) bags (0.0375 mm thick), plastic crates lined with dried banana leaf, plastic crates lined with *teff* straw and plastic crates without lining (as a control) were used as packaging materials with the three varieties. Each cultivar of graded fruit was packaged using each packaging materials and placed in an open air in three replications. Six hands of fruits were packed and used per replication. A total of 90 hands were used (including those fruits included for use in the sensory evaluation) for all the three cultivars, four packaging materials, the control and three replications.

Treatment and experimental design The treatment consisted of a factorial combination of two factors i.e. cultivars and packaging materials. Three cultivars; *Williams I*, Giant Cavendish, and *Poyo* and five packaging materials; high density polyethylene (HDPE) bags, low density polyethylene (LDPE) bags, dried banana leaf (BL), *teff* straw (TS) and control (which were not packaged) were used for the experiment. A total of forty five experimental units were used with three replications. Each treatment consisted of uniform sized fruits placed in plastic crates which were stored at room temperature in the laboratory. The treatments were arranged in randomized complete block design (RCBD). Sample of five fingers were used for analysis on each sampling dates per replication.

Data collection Every 3 days of storage, five fingers were taken randomly from each replication for determination of physical and chemical qualities of fruits. Data for all the postharvest treatments were taken on 0, 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33 and 36 days. Physical, chemical and subjective data were taken from sampled banana fruits during the storage period as follows:

Temperature and relative humidity Both temperature and relative humidity of the storage room were recorded throughout the period with a hygrometer (Campa Flow model 8612).

Physiological weight loss The physiological weight loss was determined using the methods described by Workneh et al. (2011a). The physiological weight loss (PWL) was calculated for each sample prior to other destructive data. It was determined using sensitive balance (type DT 2K model Lark ® 511214).

Colour Colour was measured by comparing with the colour chart described by Dadzie and Orchard (1997). The chart consisted of the seven stage of banana ripening where 1 is dark green, 2 is light green, 3 is more green than yellow, 4 is more yellow than green, 5 is yellow with green tips, 6 is fully yellow, and 7 is flecking (Kader 1992).

Peel and pulp thickness After cutting each fruit transversely at the midpoint, the peel and pulp thickness were measured separately with a pair of calipers. Peel thickness was measured by slicing the fruit in half at the mid-point perpendicular to the longitudinal axis.

Pulp to peel ratio Pulp and peel weight were determined after fingers were hand-peeled. The peel and the pulp were weighed separately with digital balance (type Denver Instrument XL-1810). After measuring, the pulp was divided to the peel weight to get pulp to peel ratio (Dadzie and Orchard 1997).

Pulp firmness Assessment of firmness is important in the evaluation of fruit susceptibility to physical or mechanical damage or postharvest handling (Dadzie and Orchard 1997). It was measured using fruit pressure tester or penetrometer (model FT 327).

Dry matter of the pulp It was measured first by weighing the empty container (A) then 30 g of chopped fresh pulp was placed on the container and was measured (B). The sample was placed in an oven at 100 °C over night (24 h). The sample was weighed again after drying (C) and then the percentage of dry matter content of the pulp was calculated as follows:

$$\text{Weight of wet sample (D)} = B - A$$
$$\text{Weight of dry sample (E)} = C - A$$
$$\text{Moisture content (\%)} = \frac{D-E}{D} \times 100$$
$$\text{Dry matter content (\%)} = 100 - (\text{\% moisture content})$$

Decay loss Any decay loss during storage was assessed and the type of the loss was identified. The percentage of decayed fruits was determined by dividing number of decayed fruits to number of unmarketable fruits. The disease type was also identified by the help of coloured photographs found in Dadzie and Orchard (1997).

Percentage of marketability The marketable quality of fruits was subjectively assessed according to the procedure of Workneh et al. (2011a and b). These descriptive quality attributes were determined subjectively by observing the level of visible mould growth, decay, shriveling, smoothness, and shininess of fruits. A 1–9 rating with1=unusable, 3=usable, 5=fair, 7=good, 9=excellent was used to evaluate the fruit quality. Fruits receiving a rating 5 and above were considered as marketable. The numbers of marketable fruits were used as a measure to calculate the percentage of marketable fruits during storage.

Statistical analysis Significance tests were made by analysis of variance (ANOVA) for factorial arrangement in Randomized Complete Block Design with three cultivars (*Williams I*, Giant Cavendish, and *Poyo*), five packaging materials (HDPE bags, LDPE bags, BL, TS) and the control in three replication using SAS (Statistical Analysis System) of version 9. Comparisons of the treatment means were done using Least Significant Difference (LSD) test.

Results and discussion

Physiological weight loss The interaction effect of packaging materials with cultivars showed a significant difference ($P \leq 0.05$) except on day 9, from 21 to 27 and on day 36. The highest value of weight loss was recorded for *Williams I*, which was kept unpackaged (24.8 %) under ambient condition whereas on the same sampling date, least value of WT loss was observed for *Poyo* kept in HDPE bags (2.1 %). At the end of the storage period of 36 days, higher value of weight loss was recorded for *Williams I* kept in LDPE bags (9.7 %) and whereas *Giant Cavendish* packaged using HDPE bags showed lower weight loss (7.8 %) (Table 1). Generally, fruits kept in both plastic films had the lowest weight loss than banana fruits kept in the rest of packaging materials and the control. Both plastic films, HDPE and LDPE reduced the weight loss by two fold when compared to the loss associated with control fruits during the storage period under ambient condition. Thompson (2001) reported that weight loss of fruits in polyethylene bags was far low than from unpackaged fruits in which after 4 weeks of storage the weight loss was found as 1.8 and 2.1 %, respectively, for fruit stored in 0.0375 mm and 0.05 mm bags and 12.2 % for fruit stored without wrapping.

On the other hand, banana fruits kept both in BL and TS had about the same value on some of the days whereas a significant ($P \leq 0.05$) difference was also observed on some of the sampling days between BL and TS packaging materials. At the end of date 18, banana fruits from TS packaging treatment were found to have more weight loss than fruits from BL packaging treatment. Weight loss from these packaging was in between the plastic films and the control but by far higher than the former packaging treatments.

Weight loss of banana fruits was found to be significant ($P \leq 0.05$) over the storage period of 36 days. Fruits packaged in high density polyethylene (HDPE) and low density polyethylene (LDPE) bags exhibited the lowest weight loss while nonpackaged fruits showed the highest percentage of weight loss (which was about 24.0 %) more than the two plastic bags on the average at the end of day 15. Also, fruit nested in the dried banana leaf (BL) and *teff* straw (TS) exhibited by far a higher weight loss when compared to weight loss of banana fruit packaged in the polyethylene bags. Both dried banana leaf and *teff* straw were relatively better in preventing the loss by about 3.5 % more than the loss from nonpackaged banana fruits. The total weight loss was greater for control fruits which stored for short period of time when compared with the weight of banana fruits packaged using the two plastic bags. Some of the moisture loss from the peel could also be observed through shrinkage of the peel. This result was in accordance with that of Nair et al. (1992) who reported that, after harvest fruit lost weight due to water loss. The faster the rate of weight loss, the shorter the ripening time was. Stover and Simmonds (1987) also reported that banana fruits lost weight due to respiration and transpiration as a result of which the appearance, textural and nutritional qualities of the fruit were negatively affected.

After day 15, non packaged banana fruits totally became unmarketable and those stored in the dried banana leaf and *teff* straw continued to be marketable until day 18 with the final weight loss of 19.753 % and 20.904 %, respectively. The reduced weight loss in the plastic films could be attributed to the reduction in respiration and transpiration rate while the increased weight loss in non packaged fruits could be due to faster respiration and transpiration of the fruits. It was concluded that reduced O_2 and increased CO_2 within the packaging films decreased the respiration rate of banana

Table 1 Interaction effect of packaging materials and cultivar on the physiological weight loss of banana fruits over a storage period of 36 days at ambient condition

Treatments	Storage period (days)											
	3	6	9	12	15	18	21	24	27	30	33	36
Cultivar + packaging												
WI + LDPE	0.313^{f}	0.612^{e}	1.753	2.247^{e}	2.868^{h}	3.281^{e}	4.190	4.469	4.912	6.789^{a}	7.729^{a}	9.688
WI + HDPE	0.317^{f}	0.745^{e}	1.973	2.137^{e}	2.453^{h}	3.154^{e}	4.162	4.265	4.696	6.004^{c}	7.516^{bc}	8.576
WI + BL	5.716^{b}	8.185^{b}	10.834	14.837^{c}	19.541^{cd}	22.105^{ab}	–	–	–	–	–	–
WI + TS	5.715^{b}	8.466^{b}	10.718	14.997^{c}	20.182^{c}	22.233^{a}	–	–	–	–	–	–
WI + Control	6.770^{a}	10.176^{a}	12.941	21.806^{a}	24.797^{a}	–[1]	–	–	–	–	–	–
PY + LDPE	0.137^{f}	0.440^{e}	1.456	1.897^{e}	2.320^{h}	2.795^{e}	4.145	4.451	4.952	6.524^{b}	7.633^{ab}	9.157
PY + HDPE	0.281^{f}	0.682^{e}	1.097	1.561^{e}	2.078^{h}	2.487^{e}	4.169	4.270	4.713	5.261^{d}	6.745^{d}	8.150
PY + BL	4.719^{c}	6.889^{c}	10.005	13.558^{d}	17.613^{e}	19.323^{c}	–	–	–	–	–	–
PY + TS	4.737^{c}	6.895^{c}	11.272	13.693^{d}	18.931^{d}	20.898^{b}	–	–	–	–	–	–
PY + Control	5.514^{b}	8.644^{b}	12.640	16.518^{b}	23.570^{b}	–	–	–	–	–	–	–
GC + LDPE	0.369^{f}	0.755^{e}	1.232	1.824^{e}	2.441^{h}	3.154^{e}	4.144	4.422	4.857	5.979^{c}	7.467^{c}	8.770
GC + HDPE	0.299^{f}	0.823^{e}	1.087	1.500^{e}	2.151^{h}	3.064^{e}	4.148	4.277	4.722	5.251^{d}	6.721^{d}	7.797
GC + BL	2.610^{e}	5.537^{d}	8.762	14.029^{d}	13.134^{g}	17.832^{d}	–	–	–	–	–	–
GC + TS	3.908^{d}	6.405^{c}	10.340	13.697^{d}	14.981^{f}	19.580^{c}	–	–	–	–	–	–
GC + Control	4.651^{c}	9.882^{a}	12.421	16.782^{b}	23.505^{b}	–	–	–	–	–	–	–
SE	0.133	0.233	0.357	0.273	0.428	0.446	–	–	–	–	–	–
CV	7.518	8.007	8.556	4.707	5.844	6.634	–	–	–	–	–	–
Significance												
Cultivar X Packaging	***	***	NS	***	***	**	NS	NS	NS	**	***	NS

(n=3)

LDPE low density polyethylene; *HDPE* high density polyethylene; *WI Williams I*; *PY Poyo*; *GC* Giant Cavendish; *BL* dried banana leaf; *TS teff* straw

[1] Indicate treatments in which all the fruits were already discarded. A, Cultivar; B, Packaging; NS, ***, **indicate nonsignificant or significant differences at $P \leq 0.001$ or $P \leq 0.01$, respectively, and means within the same column followed by a common letter are not significantly different at $P<0.05$ (LSD test)

fruit but when the fruits were moved to normal air these brought about faster respiration, because O_2 and CO_2 levels equilibrated (Nair et al. 1992).

The difference between LDPE and HDPE bags was insignificant ($P>0.05$) till day 21 and it became significant ($P\leq0.05$) from day 24 until the end. HDPE bag was found to prevent the weight loss by about 1 % more than LDPE bags. This could be attributed to the permeability difference between the two plastic films for water vapor and gases as well (Thompson 2001). This difference in weight loss did not bring significant differences in marketability of the banana fruits when the effect of flexible film packaging was considered.

A significant ($P\leq0.05$) difference in weight loss was observed among the three cultivars except on day 21, 24 and 27 in which the difference among cultivars became insignificant ($P>0.05$). In general, the highest value of weight loss was observed in WI whereas the lowest value was recorded for GC during the sampling dates except on some days in which GC and PY also lost a relatively the same weight. This may be due to the fact that, banana fruits with high surface area would loss more water than small fruits or smaller fruits lose more water than bigger ones (Dadzie and Orchard 1997). In addition, the weight loss can also be related with low relative humidity of the room throughout the storage periods which was by far low from the optimum recommended relative humidity (RH) for banana storage. Blankenship and Herdeman (1995) recommended a constant high RH of 95 % during ripening in order to obtain better quality banana fruit compared to storage at lower relative humidity. Lower RH is the driving force for water loss from the fruit. Low RH reduces the green life and can produce peel symptoms that are similar to the damage of chilling injury (Turner 2001).

Peel colour Packaging material had significant ($P\leq0.05$) effect on the change in peel colour of banana fruits during the storage period of 36 days under ambient conditions (Table 2). On day 3, only non-packaged fruits were significantly ($P\leq0.05$) different from the rest in the development of peel colour. Bananas packaged using plastic films (LDPE and HDPE) developed excellent type of colour, whereas fruits kept in banana leaf, *teff* straw and the control showed dull type of colour. This might be due to lower percentage of relative humidity in the storage room. This problem was reduced by the modification of the environment around the produce through the use of the plastic films. Dadzie and Orchard (1997) reported that the market quality and consumer acceptance of banana, cooking banana and plantain are significantly influenced by the colour of the fruit. Thus, the result of the present study showed that attractive yellow colour could be obtained by packaging of banana fruits in plastic bags, thereby improving its marketability.

At the end of day 15, the peel colour of banana fruits packaged in LDPE and HDPE plastic films were in between stage two and three whereas fruits from the control attained colour stage six and above (Table 2), which was the last stage of ripening. These values were attained for banana fruits packaged in plastic bags around day 30 and on wards. Similar result was also reported by Ahmad et al. (2006) that bananas stored at lower O_2 levels were slightly greener than those which were stored at higher O_2 levels. The loss of green colour is due to chlorophyll degradation, which subsequently reveals the yellow carotenoid pigments (Marriott and Lancaster 1983; Stover and Simmonds 1987; Seymour 1993).

The difference was significant ($P<0.05$) among cultivars starting from date 12 until 24. William I was found to have a relatively higher value of the peel colour. But as ripening progresses, the cultivars had the same stage of ripening. At the end of the storage, *Williams I*, *Poyo* and *Giant Cavendish* attainted similar peel colour stage.

Peel thickness There was a decreasing trend in the peel thickness of banana fruits which could be explained as ripening progresses, by starch degradation to soluble sugars which creates a water potential gradient between the peel and the pulp. Since the pulp has more sugars than the peel, water starts to move to the pulp and peel thickness continue decreasing throughout the ripening phase (Dadzie and Orchard 1997).

Packaging had a significant ($P\leq0.05$) effect on the peel thickness of banana cultivars throughout the storage period of 36 days. Control banana fruits exhibited the lowest peel thickness (0.332 cm) already after 15 days of storage, whereas banana fruits packaged in high density polyethylene bags and low density polyethylene bags had peel thickness of 0.355 cm and 0.336 cm, respectively, even at the end of the storage period (Table 3). This could be attributed to the fact that the peel lost water to the atmosphere through transpiration and also to the pulp. Of course, these losses were pronounced in the control banana fruits which resulted in thinner peel. The peel thickness of banana fruit packaged in *teff* straw was found to be thinner than the peel thickness of banana fruit packaged in banana leaf except on day 18 of storage. However, the difference in peel thickness of banana fruits packaged in banana leaf and *teff* straw remained to be insignificant ($P>0.05$), except on day 12 in which the peel thickness of banana fruits packaged in *teff* straw were found to be significantly thinner than those nested in dried banana leaf.

The flexible film packaging had significant ($P\leq0.05$) effect on the peel thickness of banana fruits during the storage period of 36 days under ambient condition. The physiological weight loss was found to be higher in bananas subjected to LDPE bag packaging compared to weight

Table 2 Effect of packaging materials on peel colour (1–7 scoring) development of banana cultivars over a storage period of 36 days at ambient condition

Treatments	Storage period (days)												
	0	3	6	9	12	15	18	21	24	27	30	33	36
Packaging													
LDPE	–[2]	1^{b}	1.544^{c}	2.066^{d}	2.546^{c}	2.900^{c}	3.411^{b}	4.093^{a}	4.611^{a}	6.492^{a}	5.577	6.188	6.944
HDPE	–	1^{b}	1.550^{c}	1.916^{d}	2.561^{c}	2.542^{d}	3.423^{b}	3.758^{b}	4.416^{b}	5.172^{b}	5.550	6.166	6.888
BL	–	1^{b}	2.616^{b}	3.711^{c}	4.888^{b}	5.522^{b}	6.894^{a}	–	–	–	–	–	–
TS	–	1^{b}	2.633^{b}	5.066^{b}	5.950^{a}	5.538^{b}	6.883^{a}	–	–	–	–	–	–
Control	–	1.616^{a}	3.033^{a}	6.311^{a}	5.777^{a}	6.733^{a}	–[1]	–	–	–	–	–	–
SE	–	0.027	0.032	0.066	0.082	0.099	0.073	0.044	0.047	0.104	0.070	0.093	0.052
Cultivar													
WI	1	1.123	2.253	3.836	4.494^{a}	4.809^{a}	5.341^{a}	4.086^{a}	4.650^{a}	5.841	5.641	6.166	6.919
PY	1	1.123	2.290	3.783	4.370^{a}	4.698^{a}	5.075^{b}	3.833^{b}	4.566^{a}	5.841	5.550	6.200	6.917
GC	1	1.123	2.283	3.823	4.170^{b}	4.434^{b}	5.042^{b}	3.858^{b}	4.325^{b}	5.831	5.500	6.166	6.914
SE	0	0.021	0.024	0.051	0.064	0.076	0.063	0.055	0.058	0.128	0.085	0.114	0.065
CV	0	7.448	4.228	5.198	5.705	6.396	4.271	3.435	3.169	5.394	3.776	4.546	2.285
Significance													
Cultivar	NS	NS	NS	NS	**	**	**	*	**	NS	NS	NS	NS
Packaging	–	***	***	***	***	***	***	***	*	***	NS	NS	NS

(n=3)

LDPE low density polyethylene; *HDPE* high density polyethylene; *WI Williams I*; *PY Poyo*; *GC* Giant Cavendish; *BL* dried banana leaf; *TS teff* straw

[1] Indicate treatments in which all the fruits were already discarded. [2] 0 day data is the same as the 0 day data for freshly harvested fruits cultivars as indicated. NS, ***, **indicate nonsignificant or significant differences at $P \leq 0.001$ or $P \leq 0.01$, respectively, and means within the same column followed by a common letter are not significantly different at $P<0.05$ (LSD test)

Table 3 Effect of packaging materials on peel thickness (cm) of banana cultivars over a storage period of 36 days at ambient condition

Treatments	Storage period (days)												
	0	3	6	9	12	15	18	21	24	27	30	33	36
Packaging													
LDPE	–[2]	0.412^{a}	0.407^{a}	0.414^{a}	0.406^{a}	0.393^{a}	0.391^{a}	0.381	0.371^{b}	0.380^{b}	0.351^{b}	0.348^{b}	0.336^{b}
HDPE	–	0.414^{a}	0.405^{a}	0.415^{a}	0.410^{a}	0.392^{a}	0.382^{a}	0.387	0.380^{a}	0.396^{a}	0.374^{a}	0.371^{a}	0.355^{a}
BL	–	0.411^{a}	0.391^{b}	0.384^{b}	0.373^{b}	0.348^{b}	0.317^{b}	–	–	–	–	–	–
TS	–	0.403^{a}	0.381^{b}	0.380^{b}	0.367^{bc}	0.331^{b}	0.326^{b}	–	–	–	–	–	–
Control	–	0.381^{b}	0.361^{c}	0.356^{c}	0.354^{c}	0.332^{b}	–[1]	–	–	–	–	–	–
SE	–	0.006	0.004	0.004	0.0154	0.006	0.003	0.003	0.002	0.004	0.005	0.007	0.002
Cultivar													
WI	0.401	0.397	0.379^{b}	0.374^{b}	0.374^{b}	0.353	0.351^{b}	0.373^{b}	0.368^{ab}	0.366^{b}	0.348^{b}	0.351	0.333^{b}
PY	0.408	0.406	0.395^{a}	0.400^{b}	0.384^{ab}	0.357	0.350^{b}	0.381^{b}	0.361^{b}	0.390^{a}	0.361^{b}	0.355	0.338^{b}
GC	0.411	0.410	0.393^{a}	0.395^{a}	0.389^{a}	0.368	0.361^{a}	0.398^{a}	0.396^{a}	0.408^{a}	0.378^{a}	0.373	0.366^{a}
SE	0.000	0.004	0.003	0.003	0.004	0.005	0.002	0.004	0.002	0.005	0.005	0.008	0.003
CV	0.000	4.174	3.558	3.201	4.164	5.498	2.7528	2.991	1.895	3.899	3.437	5.578	2.339
Significance[3]													
Cultivar	***	NS	**	***	**	NS	*	*	*	*	**	NS	***
Packaging	–	**	***	***	***	***	***	NS	*	*	**	*	***

(n=3)

LDPE low density polyethylene; *HDPE* high density polyethylene; *WI Williams I*; *PY Poyo*; *GC* Giant Cavendish; *BL* dried banana leaf; *TS teff* straw

[1] Indicate treatments in which all the fruits were already discarded. [2] 0 day data is the same as the 0 day data for freshly harvested fruits cultivars as indicated. NS, ***, **, *indicate nonsignificant or significant differences at $P \le 0.001$, $P \le 0.01$ or $P \le 0.05$, respectively, and means within the same column followed by a common letter are not significantly different at $P < 0.05$ (LSD test)

losses of bananas packaged in HDPE bags. As a result, HDPE bags packaged fruits were found to had thicker peels than LDPE bags packaged banana fruits. Thompson (2001) reported that there is a difference in permeability between high density and low density polyethylene plastic bags both for water vapor and gases.

Cultivars had also significant ($P \leq 0.05$) difference on peel thickness during the 36 days of storage under ambient storage conditions except on date 3, 15 and 33. This was because as it was discussed earlier concerning the weight loss of cultivars, the smaller the fruit the more it losses water to the atmosphere resulting in thinner peel thickness. *Williams I* had relatively lower value of peel thickness and *Giant Cavendish* had thicker peels whereas *Poyo* was in between the two cultivars in terms of peel thickness. At the end of the storage period peel thickness for *Williams I*, *Poyo* and *Giant Cavendish* were 0.333 cm, 0.338 cm and 0.366 cm respectively (Table 3).

Pulp thickness Pulp thickness showed an increasing trend over the storage period of 36 days under ambient conditions (Table 4). The reason for this is that water moves from the peel to the pulp due to the difference in water potential between the pulp and the peel because of the breakdown of starch to sugar in the pulp tissue (Gowen 1995).

Packaging materials had significant ($p \leq 0.05$) effect on the pulp thickness of banana cultivars. At the end date 12, the highest pulp thickness (3.427 cm) was recorded for control banana fruits whereas the lowest pulp thickness was for fruits packaged in LDPE and HDPE bags. Pulp thickness of banana fruits packaged in dried banana leaf and *teff* straw were 3.394 cm and 3.386 cm, respectively, on day 12. This result reveals that the enzymatic activity of banana fruits packaged both in LDPE bags and HDPE bags was slower when compared to the enzyme activity of banana fruits packaged using dried banana leaf and *teff* straw or non packaged fruits (control). As a result starch degradation was slower and hence less amount of water has entered from the peel to the pulp in the case of the two plastic bag packagings there by thin pulp thickness was observed for these packaging treatments at the beginning of the storage period. The same result was reported by Salunkhe and Kadam (1995) that banana fruits packaged in 150 gauge polyethylene bag were found to have slower enzymatic activity there by the process of starch degradation was slower than open air kept banana fruits.

The difference between BL and TS packaged fruits was insignificant throughout the storage period of 18 days. Whereas the difference between HDPE and LDPE bag packaged fruits was insignificant until date 30, but it became significant thereafter. In which on date 33 and 36 HDPE packaged bag fruits had thicker pulp than LDPE bag packaged. According to Thompson (2001) there is difference in permeability for gases and water vapour between HDPE and LDPE bags packagings there by less enzymatic activity could be observed for the former packaging treatment.

Significant ($P \leq 0.05$) differences were observed among cultivars throughout the storage period of 36 days. *Giant Cavendish* had a higher value of pulp thickness throughout the storage period. This was due to the natural size of the cultivar when compared with *Poyo* and *Williams I*. Even though, they were not statistically different at $P \leq 0.05$ level of significance, the cultivar *Poyo* had relatively thicker pulp than *Williams I*. Towards the end of the storage period, the pulp thickness of Giant Cavendish, *Poyo* and *williams I* were 3.501 cm, 3.416 cm, and 3.405 cm, respectively (Table 4).

Pulp to peel ratio Pulp to peel ratio was significantly ($P \leq 0.05$) increased throughout the ripening period (Table 5). Significant difference was observed on the pulp to peel ratio of banana fruits packaged in the different packaging treatments. Fruits packaged in HDPE and LDPE bags had the lowest value when compared to the pulp to peel ratio of banana fruits stored in banana leaf, *teff* straw and non packaged fruits at the end of the day 15. Control banana fruits showed significantly ($P \leq 0.05$) higher pulp to peel ratio throughout the 15 days of storage than the Pulp to peel ratio of fruits stored in banana leaf and *teff* straw, which could be due to the loss of water from the peel to the atmosphere and to the pulp. The ratio of pulp to skin is largely governed by water relations of the fruit. The ratio is about 1.2–1.6 in green fruit and it may rises to 2.2–2.6 at advanced ripeness 3 and above in rotting fruit after prolonged storage (Gowen 1995). This rise in pulp to peel ratio is related to changes in sugar concentrations in the two tissues. Sugar increased more rapidly in the pulp than in the skin and this difference is reflected in a differential change in the osmotic pressure. The consequence is that water is withdrawn from the skin by the pulp and the pulp to peel weight ratio changes accordingly. The same finding was reported by Simmonds (1959). In the present study, the peel weight continued in decreasing whereas the pup weight continued in increasing and when the pulp was divided by the peel which gave an increasing trend of in pulp to peel ratio of bananas.

The difference in pulp to peel ratio of banana fruits packaged in TS and BL packaging treatments was insignificant throughout the storage period. Whereas, significant difference ($P \leq 0.05$) was observed in pulp to peel ratio of bananas between HDPE and LDPE bags starting from day 24 onwards. HDPE bags were found to maintain lower ratio, which was also related with the weight loss of banana fruits. After 36 days of storage, the ratio was 2.7 for fruits packaged in HDPE bags, whereas 2.7 for fruits packaged in LDPE bags (Table 5). Similar finding was reported by

Table 4 Effect of packaging materials on pulp thickness (cm) of banana cultivars over a storage period of 36 days at ambient condition

Treatments	Storage period (days)												
	0	3	6	9	12	15	18	21	24	27	30	33	36
Packaging													
LDPE	–[2]	3.164	3.187^{c}	3.211^{c}	3.263^{b}	3.324^{b}	3.337	3.348	3.361	3.516	3.491	3.423^{b}	3.427^{b}
HDPE	–	3.163	3.186^{c}	3.294^{bc}	3.236^{b}	3.276^{b}	3.344	3.337	3.330	3.476	3.485	3.472^{a}	3.454^{a}
BL	–	3.158	3.338^{b}	3.496^{a}	3.394^{a}	3.433^{a}	3.363	–	–	–	–	–	–
TS	–	3.160	3.314^{b}	3.399^{ab}	3.386^{a}	3.472^{a}	3.355	–	–	–	–	–	–
Control	–	3.161	3.393^{a}	3.444^{ab}	3.427^{a}	3.323^{b}	–[1]	–	–	–	–	–	–
SE		0.002	0.008	0.064	0.014	0.036	0.027	0.015	0.027	0.049	0.017	0.013	0.005
Cultivar													
WI	3.010^{c}	3.144^{b}	3.255^{b}	3.289^{b}	3.305^{b}	3.321	3.306^{b}	3.306^{b}	3.315^{b}	3.416^{b}	3.436^{b}	3.416^{b}	3.405^{b}
PY	3.080^{b}	3.142^{b}	3.262^{b}	3.311^{b}	3.284^{b}	3.375	3.325^{b}	3.316^{b}	3.286^{b}	3.431^{b}	3.441^{b}	3.434^{b}	3.416^{b}
GC	3.110^{a}	3.197^{a}	3.335^{a}	3.507^{a}	3.434^{a}	3.401	3.418^{a}	3.406^{a}	3.435^{a}	3.641^{a}	3.588^{a}	3.491^{a}	3.501^{a}
SE	0.000	0.002	0.006	0.049	0.011	0.027	0.024	0.018	0.033	0.060	0.021	0.016	0.007
CV	0.00	0.210	0.784	5.742	1.319	3.208	2.444	1.334	2.457	4.253	1.463	1.206	0.520
Siggnificance													
Cultivar	***	***	***	**	***	NS	**	**	*	*	***	*	***
Packaging	–	NS	***	*	***	**	NS	NS	NS	NS	NS	*	**

(n=3)

LDPE low density polyethylene; *HDPE* high density polyethylene; *WI Williams I*; *PY Poyo*; *GC* Giant Cavendish; *BL* dried banana leaf; *TS teff* straw

[1] Indicate treatments in which all the fruits were already discarded. [2] 0 day data is the same as the 0 day data for freshly harvested fruits cultivars as indicated. NS, ***, **,*indicate nonsignificant or significant differences at $P \leq 0.001$, $P \leq 0.01$, $P \leq 0.05$, respectively, and means within the same column followed by a common letter are not significantly different at $P<0.05$ (LSD test)

Table 5 Effect of packaging materials on pulp to peel ratio of banana cultivars over a storage period of 36 days at ambient condition

Treatments	Storage period (days)												
	0	3	6	9	12	15	18	21	24	27	30	33	36
Packaging													
LDPE	–[2]	2.207^{b}	2.156^{d}	2.237^{c}	2.257^{c}	2.303^{c}	2.385^{b}	2.457	2.551^{a}	2.642^{a}	2.689^{a}	2.728^{a}	2.748^{a}
HDPE	–	2.218^{b}	2.216^{c}	2.237^{c}	2.255^{c}	2.269^{c}	2.363^{b}	2.461	2.501^{b}	2.601^{b}	2.668^{b}	2.694^{b}	2.720^{b}
BL	–	2.268^{b}	2.337^{b}	2.401^{b}	2.570^{b}	2.596^{b}	2.755^{a}	–	–	–	–	–	–
TS	–	2.277^{b}	2.348^{b}	2.404^{b}	2.437^{b}	2.579^{b}	2.756^{a}	–	–	–	–	–	–
Control	–	2.494^{a}	2.429^{a}	2.567^{a}	2.799^{a}	2.814^{a}	–[1]	–	–	–	–	–	–
SE	–	0.030	0.015	0.015	0.048	0.014	0.010	0.007	0.009	0.005	0.003	0.006	0.004
Cultivar													
WI	2.150^{a}	2.299^{ab}	2.352^{a}	2.408^{a}	2.582^{a}	2.586^{a}	2.640^{a}	2.470^{a}	2.570^{a}	2.645^{a}	2.704^{a}	2.749^{a}	2.800^{a}
PY	2.200^{b}	2.340^{a}	2.329^{a}	2.386^{a}	2.361^{b}	2.550^{b}	2.550^{b}	2.475^{a}	2.525^{b}	2.625^{b}	2.683^{b}	2.721^{b}	2.734^{b}
GC	2.221^{c}	2.239^{b}	2.209^{b}	2.313^{b}	2.447^{b}	2.400^{c}	2.504^{c}	2.431^{b}	2.483^{c}	2.594^{c}	2.648^{c}	2.664^{c}	2.681^{c}
SE	0	0.023	0.012	0.012	0.037	0.011	0.009	0.009	0.011	0.006	0.004	0.005	0.005
CV	0	3.995	2.072	1.991	5.895	1.700	1.225	0.952	1.139	0.588	0.386	0.516	0.482
Significance													
Cultivar	***	***	***	***	***	***	***	*	**	***	***	***	***
Packaging	–	*	***	***	***	***	***	NS	**	***	**	***	***

(n=3)

LDPE low density polyethylene; *HDPE* high density polyethylene; *WI Williams I*; *PY Poyo*, *GC* Giant Cavendish; *BL* dried banana leaf; *TS teff* straw

[1] Indicate treatments in which all the fruits were already discarded. [2] 0 day data is the same as the 0 day data for freshly harvested fruits cultivars as indicated. NS, ***, **, *indicate nonsignificant or significant differences at $P \leq 0.001$, $P \leq 0.01$, $P \leq 0.05$, respectively, and means within the same column followed by a common letter are not significantly different at $P<0.05$ (LSD test)

Salunkhe and Kadam (1995) that unripe banana subjected to ripening in polyethylene bags of 150 gauge thickness at ambient temperature had significantly lower pulp to peel ratio indicating that the ripening process was slow.

The differences in pulp to peel ratio during ripening in storage under ambient conditions varied significantly ($P \leq 0.05$) among cultivars. This was also related to pulp and peel thickness of banana fruits. *Williams I* had the lowest value of peel weight due to more loss of water to the atmosphere because of its small size, and hence pulp to peel ratio expected to be higher for this cultivar. Throughout the storage period, *Giant Cavendish* had the lowest ratio while *Poyo* had a value in between *Williams I*. Pulp to peel ratio of *Williams I*, *Poyo* and *Giant Cavendish* were 2.8, 2.7 and 2.7, respectively, towards the end of the storage period under ambient condition (Table 5).

Pulp firmness Fruit firmness was decreased steadily during the 36 days of storage. This process was by far faster in control fruits than polyethylene bag packaged fruits. The softening process was also a little bit slower in banana leaf and *teff* straw packaged fruits than control fruits.

Packaging significantly ($P \leq 0.05$) affected the fruit firmness stored for a storage period of 36 days. Fruits from polyethylene bags were firmer than fruits from dried banana leaf, *teff* straw and control fruits at the beginning of the storage period under ambient condition. At the end of day 15, fruits from the plastic films require a force of 4.5 kg and above while those from the BL and TS required a force of 2.1 Kg and 2.0 Kg, respectively. Where control fruits required a kilogram force of 0.561 Kg (Table 6). This could be due to the reduced weight loss resulting from reduced respiration or lower enzyme activity for banana fruits packaged in HDPE and LDPE bag packaging treatments. It has previously been reported by Salunkhe and Desai (1984) that controlled atmosphere storage or modified atmosphere packaging with high CO_2 inhibits the breakdown of peptic substances, which retains fruit texture and remains firmer for a longer period. Firmer ripe fruit was considered as one of the benefits of controlled atmosphere storage or modified atmosphere packaging to reduce mechanical damage, avoid fungal infection and increase shelf life of fruits.

Significance ($P \leq 0.05$) difference in firmness of banana fruits packaged using HDPE and LDPE plastic bags was observed from day 24 to 30. HDPE bag was found to maintain firmer fruits than LDPE bags. This could be due to a relatively higher value of weight loss which was observed in the case of LDPE bags. Loss of firmness or softening during ripening has been associated with two or three processes. The first is the breakdown of starch to soluble sugar. The second is the breakdown of the cell walls or reduction in the middle lamella cohesion due to solubilisation of pectic substances. The third is the movement of water from the peel to the pulp during ripening due to the process of osmosis (Dadzie and Orchard 1997).

Regarding the cultivars, significant difference ($P \leq 0.05$) was observed starting from date 9 until date 27. On day 0, 12 and 24, the difference in firmness became highly significant ($P \leq 0.05$). On these days, *Giant Cavendish* was found to be firmer followed by *Poyo*. *Williams I* had the lowest value of firmness. This was related to the weight loss of cultivars. In the present study, *Williams I* was smaller in size than *Giant Cavendish* and *Poyo* and hence, the smaller the fruit the more it loses water to the atmosphere and the faster it loses its firmness.

Dry matter of the pulp Packaging significantly ($P \leq 0.05$) affected the dry matter content of banana fruits over the storage period of 36 days (Table 7). At the end of date 15, the highest value of dry matter was maintained for fruits kept in the plastic bags while for control fruits the lowest value was observed. The dry matter content of banana fruits subjected to BL and TS packaging remained to be higher than the dry matter content of control fruits, but by far lower than that of banana fruits subjected to the plastic bags packaging. The decrease in the dry matter content was 2.2 % for control banana fruits but around 0.31 % on average both for HDPE and LDPE bags at the end of day 15 of storage under ambient conditions. The final decrease in pulp dry matter in fruits packaged using dried banana leaf and *teff* straw were 1.8 % and 2.0 %, respectively, at the end of day 18 under ambient storage conditions.

The difference between the dry matter content of banana fruits subjected to both flexible film packaging was not significant at $P > 0.05$ at the beginning of the storage periods. But it became significant at the later storage periods. Assessment of dry matter content is essential because, the high rate of respiration accompanied by water loss that occurs in plantain and banana during ripening, particularly at the climacteric stage cause a net reduction in the proportion of the fruit dry matter (Dadzie and Orchard 1997). These two processes, rate of respiration and water loss, was slowed down for banana fruits subjected to HDPE and LDPE bags packaging treatments. This resulted in a higher dry matter content in banana fruits packaged in HDPE and LDPE bags than the bananas subjected to other treatments.

The difference among cultivars was significant ($P \leq 0.05$) except on date 3 and 21. *Poyo* had the highest percent of pulp dry matter followed by *Giant Cavendish* and then *Williams I*. At the end of the storage period, pulp dry matter of *Poyo*, *Giant Cavendish* and *Williams I* were 26.9 %, 26.8 % and 26.7 % respectively. Banana with the longest fruit ripening time and hardest pulp, had the highest dry matter content and fruit dry matter content may be related to storage life and fruit quality in which the higher the dry matter content, the better the eating quality (Dadzie and Orchard 1997).

Table 6 Effect of packaging materials on pulp firmness (Kg cm^{-2}) of banana cultivars over a storage period of 36 days at ambient condition

Treatments	Storage period (days)												
	0	3	6	9	12	15	18	21	24	27	30	33	36
Packaging													
LDPE	–[2]	5.393^{a}	4.732^{a}	4.430^{b}	5.322^{a}	5.055^{a}	3.667^{a}	3.354^{a}	2.074^{b}	2.681^{b}	1.500^{b}	0.990	0.511
HDPE	–	5.348^{ab}	4.756^{a}	5.958^{a}	4.897^{b}	4.131^{b}	3.545^{a}	3.352^{a}	3.290^{a}	3.131^{a}	2.048^{a}	1.000	0.522
BL	–	5.285^{b}	4.188^{b}	4.016^{c}	3.164^{d}	2.082^{c}	0.583^{b}	–	–	–	–	–	–
TS	–	5.303^{ab}	3.205^{c}	3.564^{d}	3.594^{c}	1.983^{c}	0.638^{b}	–	–	–	–	–	–
Control	–	5.162^{c}	4.131^{b}	3.774^{d}	2.594^{e}	0.561^{d}	–[1]	–	–	–	–	–	–
SE		0.035	0.060	0.069	0.050	0.058	0.066	0.047	0.022	0.017	0.011	0.004	0.009
Cultivar													
WI	5.660^{c}	5.287	4.174	3.968^{b}	3.526^{c}	2.610^{b}	2.010^{b}	3.113^{b}	2.358^{c}	2.828^{b}	1.790	0.996	0.508
PY	5.890^{b}	5.307	4.240	4.184^{a}	3.950^{b}	2.784^{a}	2.062^{b}	3.350^{a}	2.718^{b}	2.938^{a}	1.750	0.991	0.516
GC	5.970^{a}	5.300	4.193	4.116^{ab}	4.228^{a}	2.774^{a}	2.254^{a}	3.295^{ab}	2.970^{a}	2.951^{a}	1.783	0.996	0.525
SE	0.000	0.027	0.046	0.054	0.039	0.045	0.057	0.058	0.028	0.021	0.013	0.005	0.011
CV	0.000	2.029	4.285	5.128	3.870	6.435	6.428	4.387	2.570	1.831	1.848	1.335	5.300
Significance													
Cultivar	***	NS	NS	*	***	*	*	*	***	**	NS	NS	NS
Packaging	–	**	***	***	***	***	***	NS	***	**	***	NS	NS

(n=3)

LDPE low density polyethylene; *HDPE* high density polyethylene; *WI Williams I*; *PY Poyo*; *GC* Giant Cavendish; *BL* dried banana leaf; *TS teff* straw

[1] Indicate treatments in which all the fruits were already discarded. [2] 0 day data is the same as the 0 day data for freshly harvested fruits cultivars as indicated. NS, ***, **indicate nonsignificant or significant differences at $P \leq 0.001$, $P \leq 0.01$, respectively, and means within the same column followed by a common letter are not significantly different at $P<0.05$ (LSD test)

Table 7 Effect of packaging materials on pulp dry matter (%) of banana cultivars over a storage period of 36 days at ambient condition

Treatments	Storage period (days)												
	0	3	6	9	12	15	18	21	24	27	30	33	36
Packaging													
LDPE	–[2]	28.461	28.314^{a}	28.169^{a}	28.158^{a}	28.175^{a}	28.216^{a}	27.967^{b}	27.925^{a}	27.899^{b}	27.343^{b}	27.288	26.776
HDPE	–	28.563	28.335^{a}	28.132^{a}	28.181^{a}	28.221^{a}	27.075^{a}	28.133^{a}	27.901^{b}	27.940^{a}	27.475^{a}	27.312	26.789
BL	–	28.506	27.941^{d}	28.083^{a}	27.344^{b}	27.014^{b}	26.700^{b}	–	–	–	–	–	–
TS	–	28.498	28.268^{b}	27.547^{b}	27.343^{b}	27.060^{b}	26.472^{c}	–	–	–	–	–	–
Control	–	28.528	28.169^{c}	27.509^{b}	26.121^{c}	26.325^{c}	–[1]	–	–	–	–	–	–
SE		0.038	0.011	0.073	0.023	0.044	0.074	0.014	0.008	0.009	0.015	0.013	0.019
Cultivar													
WI	28.550^{a}	28.512	28.166^{b}	27.952^{a}	27.499^{b}	27.319^{b}	27.319^{b}	28.043	27.886^{b}	27.898^{b}	26.416^{c}	27.222^{b}	26.742b
PY	28.53^{b}	28.539	28.189^{b}	28.036^{a}	27.885^{a}	27.590^{a}	27.540^{a}	28.070	27.945^{a}	27.946^{a}	28.066^{a}	27.449^{a}	26.851a
GC	28.500^{c}	28.482	28.261^{a}	27.676^{b}	27.503^{b}	27.249^{b}	27.238^{b}	28.037	27.909^{b}	27.914^{ab}	27.746^{b}	27.229^{b}	26.755b
SE	0.0001	0.030	0.007	0.056	0.018	0.034	0.064	0.019	0.009	0.011	0.018	0.016	0.016
CV	0.001	0.409	0.088	0.787	0.255	0.483	0.811	0.158	0.080	0.104	0.165	0.146	0.154
Significance													
Cultivar	***	NS	***	***	***	***	**	NS	**	*	***	***	**
Packaging		NS	***	***	***	***	***	***	*	*	***	NS	NS

(n=3)

LDPE low density polyethylene; *HDPE* high density polyethylene; *WI Williams I*; *PY Poyo*; *GC* Giant Cavendish; *BL* dried banana leaf; *TS teff* straw

[1] Indicate treatments in which all the fruits were already discarded. [2] 0 day data is the same as the 0 day data for freshly harvested fruits cultivars as indicated. NS, ***, **, *indicate nonsignificant or significant differences at $P \leq 0.001$, $P \leq 0.01$, $P \leq 0.05$, respectively, and means within the same column followed by a common letter are not significantly different at $P < 0.05$ (LSD test)

Table 8 Effect of packaging material on the percent of marketability of banana cultivars over a storage period of 36 days at ambient condition

Treatments	Storage period (days)												
	0	3	6	9	12	15	18	21	24	27	30	33	36
Packaging													
LDPE	–[2]	100	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100	100	92.1	84.0^{a}	74.2^{a}	58.8^{a}
HDPE	–	100	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100	100	91.7	78.3^{b}	71.7^{b}	56.9^{b}
BL	–	100	100^{a}	93.1^{b}	83.2^{b}	72.6^{b}	56.3^{b}	–	–	–	–	–	–
TS	–	100	100^{a}	93.1^{b}	82.0^{b}	68.4^{c}	55.2^{c}	–	–	–	–	–	–
Control	–	100	94.8^{b}	84.9^{c}	68.6^{c}	55.n	–[1]	–	–	–	–	–	–
SE		0	0.256	0.421	0.599	0.546	0.291		0	0.392	0.619	0.418	0.457
Cultivar													
WI	100	100	98.8	93.5^{b}	85.9^{b}	78.6^{b}	77.6	100	100	91.9	81.9	73.6	57.8
PY	100	100	98.8	94.1^{b}	86.5^{ab}	79.8^{a}	77.8	100	100	91.9	80.4	72.1	57.6
GC	100	100	99.3	95.1^{a}	87.9^{a}	79.6^{a}	78.2	100	100	92.0	81.1	73.0	58.1
SE	0	0	0.3	0.9457	0.464	0.376	0.252	0	0	0.480	0.758	0.513	0.560
CV	0	0	1.003	1.341	2.073	1.839	1.122	0	0	1.280	2.291	1.724	2.371
Significance													
Cultivar	NS	NS	NS	**	*	*	NS	NS	NS	NS	NS	NS	NS
Packaging		NS	***	***	***	***	***	NS	NS	NS	***	**	*

(n=3)

LDPE low density polyethylene; *HDPE* high density polyethylene; *BL* banana leaf; *TS teff* straw; *WI Williams I*; *PY Poyo*; *GC* Giant Cavendish; *BL* dried banana leaf; *TS teff* straw

[1] Indicate treatments in which all the fruits were already discarded. NS, ***, **, *indicate significant differences at $P \leq 0.001$, $P \leq 0.01$ or $P \leq 0.05$, respectively, and means within the same column followed by a common letter are not significantly different at $P<0.05$ (LSD test)

Decay loss Until day 12, none of the fruits decayed which could be due to the low relative humidity of the storage room which disfavors the multiplication of microorganism (data not shown). Decay loss of 16.0 % was observed for *Poyo* cultivar stored at ambient conditions. This could be due to faster respiration resulting to the tissue softening that could in turn facilitate entrance for decay causing microorganisms. Whereas, the fruits subjected to HDPE bags, LDPE bags, BL and TS packagings remarkably had no sign of diseases (data not shown). Even up t0 day 24 of storage, all the fruits were marketable without any sign of decay. In the present study, it was found that unmarketability of fruits subjected to HDPE and LDPE packaging was totally due to decayed fruits (Table 8). Though significant ($P \leq 0.05$) difference was observed in the performance of the two plastic bags in terms of physiological weight loss, none of the fruits were unmarketable due to the difference in weight loss rather it was due to decay loss. From day 27 to 36, there was a decrease in the marketability of fruits in both plastic bags. At the end of the storage period, marketability of fruits subjected to HDPE and LDPE bags was 56.9 % and 58.8 %, respectively which indicated that there was a significant difference between the two plastic films on controlling decay of banana fruits. Even though, the plastic films were perforated equally, the permeability of HDPE bags to gases and water vapor was obviously lower than that of LDPE bags (Thompson 2001). The result of the present study showed that the reason for unmarketability of fruits from these packages was totally due to decay losses caused by decay microorganisms.

In addition to decay loss, the type of postharvest disease occurred during the storage period was identified using coloured photograph of the diseases as described by Dadzie and Orchard (1997). Anthracnose and crown rot were the two postharvest diseases of that appeared during the study. Symptoms of crown rot included softening and blackening of tissues at the cut crown surface, white mould was observed on the surface of the cut crown. Whereas the symptom of anthracnose was small circular and brown to dark brown spots.

Percentage of marketability The percentage marketability of banana fruit was significantly ($P \leq 0.05$) affected by the packaging materials. After 15, all the control fruits became unmarketable whereas fruit packaged in BL and TS continued until day 18 (Table 8). Since fruits were exposed directly to the atmosphere, control fruits had lost more weight than banana leaf and *teff* straw. In the present study, the main causes of unmarketability of control fruits was weight loss. Even though fruits packaged in BL and TS were found to be better than control fruits in preventing the weight loss, they became unmarketable totally due to weight loss. But fruits packaged in polyethylene bags continued being marketable until date 36. Ben-Yenonshuna (1985) reported that, packaging of climacteric fruits in low density polyethylene bags delay ripening and softening, and hence improves marketability.

At the beginning of the storage period, the difference between the plastic packagings was insignificant. Starting from day 30, a significant difference was observed. This may be due to the difference in permeability of plastic films to gases in which banana fruits from the LDPE bags had lost more weight than the HDPE but not significantly affected the percentage of marketability. At the end of the storage period HDPE maintained marketability to 56.9 % whereas LDPE kept to 58.8 % (Table 8). This difference in marketability of banana fruits contributed to percentage of decayed fruits in which more percent of decayed fruits were obtained from HDPE.

The difference among cultivars was significant ($P \leq 0.05$) from date 9 to 15. *Williams I* was found to have less percent of marketability than *Giant Cavendish* and *Poyo*. This difference could be related to the weight loss of cultivars. In the present study, *Williams I* was smaller in size than the two cultivars and hence it loses more weight due to its higher surface area to volume ratio.

Conclusion

Packaging significantly ($P \leq 0.05$) affected the PWL, peel colour, peel and pulp thickness, pulp to peel ratio, pulp firmness, dry matter of the pulp, decay loss and marketability. Modified atmosphere created by the polyethylene bags reduced weight loss. The reduction in weight loss was higher in banana fruits that were packaged in polyethylene bags than the weight loss from the banana fruit samples that were packaged in the low density polyethylene bags. The weight loss of non-packaged fruits was found to be significantly higher than the weight loss of fruits packaged in plastic films. This in turn resulted in low percentage of marketable fruits during the storage period at ambient conditions. Peel thickness was also maintained better in the packaged fruits than in the non packaged banana fruits. Dried banana leaf and *teff* straw packaging were found to be better in keeping the weight loss and peel thickness than weight losses from control fruits. Pulp thickness was also significantly ($P \leq 0.05$) affected by the packaging materials. Higher pulp thickness was maintained in packaged banana fruits. Packaging affected the pulp to peel ratio of banana fruits. Lower pulp to peel ratio was maintained for packaged banana fruit. Banana fruits that were subjected to BL and TS treatments were better in maintaining the pulp to peel ratio to lower than control banana fruits. Concerning firmness, higher values were maintained by the packaging treatments.

Both HDPE and LDPE bags kept the banana fruit firmer than the other treatments. Similarly, packaging affected the pulp dry matter of the banana cultivars. The control banana fruits were found to have lower dry matter. Higher value of pulp dry matter was maintained by packaging treatments. A higher percent of decayed fruits was observed in both plastic bags. The use of HDPE and LDPE bag packagings was found to be the best in extending the shelf life and maintaining the quality attributes of banana fruits.

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