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Full Length Research Paper

Preliminary assessment of shea butter waxing on the keeping and sensory qualities of four plantain (*Musa* aab) varieties

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Over the last few years, the production of plantain has been increasing due to the introduction of some high yielding varieties. Unfortunately, very high post-harvest losses are incurred annually due to lack of appropriate storage technologies. This study evaluated the effect of shea butter as a food-grade wax on the pre-climacteric life and sensory qualities of four plantain varieties (*Apem*, *Apentu*, *Asamienu* and *Oniaba*). Waxing was achieved by brushing shea butter on fruits surfaces. The fruit diameter before waxing (d_1) and after waxing (d_2) was measured and the difference (d_2-d_1) taken as the waxing thickness. Parameters assessed were the uniformity of ripening, gloss quality, incidence of off-flavours and disorders. Waxing thickness of 0.5 and 1 mm resulted in irregular ripening, green-soft disorder and off-flavours. However, thin layer waxing (<0.05mm) prolonged the pre-climacteric life to 22, 20, 17, and 15 days in *Apem*, *Apentu*, *Oniaba* and *Asamienu* respectively. A prolonged post-climacteric life from 4 to 6 days across varieties as well as firm texture at senescence was recorded. Shea butter waxing resulted in significant decrease (P<0.001) in physiological weight loss of 9.46% by 22 days after storage compared to control which had 21.25% by 10 days of storage. Principal component analysis of sensory attributes showed that mouth-feel, colour, flavour and tastes accounted for 36.67 % of data variation whist texture alone accounted for 21.1% of data variability. Due to increasing lobby against the use of post-harvest chemicals, as consumers now want products with high nutritional value rather than having just superior external qualities, the use of shea butter as a food-grade wax can be further explored since no safety or residual effect is foreseeable.

Key words: Plantain, food-grade waxing, shelf life, sensory qualities.

INTRODUCTION

Plantains (*Musa* spp. AAB and ABB) are an important cash and subsistence crop, and together with banana provide up to 25% of the energy requirement in the developing world (Dadzie and Orchard, 1997; Ferris, 1997; Frison and Sharrock, 1999). The plantain fruits are consumed as main meals and snack at all stages of ripeness; green-mature, yellow-green, ripe or over-ripe. Over the last few years in Ghana, the production of plantain has increased tremendously due to the introduction of high yielding varieties which are resistant to black *sigatoka* virus disease (Dankyi et al., 2007; Dzomeku et al., 2007). Unfortunately, post-harvest losses as high as 10 to 30% are associated with the crop, because plantains have a short pre-climacteric period of less than one week and a shelf life of about 11 days under ambient conditions. Losses are severe among resource-poor farmers and small-scale handlers due to the lack of knowledge of the biological and environmental factors involved in the quality deterioration. Processing the fruits into commercial preservable products will naturally have been the main intervention to reduce these losses. Unfortunately, most families prefer to use plantains in the fresh and unprocessed form for cooking.

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Alternative storage is therefore necessary where there is a need to extend the shelf life beyond one week. In-depth research on alternative methods of storage for plantain such as cold storage, hypobaric storage, irradiation, modified atmosphere, evaporative cooling, and some postharvest chemicals have been investigated (Kader, 1999; Ahmed et al., 2006; Yahia, 2006, Sugri and Johnson, 2009). However, some of these methods are quite complex and beyond the technical and economic capacities of the small-scale handlers. In addition the objective of most of these studies was to investigate the effect of these treatments in respect to sensory properties, such as colour, texture, taste or changes in organic acids and carbohydrates. But in recent years, there are widespread negative public perception and health lobby against the use of postharvest treatments (Schreiner and Huyskens-Keil, 2006). This trend has resulted in consumers wanting products with high health-promoting compounds rather than having just superior external quality attributes. Though there is little evidence at the moment to support that the use of approved postharvest treatments is hazardous to human health. To meet this shift in consumer needs, some attention has shifted to explore the potential of surface coating particularly food-grade waxes to maintain the quality of harvested fresh produce and to reduce the volume of disposable non-biodegradable packaging materials (Schreiner and Huyskens-Keil, 2006; Adetuyi et al., 2008).The objective of this study was therefore to evaluate the effect of shea butter as a food-grade wax on the shelf life and sensory qualities of four plantain varieties (*Apem*, *Apentu*, *Asamienu* and *Oniaba*).

MATERIALS AND METHODS

Plantain samples

Uniformly ¾ mature-green fruits of four plantain varieties were obtained from an arranged supplier in a local market in Accra for the study. The varieties were: two French plantains (*Apem* and *Oniaba*), a False horn plantain (*Apentu*) and True Horn (*Asamienu*). Three of the varieties, *Apem*, *Apentu* and *Asamienu*, are triploid land races, while *Oniaba* is an intermediate variety. These varieties are the most populous in local markets in Ghana. The fruits were pre-cooled with a mist of water upon arrival at the storage room. Fingers were randomly selected for the treatments and incubated under ambient tropical conditions (28±5°C and 75±5 rh).

Bunch, fruit and peel characteristics

Data on bunch, fruit and peel characteristics were recorded. These include number of hands per bunch, fingers per hand, fruit weight and length, peel thickness, pulp weight and thickness, peel chlorophyll and pulp to peel ratio (Table 3). These traits vary between hybrids and at different maturities; and in associations with other conditions of handling influence the postharvest shelf life.

Procedure for waxing

Waxing was done by brushing the shea butter on fruit surfaces to achieve a uniform smear of three thicknesses: 0.05, 0.5 and 1 mm. Wax thickness was determined using a Mitituyo micrometer screw gauge (0.01–150 mm range). The fruit diameter before waxing (d_1) and after waxing (d_2) was measured and the difference in diameter (d_2-d_1) was taken as the wax thickness.

Analysis of chemical properties

Data on chemical characteristics such as pulp pH, total soluble solids (TSS) and total titratable acidity (TTA) were determined at stages 1, 4 and 6 of ripening using standard laboratory procedures (AOAC, 1990).

Physiological weight loss

Weight loss in waxed fruits compared to fruits stored at room temperature was determined daily. The total weight loss (TWL) was expressed as percentage of the original weight during the storage period. Weight loss percentage per day (WL/D) was calculated by dividing total weight loss by the number of days taken to reach stage 6 (Ahmed et al., 2006).

Sensory analysis

A five-point Hedonic scale was used to score samples for taste, colour, flavour, texture, mouth feel and overall acceptability (Table 1). Plantain samples were roasted in an oven with the temperature set at medium to high. Coded samples per treatment were served to each member of 13 trained panelists for the sensory evaluation.

Estimation of storage life

The storage life was expressed as the time between storage and when fruits became unwholesome for consumption. Daily observation for colour changes was made throughout the period of storage. Peel colour was measured using a colour chart. The criteria for determining the three stages of ripening are based on the pattern of colour change during ripening. This has been divided into ten stages; each stage has a characteristic peel colour, physico-chemical properties and forms of utilization (Dadzie and Orchard, 1997; Baiyeri, 2001) (in Table 2).

Data analysis

The design was a 4 x 3 factorial experiment in a completely randomized design with six replications. Data was subjected to analysis of variance (ANOVA) using Genstat (Release 7:22) statistical package. Test of significance between treatment means was by Fisher's Least Significance Difference (F-LSD) at 5% probability level. A further data reduction technique using principal component analysis (PCA) was done to establish variations, patterns and relations in the data (Smith, 2002).

RESULTS

Bunch, fruit, pulp and peel characteristics

Fruits of *Asamienu* and *Apentu* were bigger in size than *Apem* and *Oniaba* (Table 3).The former recorded higher fruit length of 32.25 and 28.13 cm, fruit diameter of 17.98 and 17.22 cm, fruit weight of 313.2 and 227.7 g and pulp diameter of 12.55 and 12.02 cm respectively. The peel

Table 1. Description of quality attributes for the sensory evaluation.

Score	Taste (sweetness)	Flavour (characteristic smell and aroma)	Mouth-feel	Colour	Texture (hardness or softness)	Overall acceptability
5	Extremely sweet	Extremely strong	Excellent	Very yellow	Very hard	Excellent
4	Very sweet	Very strong	Very good	Yellow	Hard	Very good
3	Sweet	Strong	Good	Pale yellow	Slightly hard	Good
2	Slightly sweet	Slightly strong	Fair	Slightly yellow	Soft	Fair
1	No sweetness	Off-flavours	Dislike	Almost white	Very soft	Dislike

Table 2. Peel colour changes of plantain at various stages of ripening.

*Physiological phases	Ripening stage (colour score)	Description of peel colour
1	1	Green
1	2	Pale green
2	3	Pale green with yellow tips
2	4	50% yellow 50% green
2	5	More yellow than green
2	6	All yellow
3	7	Yellow flecked with brown
3	8	50% black 50% yellow
3	9	More black than yellow
3	10	Pure black

*Physiological phases: 1: pre-climacteric; 2: climacteric; 3: senescence.

Table 3. Bunch, fruit and peel characteristics of four plantain varieties at the time of storage.

Bunch fruit and peel characteristic	Varieties			
	Apem	*Apentu*	*Asamienu*	*Oniaba*
Number of hands per bunch	8 - 10	4 - 7	1 – 2	8 - 10
Number of fruits per hand	8 - 14	5 - 7	4 - 7	8 - 13
Fruit length to diameter ratio	1.78	1.6	1.78	1.68
Fruit volume (cm^3)	99.06	237.35	265.52	87.95
Fruit length (cm)	24.05	28.13	32.25	23.95
Fruit diameter(cm)	15.05	17.22	17.98	14.89
Fruit weight (g)	117.0	227.9	313.2	132.2
Pulp diameter (cm)	11.14	12.02	12.55	10.97
Pulp weight (g)	67.77	141.2	191.4	88.19
Pulp dry matter (100 g)	36.56	38.22	36.61	39.83
Peel weight (g)	51.53	98.21	121.33	43.05
Peel thickness (mm)	3.79	5.22	5.78	3.92
Peel chlorophyll ($\mu g/cm^3$)	12.67	11.63	13.23	9.91

thickness, which has effect on the rate transpiration, of *Apem Apentu*, *Asamienu* and *Oniaba* were 3.79, 5.22, 5.78 and 3.93 mm respectively. Characteristic such as peel thickness and fruit weight may predispose the fruits to higher weight loss and mechanical bruising during handling.

Effect of waxing on pre-and-post-climacteric life

The effect of shea butter waxing on the pre-and-post-climacteric life is shown in Figures 1 and 2 respectively. The pre-climacteric (green life) is the period when the fruits remain green and firm. Thin layer shea butter

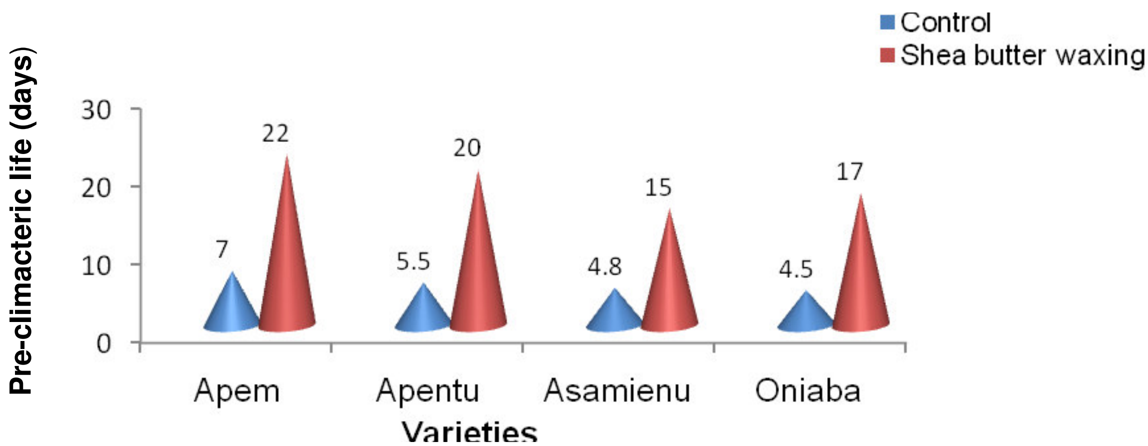

Figure 1. Effect of shea butter waxing on pre-climatic life of four plantain varieties.

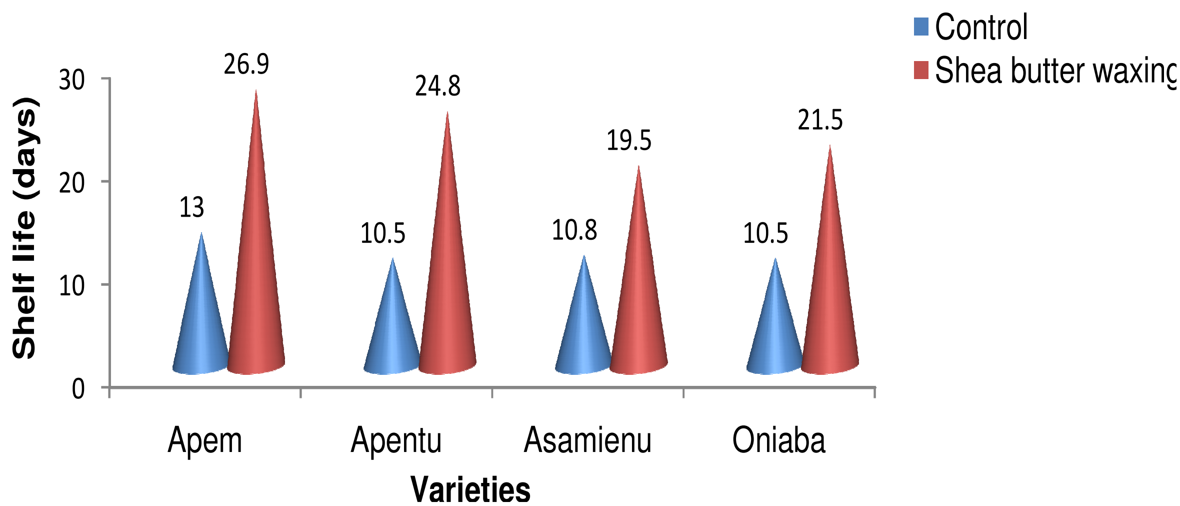

Figure 2. Effect of shea butter waxing on shelf life of four plantain varieties.

waxing (<0.05 mm) significantly (P< 0.001) prolonged the pre-climacteric life by up to 22, 20, 17, and 15 days in *Apem*, *Apentu*, *Oniaba* and *Asamienu*, respectively (Figure 1). The post-climacteric life is divided into the climacteric and senescence phases. Ripening commences when there is a trace of yellowish colouration in the peel, and is completed when the peel attains full yellow. A prolonged post-climacteric life from 4 to 6 days across varieties in addition to firm texture at senescence was recorded. The shelf life expressed as the number of days between harvest and when fruits become unwholesome for consumption was extended from 11 to 26, 24, 21 and 19 days in *Apem*, *Apentu*, *Oniaba* and *Asamienu*, respectively (Figure 2).

Effect of waxing on physiological weight loss

Less severe weight loss (WL) was recorded in the waxed fruits compared to control (Table 4). A general increase in WL was observed with prolonged storage. The waxed fruits showed reduced WL (9.46%) by 22 days of storage and a daily WL of 0.79% compared to the control (21.25%) by 10 days of storage and a daily WL of 3.55%. Due to the large fruit size and volume, *Asamienu* and *Apantu* suffered marginally high WL (10.46 and 9.51 %) and daily WL of 0.86 and 0.81 %, compared to *Apem* and *Oniaba* with total WL of 8.55 and 9.31 7.34% and daily WL of 0.75 and 0.74% respectively.

Effect of waxing on sensory qualities

For any sensory attribute, significant difference between varieties existed. Fruit flavour, taste, mouth-feel and colour were positively correlated to consumer acceptability. The range of scores for flavour (2.17 to 3.67), taste (2.50 to 4.50) and mouth-feel (2.33 to 4.50) across

Table 4. Effect of shea butter waxing on daily weight loss of four plantain varieties (%)

Days after storage	Control Varieties				Total	Shea-coated fruits Varieties				Total
	Apem	***Apentu***	***Asamienu***	***Oniaba***		***Apem***	***Apentu***	***Asamienu***	***Oniaba***	
2	3.40	6.40	6.47	5.13	5.35	1.04	1.71	1.90	1.70	1.59
4	8.13	12.30	12.67	10.33	10.86	3.23	4.44	6.33	4.57	4.64
6	16.10	21.63	24.33	20.00	20.52	5.97	7.67	8.23	8.00	7.47
8	23.23	30.33	30.33	28.00	27.98	7.67	8.30	9.27	8.63	8.47
10	37.00	38.00	*	0	35.47	8.90	9.57	10.33	10.47	9.82
12	*	*	*	*	*	11.30	12.67	14.37	12.00	12.58
14	*	*	*	*	*	13.27	14.63	15.50	12.80	14.05
16	*	*	*	*	*	13.83	14.99	16.56	13.97	15.04
18	*	*	*	*	*	15.23	15.73	16.63	15.47	15.92
20	*	*	*	*	*	16.00	16.30	17.27	16.13	16.07
22	*	*	*	*	*	16.69	18.00	18.97	16.57	17.56
WL/Variety	19.97	22.64	22.43	19.96	21.25	8.55	9.51	10.46	9.31	9.46
WL/Day	3.70	3.80	3.79	3.5	3.55	0.75	0.81	0.86	0.75	0.79

* Means fruits had ripened, %Weight loss of shea-waxed fruits is significantly (P < 0.001) lower than non-waxed fruits.

Table 5. Pulp to peel ratio of four plantain varieties at three stages of ripening.

Variety	Stage of ripening		
	Green-mature (stage 1)	**Half-ripe (stage 4)**	**Full-ripe (stage 6)**
Apem	1.06	1.25	1.77
Apentu	1.24	1.35	1.87
Asamienu	1.23	1.41	1.74
Oniaba	1.13	1.25	1.80
$LSD_{(0.05)}$	0.126	0.094	0.119
CV (%)	2.8	11.3	2.4

varieties suggest that no off-flavours or astringent taste was noticeable according to panelists' evaluation. Difference in colour was conspicuous among varieties. The average scores for *Asamienu*, *Oniaba* and *Apentu* were 3.77, 3.67 and 3.67 respectively, indicating yellowish pulp colour. The panel score showed that *Apentu*, *Oniaba* and *Apem* were sweeter (3.65, 3.63 and 3.58) than *Asamienu* (3.25). Principal component analysis (PCA) of sensory attributes could be explained using two indices: principal component one (PC1) consisting of mouth feel, colour, flavour and tastes accounted for 36.67 % of data variation, whilst PC2 made up of textural characteristics accounted for 21.1% of data variability (Figure 3).

Pulp: Peel ratio

The pulp to peel ratio assessed at three stages of ripening was not influenced by the waxing, but as ripening progressed significant difference (P< 0.05) among varieties was noticed (Table 5). At the green stage, the pulp:peel ratio of *Apentu* and *Asamienu* (1.24 and 1.23) were significantly higher (P< 0.001) than *Oniaba* and *Apem* (1.13 and 1.06) respectively. By full-ripe, the pulp to peel ratios of *Apem*, *Apentu*, *Asamienu* and *Oniaba* increased to 1.77, 1.87, 1.74 and 1.80 respectively. Higher pulp : peel ratio indicates more pulp weight in relation to peel; hence higher pulp mass to the consumer. The progressive increase in pulp/peel ratio has been attributed to the change in sugar ratios between the two tissues (Dadzie and Orchard, 1997). During ripening, there is a rapid accumulation of sugars in the pulp than in peel and this difference is reflected in the differential change in osmotic pressure. In addition, there is loss of water from the peel to the pulp and external environment.

Effect of waxing on chemical properties

Thin layer waxing (<0.05 mm) did not influence pulp pH, total titratable acidity (TTA) and total soluble solids (TSS), but significant difference (P< 0.001) between varieties existed at all three stages of ripening. However, waxing thickness above 0.05 mm could alter these properties due to anaerobic respiration. There was a general decrease in pulp pH (increased acidity) as fruits ripen. Pulp pH of green *Apentu*, *Apem*, *Asamienu* and *Oniaba* were 6.12, 6.01, 5.98 and 5.90, and by full ripe the pH decreased to 4.52, 4.41, 4.42 and 4.48 respectively (Figure 4). A dramatic rise in TSS and TTA with ripening was noticed. By full ripe, the TTA of *Apem*, *Apentu*,

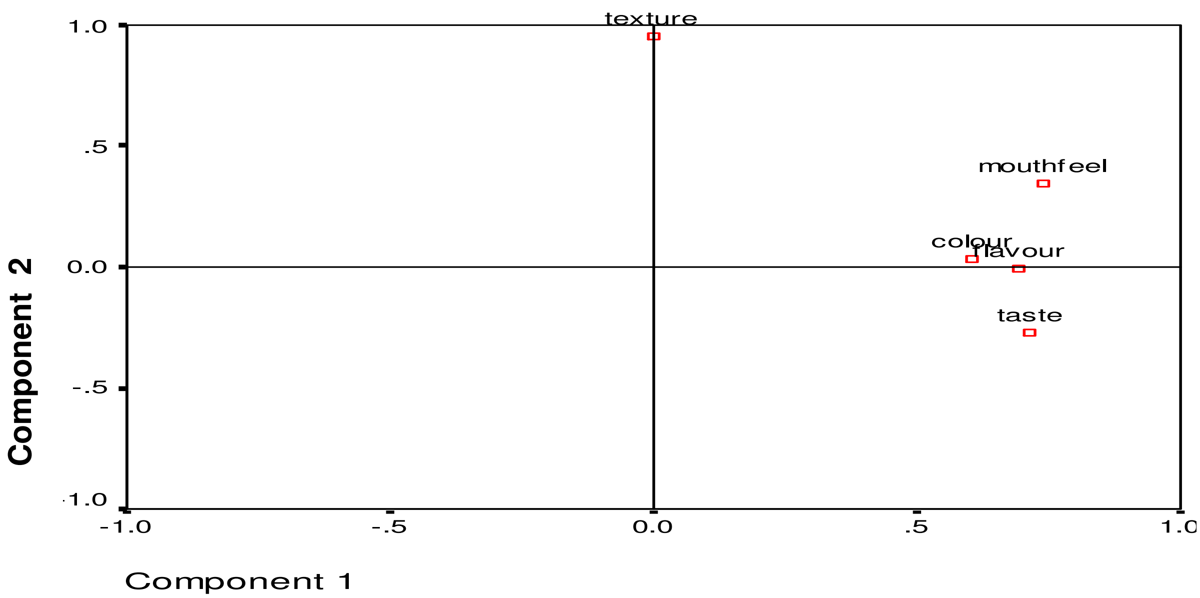

Figure 3. Loading plot from PCA of sensory attributes of four plantain varieties coated with shea butter as food-grade wax.

Asamienu and *Oniaba* were 9.72, 10.56, 8.8 and 9.91 g/l respectively (Figure 6). The TSS at the green stage did not vary among varieties and averaged around 3% brix (Figure 5). At full ripe, *Apentu* recorded the highest TSS of 21% brix compared to 18.04, 15.84 and 14.92% brix for *Oniaba*, *Apem* and *Asamienu* respectively.

DISCUSSION

Effect waxing on fruit ripening

The plantain fruits are highly perishable and climacteric. Understanding the mechanisms involved in ripening is therefore critical in reducing quality deterioration and postharvest losses. The process of ripening often involves a sudden peak in respiration and ethylene production rates and once started, cannot be halted and fruits must be consumed in a matter of days (Ferris, 1997; Alexander and Grierson, 2002). In general, the fruits continue to live the same way as in the mother plant even after harvest (Ferris, 1997; Wills et al., 1998). Normal metabolism continue in order to maintain and repair the cells, as though the fruits were not cut off from their normal supplies of water, minerals, and other simple organic products for metabolism. These substrates would normally be translocated to them from other parts of the plant. This explains why quality deterioration and senescence is rapid in fruits and vegetables after harvest. Generally, the extent of prolonged shelf life depends on the pre-harvest growth conditions, type and maturity of variety and conditions of handling (Dankyi et al., 2007; Dzomeku et al., 2007). The interplay of these factors determines rate of respiration and transpiration, the main deterioagents of fruit quality in the postharvest period.

The extended pre-climacteric and shelf life (Figures 1 and 2) show the immense potential of shea butter as food-grade wax for plantains and other high-value fruits. This prolonged shelf life can be attributed to the extent at which respiration and ethylene biosynthesis were inhibited. As reported in other studies, the waxing may have provided a microfilm coating on fruit surfaces which exerted little effect on water movement, but restricted gaseous exchange through the fruit skin, thus slowing down the rate of respiration (Wills et al., 1998; Alexander and Grierson, 2002; de Wild et al., 2003). The fruits showed reduced physiological weight loss, fresh appearance and firm texture at full ripe; indicative that the rate of transpiration and hence senescence were significantly impeded. The wax is readily available in local markets in most of the production areas, and the procedure of storage would be less sophisticated for use by beneficiaries. However, waxing thickness greater than 0.05 mm resulted in irregular ripening, green soft disorder and occurrence of off-flavours. This can be attributed to anaerobic respiration as a result of restricted gaseous exchange between fruits and external environment (Wills et al., 1998; Yahia, 2006). It may also be difficult to achieve uniform fruit ripening, but this is not a critical limitation since traditional and chemical methods are available to induce uniform ripening.

Effect of waxing on physiological weight loss

The weight loss per day of 0.79% across varieties as

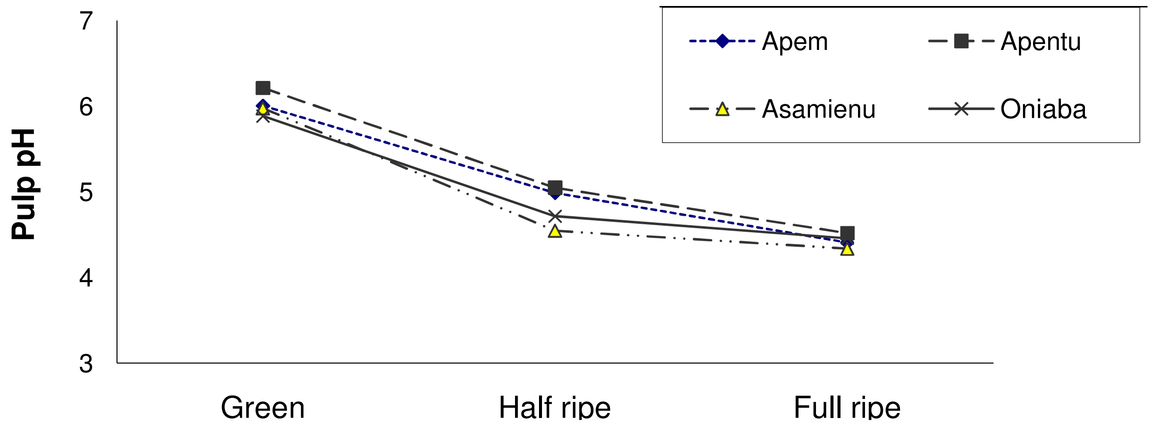

Figure 4. Changes in pulp pH at three stages of ripening.

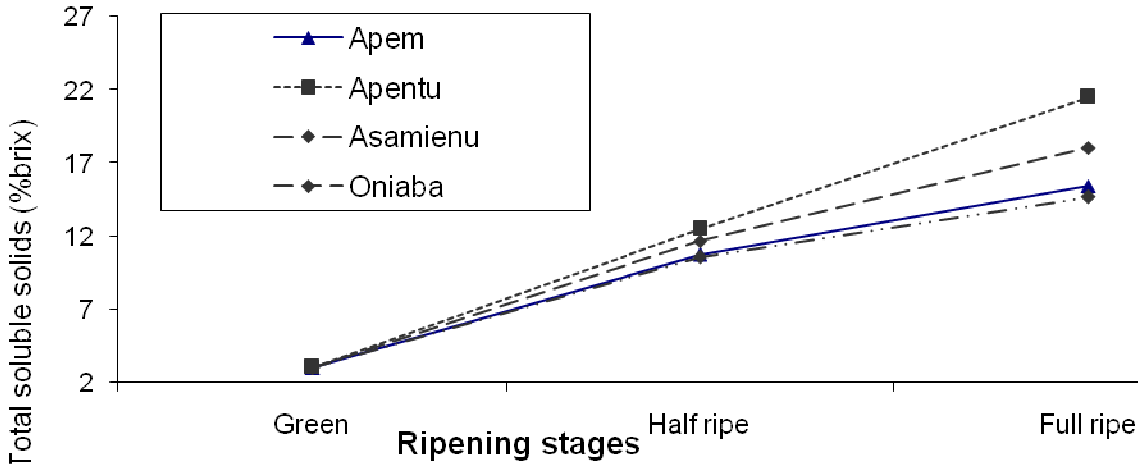

Figure 5. Changes in total soluble solids at three stages of ripening.

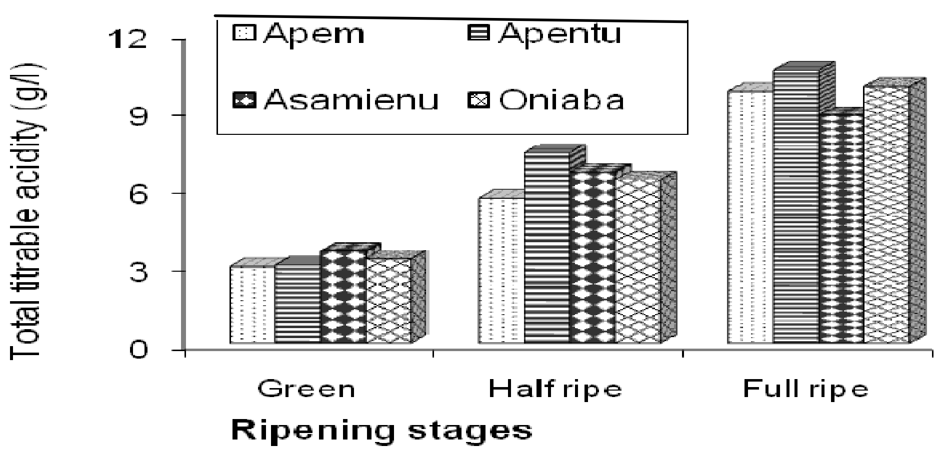

Figure 6. Changes in total titrable acidity at three stages of ripening.

compared to 3.55% of fruits held as control (Table 4) indicates the amount of reduction in physiological activities. Higher weight loss (WL) hastens physiological processes as well as quality deteriorations such as wilting, loss of firmness and flavour (Shewfelt, 1993). The rate of WL depends on the temperature and relative humidity of the storage atmosphere. The relationship between storage life and WL compares favourably with work done by others (Ferris, 1997; Sugri and Johnson, 2009). A curvilinear relationship between WL and ripening was established: for a 2% change from 2 to 4% WL per day, ripening period was prolonged by 9 days or 50%. However, for same 2% change from 8 to 10% per day, only 1 day or 5% reduction in ripening occurred. Using the fruit characteristics (Table 3), varieties with large volume or thin peel would suffer more bruises and WL during handling. Also, varieties with higher stomata density and thin peel would suffer higher weight loss which in turn accelerates ripening and quality deterioration. Studies on peel characteristics show that French plantain cultivars (e.g. *Apem* and *Oniaba*) have a more dense arrangement of stomata than other cultivars (Ferris, 1997). By surface area to volume ratio (Table 3), *Asamienu* and *Apentu* with large fruit volume (265.52 and 237.38 cm^3) would suffer higher WL than *Apem* and *Oniaba* (99.06 and 87.95 cm^3) respectively.

Effect of waxing on keeping qualities

The prolonged pre-climacteric life above two weeks across varieties is of critical significance as this connotes extended food supply, reduced postharvest losses and favourable price for both traders and consumers. In plantain marketing, the number of days fruits remain green is the most critical since several methods of utilization and processing can be explored. At the green stage, commercial processing into plantain flour and chips are feasible, but as fruits ripen only traditional dishes can be made (Baiyeri et al., 1999). In Ghana, stages 4 to 5 fruits (Table 2) are mostly roasted by women as snack which is usually eaten warm with fried groundnut on the street, whiles stages 6 to 8 fruits are suitable for frying into *red-red* and *kelewele*, both are a delicacy in Ghana. During senescence (stage 10), there is complete softening, microbial spoilage, sour taste and development of off-flavours. Subsequently the fruits become unwholesome for human consumption. According to Shewfelt (1993), the mechanism of senescence is due to physical changes such as peel browning due the breakdown of photosynthetic apparatus, loss of pulp firmness due to breakdown of starch and other non-pectic polysaccharides to sugar, and the solubilization of pectic substances in the cell wall and middle lamella resulting in reduced cohesion in the middle lamella.

The sensory evaluation was critical due to the prior limitations of waxing on ripening and sensory qualities of plantains. Outside the critical limits of CO_2 and O_2, a stress response respiration and ethylene production can be stimulated, which can lead to complex of physiological disorders such as irregular ripening, off-flavours and increase susceptibility to decay pathogens. The sensory quality analysis was therefore critical to ensure that key sensory attributes were not altered below consumer acceptability. The principal component analysis (PCA) showed that textural characteristics alone accounted for a greater proportion (21.1%) of data variation as by sensory panelists' evaluation. According to Smith (2002), once PCA has established patterns and relations in data, the results can be compressed without loss of valuable information. Several studies on plantain have established that overall consumer acceptability is positively correlated with texture, flavour, taste and colour (Baiyeri, 2001; Sugri and Johnson, 2009). In a similar study, Baiyeri (2001) found texture to be the most objective index for identifying effectiveness of storage systems for prolonging plantain green life. Thus, when evaluating any postharvest treatment to prolong the shelf life of plantain, adequate measures should be taken to keep the CO_2 and O_2 levels within the optimum range.

Conclusion

The effectiveness of postharvest treatments has been assessed mainly by the quality maintenance of harvested fruits and vegetables. However, with rising consumer interest in foods that promote health, some attention has shifted from quality maintenance to quality assurance with particular emphasis on consumer health and safety. In general, the use of chemicals as preservatives and anti-microbial food additives operate within certain regulatory controls. Prior to using any treatment to prolong shelf life, safety requirements must be satisfied. Such a chemical must achieve standards as Generally Recognized as Safe (GRAS) food storage or processing aide. Precisely, such a chemical must show no residue or pose any hazard on consumer health, operators or the environment. Due to this requirement, most chemicals previously used as postharvest treatments are no longer permitted due to concerns on toxicity or residual effects. This study showed that it possible to prolong the shelf life of plantains by using food-grade waxes such as shea butter. As part of broad interventions to reduce postharvest losses on plantain, commercial exploration of shea butter waxing can be considered since it poses no safety or residue concern. However, commercial exploration should consider the dispersability to provide a microfilm coating of less than 0.05 mm on fruit surface. This would improve gaseous exchange and luster quality. But, consumer perception and acceptability issues should be considered.

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