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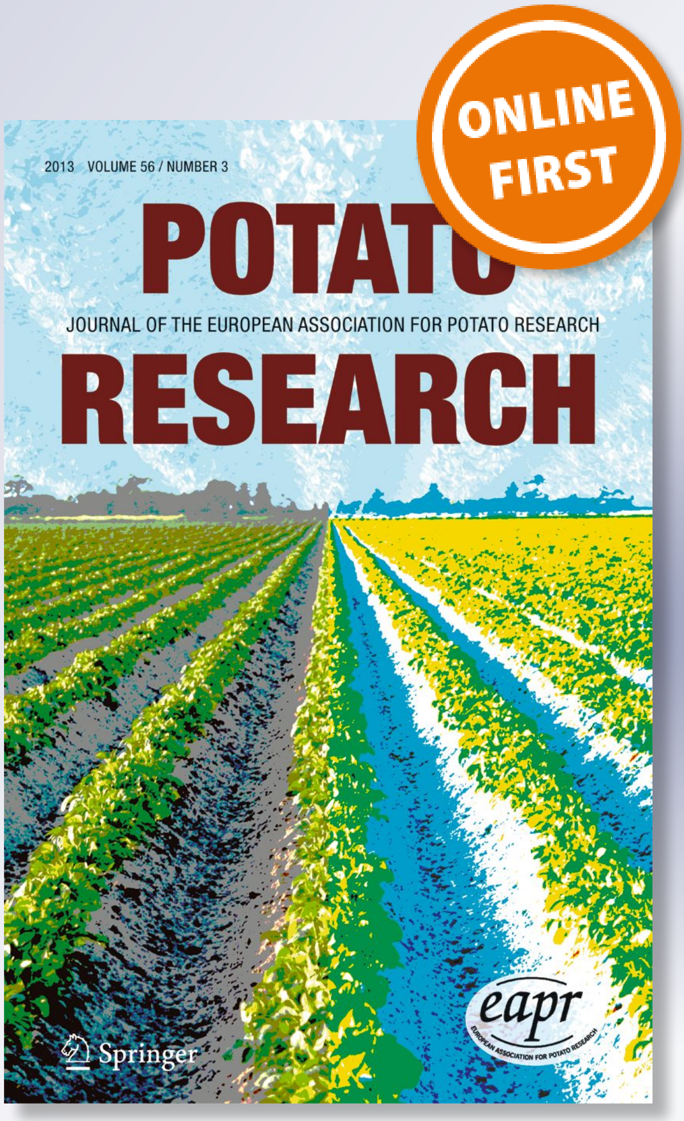

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Effect of Packaging Material on Shelf Life and Quality of Ware Potato Tubers Stored at Ambient Tropical Temperatures

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Abstract The effect of seven packaging materials (transparent perforated and non-perforated high-density polyethylene (HDPE) bags, black perforated and non-perforated low-density polyethylene (LDPE) bags, nylon gunny sacks, khaki bags and net bags) on post-harvest quality of tubers from three potato cultivars was evaluated. Data were collected on time and percentage of sprouting, weight loss rates and percentage tubers with greening and rotting. Packaging significantly reduced weight loss and rate of tuber greening but increased the rate of sprouting and decay incidences. Non-perforated PE bags were the most effective in reducing weight losses, recording losses of 0.7 to 0.9% after 32 days in storage while unpackaged tubers had weight losses of 11 to 12%. Tuber rotting was highest (60 to 66% of the tubers) in non-perforated PE bags. Greening was faster in non-packaged tubers recording 55 to 100% after 2 weeks in storage and showed high cultivar differences, but did not occur in black bags, whether perforated or non-perforated. Sprouting was complete by week 3 in all tubers packaged in non-perforated HDPE bags irrespective of cultivar. Although the non-perforated HDPE bag packaging prevented weight loss, its positive effect was counteracted by the high incidence of rotting and sprouting. Amongst the different materials evaluated, perforated low-density black PE bags were the best method for ware potato packaging due to low sprouting, reduced weight loss, low rate of tuber greening and reduced rate of tuber decay compared to other packaging materials. The study also indicated that the interaction between cultivars, packaging and storage period also affected shelf life of ware potatoes under ambient tropical conditions.

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Introduction

Potato (*Solanum tuberosum* L.) is the second most important food crop in Kenya grown by over 800,000 smallholders (NPCK 2015). The potato industry plays a major role in the Kenyan economy as it employs about 2.5 million people directly and indirectly (Abong and Kabira 2013). Most of the potato growers rely on rainfall-fed production. Unfortunately, production is slowly declining due to climate change and hence threatening food security (Mwaura 2009). The problem is further aggravated by high post-harvest losses. Post-harvest losses at the farm level are estimated at 12.8%, open market 24.4%, processing 12% and supermarkets 25% (Kaguongo et al. 2014). On average, 19% of the total production per hectare is lost every season (Kaguongo et al. 2014).) These losses have been attributed to poor storage management, use of poor-quality packages, poor handling and generally limited information (Kaguongo et al. 2014). Physical and quality losses are due to premature and excessive sprouting, tuber greening, tuber decay, transpiration and respiration. Sprouting leads to weight loss and loss of marketable tubers and reduces the nutritional and processing quality of tubers (Suttle 2003). Tuber greening occurs when tubers are exposed for an extended period to light causing chlorophyll formation in leucoplasts. As a result, the affected tubers are not marketable for food. Minimizing storage losses and extending shelf life of tubers is very important in this era of food security concerns. Modified atmosphere packaging (MAP) has been used extensively in fruits and vegetables. This technique involves modifying the atmosphere to create low O_2 and high CO_2 levels within the package atmosphere with the aim of extending the shelf life (Beaudry 2000; Mangaraj et al. 2009). In addition to atmosphere modification, MAP greatly improves moisture retention (Ben-Yehoshua et al. 1983; Yumbya et al. 2014). Modified atmospheres are generated through the natural process of respiration by the enclosed product which reduces the oxygen concentration and increases the carbon dioxide concentration under restricted gas exchange through the film barrier (Beaudry 2000). The effect of these changes in gas composition varies with commodity but it generally reduces respiration rate and susceptibility to pathogens (Kader et al. 1989; Gorris and Peppelenbos 1992). Modified atmosphere created by polymeric film has been reported to increase the storage life of fruits and vegetables through reduction of water loss, ethylene production and respiration (Mathooko et al. 1993; Mathooko 2003). Packaging potato tubers in dark plastic bags has been proposed as a way to reduce greening in retail markets (Pavlista 2001). MAP techniques have been used as an alternative to refrigeration of fresh produce as they are inexpensive and readily available. MAP is of interest in preserving ware potato quality, especially in the tropics, where cool storage is expensive and not readily available. The objective of this research was therefore to investigate the effect of packaging on the quality of ware potato tubers during short-term storage at ambient temperatures.

Materials and Methods

Plant Material

Certified tuber seeds of three genotypes, Shangi a short-dormancy cultivar and Asante and Kenya Mpya both medium-dormancy varieties, were grown at the University of Nairobi Kabete Field Station farm between April and July 2013 and between October 2013 and January 2014. Standard agronomic practices recommended for potatoes including ridging, pest control, fertilization and weeding were utilized. Freshly harvested potato tubers free of any evident disease and without any signs of sprouting were selected for packaging.

Packaging Treatments

Seven types of packaging materials were used in the experiment: black non-perforated and perforated low-density polyethylene (LDPE) bag, clear/transparent non-perforated and perforated high-density polyethylene (HDPE) bag, khaki bag, nylon gunny sack, net/mesh bag and open trays as control. The perforated bags each had 20 holes of 3-mm diameter covering 2% of total surface area of the bag. The treatments were laid out in a completely randomized block design (CRBD) replicated three times. Each package had 20 tubers.

Data Collection

Data were collected on dormancy, sprouting, weight loss, tuber greening and rotting. Dormancy period was recorded as number of days since harvesting to when 80% of tubers had visible sprouts of 3 mm in length. Ten tubers from each treatment were randomly sampled and observed initially at 7-day intervals until one of the tubers produced the first sprout in each treatment, and then at 4-day intervals to accurately record the dormancy period. Sprouting was expressed as a percentage of the number of tubers sprouted to the total number per sample. Weight measurements were done at the beginning of the experiment and every 4 days thereafter to determine the weight loss trend over 32 days of storage. The decrease in weight was expressed as a percentage of the initial weight, with weight including sprouts. Tuber greening was evaluated visually and the number of green tubers within each package recorded. Any tuber showing signs of a green colouration was considered to have greened. Evaluations on tuber rotting were made visually by observing each tuber for any signs of dry and soft rots and incidence was recorded as a percentage of the total number of tubers in a sample. The number of rotten tubers within a sample was recorded for 5 weeks.

Data Analysis

All data were subjected to analysis of variance using Genstat statistical program (Genstat 2010). Mean differences among the treatments were separated by Tukey's least significant difference procedure at 5% level of significance.

Results

Dormancy Duration and Sprouting

There was significant ($p \leq 0.05$) interaction between package type and cultivar. Non-perforated black LDPE and clear HDPE bags significantly reduced dormancy of the three cultivars compared to the other packaging and the control with the highest reduction recorded for non-perforated clear HDPE bags (Table 1). In contrast, perforated black LDPE and clear HDPE bags significantly increased the dormancy of cultivar Kenya Mpya as compared to the other packaging and control (Table 1). Generally, tubers of cultivar Shangi had the shortest dormancy period irrespective of the type of package. Kenya Mpya tubers packaged in perforated LDPE, perforated HDPE and nylon gunnysack had longer dormancy period than those packaged in trays, khaki bag, net bag and non-perforated black LDPE bag. Cultivars Asante and Kenya Mpya packaged in nylon gunny sacks, perforated HDPE and perforated LDPE bags had longer dormancy period than that of unpackaged control tubers (Table 1).

Tuber sprouting percentage differed significantly ($p \leq 0.05$) among packaging treatments, storage duration and cultivars (Table 2). Sprouting of all genotypes commenced in the second week of storage for tubers packaged in non-perforated HDPE bags. Significant differences in sprouting percentage among tubers of the three cultivars packaged in non-perforated HDPE bags were observed in week 2; thereafter, differences among cultivars were not observed (Table 2). Generally, sprouting was observed earlier in cultivar Shangi in all the packages tested compared to Asante and Kenya Mpya tubers. Tubers packaged in non-perforated LDPE bags had over 80% tubers sprouted by weeks 4, 8 and 10 for cultivars Shangi, Asante and Kenya Mpya tubers, respectively (Table 2). Sprouting of cultivar Asante and Kenya Mpya tubers packaged in khaki bags, net bags, nylon gunnysack bags, perforated PE bags and the unpackaged control tubers commenced at week 10. Generally, the percentage of sprouted tubers of all the cultivars increased with increased storage duration. At the end of week 12, there

Table 1 Effect of packaging on dormancy duration (days from harvest to end of dormancy) of three potato cultivars in Kenya

Package type	Cultivars		
	Asante	Kenya Mpya	Shangi
Control	78.3^{abc}	70.3^{cd}	40.0^{f}
Khaki bag	75.3^{abcd}	72.0^{bcd}	40.0^{f}
Net bag	74.7^{abcd}	72.0^{bcd}	36.0^{fg}
Non-perforated black LDPE bag	56.0^{e}	66.3^{de}	28.0^{gh}
Non-perforated clear HDPE bag	17.0^{hi}	19.0^{hi}	10.0^{i}
Nylon gunnysack	77.3^{abcd}	82.0^{ab}	35.0^{fg}
Perforated black LDPE bag	78.7^{abc}	84.0^{a}	36.0^{fg}
Perforated clear HDPE bag	84.0^{a}	83.7^{a}	33.0^{fg}

Means in rows and columns with different superscript letters indicate significant differences ($p < 0.05$) in treatment means based on Tukey's protected least significant difference (LSD) were no significant differences in sprouting percentage among the packages as well as among cultivars (Table 2).

Weight Loss

The least cumulative weight loss over 32 days in storage was observed in tubers packaged in non-perforated HDPE and LDPE bags for all the cultivars with no significant difference between the HDPE and LDPE bags (Table 3). High weight loss was observed for unpackaged tubers recording 11.3, 10.7 and 11.5% weight loss for cultivars Shangi, Asante and Kenya Mpya, respectively (Table 3). This was approximately 15.8, 14.3 and 13 times more weight loss than that of non-perforated HDPE and LDPE bags. Net bag packaging also resulted in significantly higher weight loss than the rest of packaging materials, namely 9.1, 10.3 and 10.7% weight loss for cultivars Shangi, Asante and Kenya Mpya, respectively (Table 3). However, for cultivar Shangi, it was slightly lower than that of non-packaged tubers. When the PE bags were perforated, weight loss was significantly higher than when they were not perforated. Nylon gunny sack and khaki bag packaging had moderate effect on weight loss. Weight loss differed slightly among the cultivars, with Kenya Mpya having a higher total weight loss compared to Asante in all of the packages tested (Table 3).

Weight loss during the 4-day measuring intervals decreased with storage time. The tubers stored in non-perforated PE bags maintained the lowest weight loss trend among the packaging materials throughout the experimental duration (Fig. 1). Weight losses during the first 12 days of storage were high across all the treatments whereas unpackaged tubers recorded the highest weight loss during the first 8 days in storage (Fig. 1). Towards the end of experimental duration, the rate of weight loss trend became similarly low and tubers packaged in khaki bags, net bags, nylon gunny sack and control displayed a similar weight loss trend (Fig. 1) but were still significantly higher than that of tubers packaged in PE bags. Despite heavy sprouting of tubers packaged in non-perforated PE bags, it was also observed that tubers preserved their initial firmness for a long period of storage, while non-packaged tubers significantly shrivelled.

Greening Incidence

Packaging reduced the frequency at which greening of tubers occurred (Table 4). The most effective packages in reducing greening were perforated and non-perforated black LDPE bags. In 5 weeks of storage, tubers packaged in black LDPE bags had no visible green colouration. Greening was 100% in unpackaged tubers and tubers packaged in net bags after 5 weeks. Khaki bags significantly lowered the number of green tubers and at the end of storage, greening was 27, 43 and 50% for cultivars Asante, Shangi and Kenya Mpya, respectively. At the end of 5-week storage, 100% greening was observed for cultivars Shangi and Kenya Mpya, packaged in nylon gunny sacks, net bags, perforated clear HDPE bags and the control. Generally, the number of green tubers increased with storage time. The unpackaged tubers began forming visible green colouration within 7 days of the experiment. The most susceptible cultivar was Kenya Mpya with tubers recording 100% greening in 7 days. Asante tubers recorded significantly lower greening incidences in most packaging materials tested while Kenya Mpya tubers recorded the highest (Table 4).

Table 2 Effect of packaging on percentage sprouted tubers of three potato cultivars for 12 weeks under ambient conditions in Kenya

Type of package	Sprouting (%) Cultivar	Storage duration (weeks) 1	2	3	4	5	6	7	8	9	10	11	12
Unpackaged (control)	Asante	0	0	0	0	0	0	0	0	0	66.7	77.8	91.1
	Kenya Mpya	0	0	0	0	0	0	0	0	0	86.7	95.6	95.6
	Shangi	0	0	0	0	68.8	84.4	91.1	100	100	100	100	100
Khaki bag	Asante	0	0	0	0	0	0	0	0	0	60	68.9	100
	Kenya Mpya	0	0	0	0	0	0	0	0	0	82.2	97.8	100
	Shangi	0	0	0	0	68.8	91.1	97.8	100	100	100	100	100
Net bag	Asante	0	0	0	0	0	0	0	0	0	75.6	80	97.8
	Kenya Mpya	0	0	0	0	0	0	0	0	0	75.6	88.9	93.3
	Shangi	0	0	0	0	82.2	86.7	93.3	100	100	100	100	100
Nylon gunny sac	Asante	0	0	0	0	0	0	0	0	0	46.7	71.1	93.3
	Kenya Mpya	0	0	0	0	0	0	0	0	0	42.2	66.7	84.4
	Shangi	0	0	0	0	82.2	88.9	93.3	100	100	100	100	100
Perforated LDPE bag	Asante	0	0	0	0	0	0	0	0	0	35.6	57.8	97.8
	Kenya Mpya	0	0	0	0	0	0	0	0	0	44.4	57.8	80
	Shangi	0	0	0	0	82.2	93.3	100	100	100	100	100	100
Perforated HDPE bag	Asante	0	0	0	0	0	0	0	0	0	20	48.9	80
	Kenya Mpya	0	0	0	0	0	0	0	0	0	35.6	60	80
	Shangi	0	0	0	0	86.7	91.1	100	100	100	100	100	100
Non-perforated LDPE	Asante	0	0	0	0	0	0	0	86.7	91.1	95.6	97.8	100
	Kenya Mpya	0	0	0	0	0	0	0	0	73.3	84.4	84.4	88.9

Table 2 (continued)

Type of package	Sprouting (%)												
	Cultivar	Storage duration (weeks)											
		1	2	3	4	5	6	7	8	9	10	11	12
	Shangi	0	0	24.4	82.2	100	100	100	100	100	100	100	100
Non-perforated HDPE	Asante	0	55.5	100	100	100	100	100	100	100	100	100	100
	Kenya Mpya	0	28.8	91.11	100	100	100	100	100	100	100	100	100
	Shangi	0	86.6	100	100	100	100	100	100	100	100	100	100
LSD (5%)		ns	7.49	8.53	12.91	10.61	5.93	3.60	4.47	5.67	17.47	16.44	8.22
LSD ($p \leq 0.05$): P	1.473												
LSD ($p \leq 0.05$): C	0.902												
LSD ($p \leq 0.05$): SD	1.804												
LSD ($p \leq 0.05$): P × C	2.551												
LSD ($p \leq 0.05$): P × SD	5.102												
LSD ($p \leq 0.05$): C × SD	3.124												
LSD ($p \leq 0.05$): P × C × SD	8.837												

HDPE high-density polyethylene bag, *LDPE* low-density polyethylene bag, *C* cultivar, *P* package type, *SD* storage duration, *ns* not significant

Table 3 Effect of packaging material on total percentage weight loss of ware potato tubers of three potato cultivars after 32 days of storage at ambient temperatures in Kenya

Type of packaging material	Weight loss (%) Cultivars		
	Asante	Shangi	Kenya Mpya
Control (trays)	10.7[fg]	11.3[g]	11.5[g]
Khaki bag	8.3[cde]	7.9[cd]	9.9[efg]
Net bag	10.3[fg]	9.1[def]	10.7[fg]
Nylon gunnysack	6.5[c]	8.2[cde]	7.4[cd]
Perforated LDPE bag	3.2[b]	4.2[b]	4.0[b]
Perforated HDPE bag	3.7[b]	3.8[b]	3.9[b]
Non-perforated LDPE bag	0.8[a]	0.8[a]	0.9[a]
Non-perforated HDPE bag	0.7[a]	0.7[a]	0.8[a]

Values followed with different superscript letters in rows and columns are significantly different according to Tukey's protected least significant difference test ($p < 0.05$)

Tuber Decay Incidences

Rotting was not observed in tubers packaged in perforated LDPE bags, nylon gunny sacks, net bags and control in open trays. During the 5 weeks of storage, decay was greatest in tubers packaged in non-perforated HDPE bags with losses being as high as 60, 66.67 and 64.44% for cultivars Asante, Shangi and Kenya Mpya, respectively (Table 5). Tubers packaged in non-perforated LDPE bags recorded the second highest rate of decay followed by those packaged in khaki bags, while for tubers packaged in perforated HDPE bags, decay was recorded for cultivar Kenya Mpya only (Table 5). In fact, there was no significant difference in decay among tubers packaged in khaki bags and perforated HDPE. There were no significant differences among the cultivars (Table 5).

Discussion

Dormancy Duration and Sprouting

Packaging tubers in clear, high-density non-perforated polyethylene bags resulted in an early end to dormancy (Table 1), the highest number of sprouts per tuber, high sprout length and thicker sprouts (data not shown). This will be attributable to changes within the package especially relative humidity and gas composition. The increased relative humidity coupled with increased carbon dioxide and low oxygen concentration and rises in temperature are likely factors that contributed to the early termination of dormancy and subsequent sprouting. High relative humidity effects on shortening tuber dormancy and enhancing sprout growth have been reported (Craufurd et al. 2001; Ezekiel et al. 2002; Shiwachi et al. 2003; Singh and Ezekiel 2003).

Atmospheric gas composition during storage has been shown to affect the tuber dormancy period. Increased carbon dioxide concentration in combination with

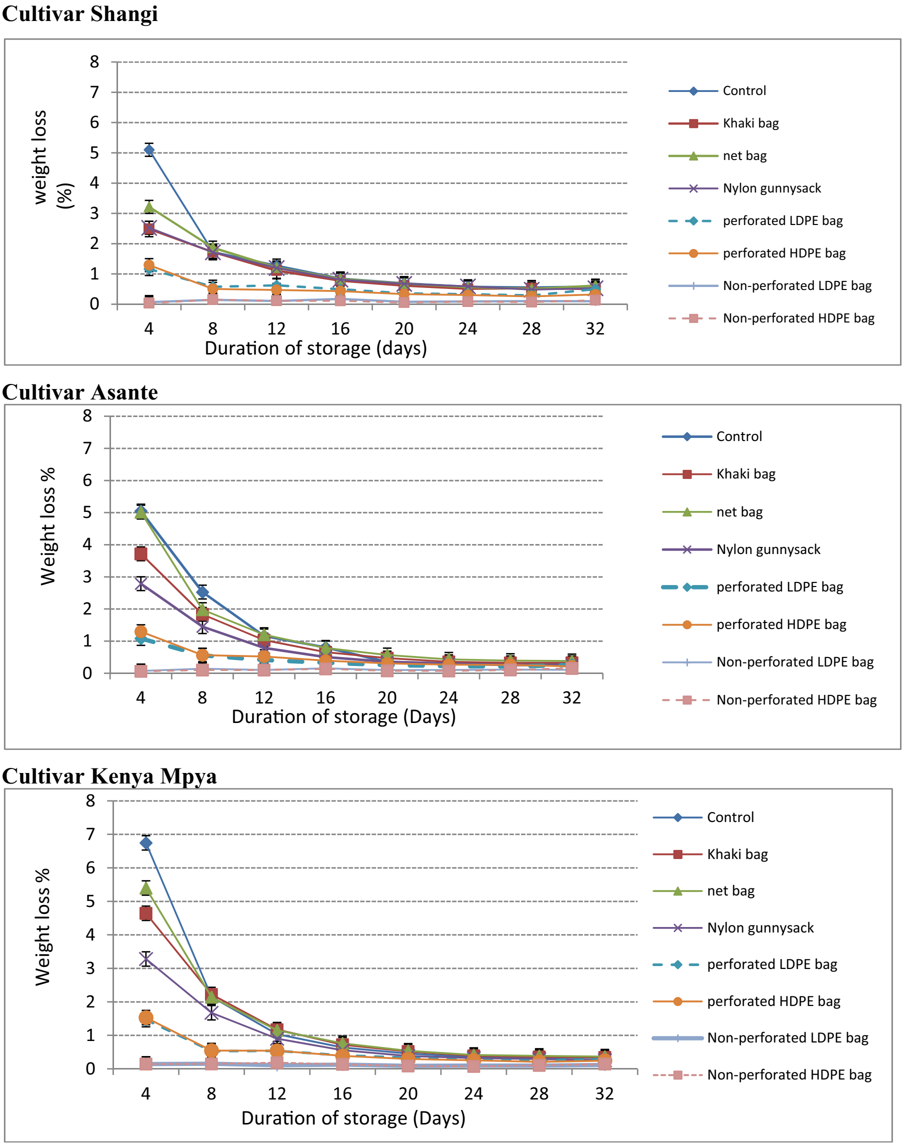

Fig. 1 Effect of packaging material on weight loss trend per 4-day interval of ware potato tubers of three cultivars stored for 32 days under ambient temperature in Kenya

reduction of oxygen to a certain concentration has been associated with faster dormancy break, increased number of sprouts and cell elongation (Coleman and Mclnerney 1997; Pinhero et al. 2009). In addition, a decrease in abscisic acid level within the potato tubers at 60% carbon dioxide and 20% oxygen has been reported (Coleman and McInerney 1997; Coleman 1998). In this study, high carbon dioxide concentration and low oxygen concentration could have been achieved due to respiration of the tubers and restriction of air movement out of the non-perforated polyethylene packages.

Table 4 Effect of packaging on tuber greening (% tubers with green colour) for three cultivars during 5-week storage under ambient conditions in Kenya

Package type	Cultivar	Storage duration (weeks)				
		1	2	3	4	5
Unpackaged (control)	Asante	36.7	55.0	78.3	100.0	100.0
	Kenya Mpya	100.0	100.0	100.0	100.0	100.0
	Shangi	51.7	100.0	100.0	100.0	100.0
Khaki bag	Asante	0.0	1.7	6.6	15.0	26.7
	Kenya Mpya	3.3	23.3	33.3	38.3	50.0
	Shangi	0.0	5.0	5.0	16.7	43.3
Net bag	Asante	15.0	40.0	53.3	91.7	100.0
	Kenya Mpya	50.0	66.7	100.0	100.0	100.0
	Shangi	38.3	55.0	100.0	100.0	100.0
Non-perforated black LDPE	Asante	0.0	0.0	0.0	0.0	0.0
	Kenya Mpya	0.0	0.0	0.0	0.0	0.0
	Shangi	0.0	0.0	0.0	0.0	0.0
Non-perforated clear HDPE	Asante	0.0	0.0	0.0	5.0	20.0
	Kenya Mpya	0.0	6.6	16.7	43.3	60.0
	Shangi	0.0	6.6	20.0	30.0	46.7
Nylon gunnysack	Asante	1.6	20.0	33.3	48.3	61.7
	Kenya Mpya	43.3	68.3	100.0	100.0	100.0
	Shangi	26.7	50.0	70.0	75.0	100.0
Perforated black LDPE bag	Asante	0.0	0.0	0.0	0.0	0.0
	Kenya Mpya	0.0	0.0	0.0	0.0	0.0
	Shangi	0.0	0.0	0.0	0.0	0.0
Perforated clear HDPE bag	Asante	3.3	15.0	28.3	41.7	46.7
	Kenya Mpya	56.7	70.0	100.0	100.0	100.0
	Shangi	25.0	45.0	100.0	100.0	100.0
LSD (5%)		9.15	13.50	14.28	12.65	10.74
LSD ($p \leq 0.05$): C	1.88					
LSD ($p \leq 0.05$): P	3.07					
LSD ($p \leq 0.05$): SD	2.43					
LSD ($p \leq 0.05$): C × P	5.32					
LSD ($p \leq 0.05$): C × SD	4.20					
LSD ($p \leq 0.05$): P × SD	6.86					
LSD ($p \leq 0.05$): C × P × SD	11.89					

HDPE high-density polyethylene bag, *LDPE* low-density polyethylene bag, *C* cultivar, *P* package type, *SD* storage duration

High temperatures are also known to promote sprout growth (Wustman and Struik 2007). It is speculated that limited permeability within non-perforated HDPE bags could have resulted in slightly higher temperature than the surrounding ambient air. The differences observed in sprout length, number of sprouts per tuber and sprout thickness

Table 5 Effect of ware potato packaging on tuber decay (% decayed tubers) during 5-week storage under ambient storage in Kenya

Type of package	Decay (%) Cultivar		
	Asante	Kenya Mpya	Shangi
Control	0.0[a]	0.0[a]	0.0[a]
Khaki bag	4.4[ab]	4.4[ab]	4.4[ab]
Net bag	0.0[a]	0.0[a]	0.0[a]
Non-perforated LDPE bag	17.8[c]	13.3b[c]	15.6[c]
Non-perforated HDPE bag	60.0[d]	64.4[d]	66.7[d]
Nylon gunnysack	0.0[a]	0.0[a]	0.0[a]
Perforated LDPE bag	0.0[a]	0.0[a]	0.0[a]
Perforated HDPE bag	0.0[a]	2.2[a]	0.0[a]

Means in rows and columns with different superscript letters indicate significant differences ($p < 0.05$) in treatment means based on Tukey's protected least significant difference (LSD)

among cultivars can be attributed to their genetic differences (Struik 2007). Cultivar Shangi, which exhibited a short dormancy period, gave long sprouts and also high number of sprouts in every package type compared to Asante and Kenya Mpya. Similar results have been reported by Carli et al. (2010) who found a negative correlation between dormancy period and length of the longest sprout with shorter dormancy clones recording longer sprouts and more sprouts per tuber than tubers with longer dormancy periods.

Weight Loss

The post-harvest moisture content of vegetables is considered one of the most important factors in maintaining their quality and shelf life. Post-harvest weight loss brought about by water loss is a primary factor limiting post-harvest longevity in most vegetables. The acceptable weight loss in potato tubers is up to 10% since no visible shrivelling takes place at this point (Mehta and Ezekiel 2010). In this study, non-packaged tubers as well as tubers packaged in net bags lost more than 10% of their weight during 32 days of storage. The tubers were shrivelled; hence, the market value of these potatoes was greatly reduced.

Weight loss in stored tubers has been attributed to processes such as evaporation, respiration and sprouting but the main contributing factor is evaporation (Mehta and Ezekiel 2010). Sprouting results in a notably large increase in weight loss due to increased moisture evaporation resulting from sprout growth (Singh and Ezekiel 2003). Contrary to literature, the results of this study found that the highest sprouting rate, high sprout length and high number of sprouts did not result in increased weight loss. This was due to packaging of tubers especially in non-perforated PE bags. The remarkable reduction in weight loss observed in non-perforated PE bags will be linked to a high relative humidity created within the package as well as the limited permeability of the PE bags. The moisture evaporating from the tubers and sprouts condensed, creating a high in-pack relative humidity. Several studies have reported that film packaging maintains a high relative humidity and reduces water loss (Chandran 2010; Rodov et al. 1995; Ben-Yehoshua et al.1983). Additionally, high relative humidity has been reported to reduce transpiration from the produce, thereby reducing weight loss, wilting, shrivelling and loss of firmness (Aharoni et al. 2007). Although the tubers packaged in non-perforated PE bags had multiple sprouts, they appeared firmer than the non-packaged tubers that had few sprouts. High weight loss in the non-packaged tubers and those in net bags could be attributed to the high airflow rate around the tubers as observed in other studies (Whitelock et al. 1994). Generally, permeability of packaging material to moisture loss played a great role in weight loss. The more permeable a material was, the more weight was lost. The small differences observed among cultivars could be due to their genotypic differences in sprouting characteristics, skin surface and tuber dry matter concentration. Cultivar Asante has high dry matter concentration compared to Shangi and Kenya Mpya (NPCK 2015). Differences between cultivars in skin surface permeability could result from differences in cuticle thickness (Lownds et al. 1993). Also Gachango et al. (2008) attributed weight loss differences among genotypes to differences in skin surface and the dry matter concentration of the tubers. Ezekiel et al. (2002) reported that tuber weight loss differs by cultivars, storage conditions and storage durations among other factors.

Tuber Greening

Greening affects the quality and palatability of potatoes. In this study, packaging the tubers reduced the frequency at which greening occurred, probably due to lowering the light transmission. The lowest numbers of greened tubers were recorded in tubers packaged in black package (perforated and non-perforated) and the highest numbers of greened tubers occurred in trays and net bags. Khaki bags, nylon gunnysack and clear PE bags allowed some light transmission, resulting in greening (Table 4). Rosenfeld et al. (1995) reported that greening of potato tubers packaged in different bags was proportional to the amount of light allowed in. Additionally, their study found differences in glycoalkaloid levels in potato tubers packaged in materials with different light transmission. Cultivar differences in greening were observed (Table 4). Asante tubers recorded lower greening incidences in most packaging materials tested while Kenya Mpya tubers recorded the highest. Cultivar differences in the degree of greening of tubers exposed to light have been reported earlier (Percival 1999). Reeves (1988) found that greening was less in russet compared to white cultivars. This is probably the reason why cultivar Kenya Mpya, which has a cream-white skin colour, showed faster and greater incidence of tuber greening, while cultivar Asante with a pink skin colour recorded the least incidence of tuber greening. Differences in potato greening among cultivars exposed to light have been reported to be an inherited genetic factor (Jakuczun and Zimnoch-Guzowska 2006).

Tuber Decay Incidence

Tuber rot was heavier in non-perforated HDPE bags than in other packages. This may have been due to high in-pack relative humidity. Moreover, water droplets condensed on the tubers and inner film surfaces of the non-perforated PE bags could have contributed to the increased decay. Kader (2004) pointed out that having condensed moisture on commodity surfaces could enhance decay development more than increased relative humidity. Rodov et al. (2010) and Aharoni et al. (2007) suggested that having condensed moisture on the commodity surface inhibits gas exchange and enhances microbial growth. As much as high relative humidity is advantageous in reducing weight loss, it is known to increase disease incidence. In this study, high relative humidity leading to moisture condensation primarily caused increased decay in addition to soft rot (*Pectobacterium carotovorum*). Tuber respiration in the non-perforated packages could have depleted the oxygen supply. Due to the limited permeability of the non-perforated HDPE bags, temperature inside the pack could have been higher than the ambient temperature, hence contributing additionally to tuber rotting. Temperatures above 28 °C are said to favour the growth of the pathogen *P. carotovorum* and an increase in temperature increases the severity of the disease (Singh et al. 2002). No tuber rotting was reported in unpackaged, net bags, perforated bags and nylon gunny sacks. This was attributed to storage conditions that were dry, thus not conducive for disease development.

In this study, non-perforated polyethylene bags were manifestly more efficacious in preventing weight loss and maintaining a fresher looking tuber. However, these non-perforated polyethylene bags reduced shelf life by promoting sprouting and tuber decay. Perforation of the PE bags reversed the negative effect (excessive sprouting and tuber decay) of non-perforated PE bags. Low-density black PE bags were the best method for ware potato packaging due to low sprouting, reduced weight loss, low rate of tuber greening and reduced rate of tuber decay compared to other packaging materials tested.

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