RESEARCH PROGRAM ON Roots, Tubers and Bananas

CGIAR

Technical Report: Efficacy of pruning, waxing and relative humidity storage in extending shelf-life of fresh cassava roots

Extending the shelf-life of fresh cassava roots for increased incomes and postharvest losses reduction

Expanding Utilization of Roots, Tubers and Bananas and Reducing Their Postharvest Losses

March 2017

RTB ENDURE

European Commission

IFAD
Enabling poor rural people to overcome poverty

A broad alliance of research-for-development stakeholders & partners

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NARO

IITA Research to Nourish Africa

IIRR

Kyambogo University knowlegde and skills for service

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Centro Internacional de la Papa CIP

Bioversity International

CIAT Centro Internacional de Agricultura Tropical International Center for Tropical Agriculture

cirad Agricultural Research for Development

IITA Research to Nourish Africa

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The CGIAR Research Program on Roots, Tubers and Bananas (RTB) is a broad alliance led by the International Potato Center (CIP) jointly with Bioversity International, the International Center for Tropical Agriculture (CIAT), the International Institute for Tropical Agriculture (IITA) and CIRAD in collaboration with research and development partners. Our shared purpose is to tap the underutilized potential of root, tuber and banana crops for improving nutrition and food security, increasing incomes and fostering greater gender equity, especially among the world's poorest and most vulnerable populations.

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Acronyms and Abbreviations

CIAT	International Centre for Tropical Agriculture
CIP	International Potato Center
EC	European Commission
IFAD	International Fund for Agricultural Development
IIRR	International Institute of Rural Reconstruction
IITA	International Institute for Tropical Agriculture
NARO	National Agricultural Research Organization
PPD	Postharvest physiological deterioration
RH	Relative humidity storage
ROS	Reactive Oxygen Species
RTB	CGIAR Research Programme on Roots, Tubers, and Bananas
SSA	Sub-Saharan Africa

EXECUTIVE SUMMARY

Postharvest Physiological Deterioration (PPD) is one of the leading causes of postharvest losses on fresh cassava in Uganda. This is expressed as blue black root streaking accompanied by bad odor and unfavorable taste. PPD is caused by the production of scopoletin, scopolin and esculin when roots are harvested and detached from the parent plant. The deterioration reaches a maximum in about four days after harvesting with microbial spoilage of the roots. This gives cassava a shelf life of 24 to 48h after harvest. The damaged roots are unpalatable and losses can be absolute if the roots are not processed quickly into other shelf stable products. This usually means that farmers and traders along the food supply chain face losses in income and reduced food security in addition to other unintended effects such as mounting pressure to sell and hence reduced price for the traders and limited sales into distant markets. However, the potential for fresh cassava utilization for retail and other markets in Uganda is still immense and hence needs to be exploited. There is need to develop effective, user friendly and affordable technologies for reduction of PPD and for enhancing shelf life of cassava.

In previous research waxing was reported to enhance shelf life. This claim however did not specify the biochemical and other changes in the roots with this treatment and did not explain the acceptability of the waxed roots. Further there was no information on the effect of this method when coupled with pruning. Coupled to this, root storage in high humidity bags was not yet evaluated for cassava roots of Ugandan elite and local varieties. Thus the purpose of this study was to evaluate waxing and high relative humidity treatments for efficacy on PPD reduction. Specifically, it aimed at evaluating effect of waxing and relative humidity storage on PPD, reducing sugars, dry matter content, cyanide content and starch yield as well as acceptability of treated roots.

Results from this study show that pruning alone would only extend shelf life to four to seven days. However, pruning followed by high relative humidity (RH) storage extended the shelf life of fresh cassava roots to 28 days resulting in less than 51% PPD among all the cultivars. Much as reductions in amylose content were not apparent across treatments over time, there were significant differences ($P>0.05$) in amylose content for the different treatments at day 14 and 21. Pruning followed by high RH storage also did not have a significant effect of the levels of cyanide in cassava ($P>0.05$).

There was reduction in PPD and increased shelf life after waxing for all varieties compared to untreated controls. The deterioration rate for all varieties was lower than 30% after 28 days of storage compared to about 90% and 80% deterioration for the control and pruned respectively. Waxing caused reduction in the cyanogenic potential of cassava varieties with storage time much as in the waxed treatment some increments were observed. After day seven, reduction in the cyanogenic potential was recorded from an average 80ppm for all varieties and all treatments to an average of 4.4ppm by day 28 in the non-waxed roots. Waxed roots cyanogenic levels remained in the safe zone.

There was an increment in dry matter content of cassava during storage but this was lower for waxed roots. The reducing sugar contents of both waxed and non-waxed roots also increased with storage time. However, the increases observed in waxed root were lower than in the non-waxed roots and was significantly different ($P>0.05$) from the pruned treatment and the control.

Combined pruning with waxing or with high relative humidity storage results in enhanced shelf life of cassava. Sensory analysis of waxed roots remained acceptable and did not differ from freshly harvested roots up to 14 days of storage. Thus waxing and high relative humidity storage can easily be recommended for adoption for commercial use in shelf life extension of cassava.

1. INTRODUCTION

In Uganda cassava is an important staple food. Studies have shown that at least 60% of the populations grow cassava and nearly 90% of the people consume cassava in different forms at least once daily (EAAPP, 2011). Fresh cassava is widely consumed both in urban and rural areas as a snack and main meal. Fresh cassava marketing is currently an important source of income (scoping study). Uganda has a policy of releasing "sweet varieties", i.e., varieties with low levels of cyanogens. These varieties are popular, with consumer demand increasing especially in urban areas, thereby providing incomes to both women and men. However, postharvest losses along the fresh cassava value chain remain unacceptably high resulting in loss in income and food security at household and national level.

Postharvest Physiological Deterioration (PPD) is the leading cause of postharvest losses on fresh cassava roots in Uganda**.** This is expressed as blue black root streaking accompanied by bad odor and unfavorable taste. PPD is caused by the production of scopoletin, scopolin and esculin when roots are harvested and detached from the parent plant. The deterioration reaches a maximum in about four days after harvesting with microbial spoilage of the roots. This gives cassava a shelf life of 24 to 48h after harvest. The damaged roots are unpalatable and losses can be absolute if the roots are not processed quickly into other shelf stable products.

The short shelf-life limits marketing options of fresh cassava by making it difficult for the value chain actors to trade with sufficient time so as to access more distant markets. As a result, the loss in economic value of the crop due to deterioration means that there are increased marketing costs and limited access to urban markets which are often located far from the production sites (Sanchez et al., 2006).

Traditional methods to reduce postharvest losses due to PPD include leaving the roots un-harvested in the soil after maturity (eight to twelve months). The roots can also be buried in soil after harvest where they are stored up to 3 months (MOF, CLNGMCI, & NARI, 2004). The disadvantage of the latter strategy is that roots become more woody and fibrous, decreasing their palatability. Extensive in-field storage of the roots also increases susceptibility to microbial attack as well as in the reduction of extractable starch (MOF, CLNGMCI, & NARI, 2004). Other methods include coating the roots with a loamy soil paste, piling them into heaps and consequently covering with vegetation or watering daily, but all these practices only extend the shelf life by 2-3 days (Onyenwoke & Simonyan, 2014).

There is however some technological options for reducing PPD in fresh cassava roots. These options include high relative humidity storage (RH) and waxing. Extending the roots' shelf life would provide farmers and traders with fresh cassava which can be marketed for longer and to distant markets thus increasing the profitability of the fresh cassava value chain. Thus alternative, effective and user-friendly options are needed for cassava shelf life extension. Therefore, the overall purpose of this study was to evaluate the efficacy of root waxing and high relative humidity storage on PPD of selected cassava varieties.

The specific objectives of this study were:

- To evaluate the combined effect of pruning and waxing on the level of PPD and on biochemical attributes of stored roots of selected varieties
- To evaluate the effect of pruning and high relative humidity storage on levels on PPD and on biochemical attributes of selected cassava varieties
- To investigate the acceptability of the waxed and relative humidity stored roots.

2. MATERIALS AND METHODS

2.1. Sample collection

A total of 16 cassava varieties were collected from three fresh root trading routes of Uganda. Five varieties were collected from Kyenjojo. These include Nyaraboke, Kirimumpale, Bufumbo, Njule, and Kijita. Four varieties, namely, Kibonange, Bukalasa, Mpagi and Kajahi were collected from Kabarole while Hoima, Nyaraboke (also from Kyenjojo), NASE14, TIM TIM, Nyamigyera, NAROCas1, Bao and TME14 were collected from Kiryandongo. These varieties were selected because preference by farmers due to their sweetness. The varieties were rapidly screened to select nine varieties that were relatively more tolerant or resistant to PPD. These included seven indigenous land races preferred by farmers: Bukalasa, Bufumbo, Hoima, Kirimumpale, Kigita, Nyaraboke and Njule. They also included two improved or elite varieties also popular among Ugandans due to their quality attributes: NASE14 and TME14.

Roots were always harvested 12 months after planting following the method of CIAT et al. (2012). Pruning or detopping (defoliation) was conducted 7 days prior to root harvesting. One set of each cultivar harvested was left unpruned (control) while the other was pruned. Care was taken to avoid injuries to the roots during harvesting (Venturini, Santos, & Oliveira, 2015).

2.2. Waxing treatment

For the waxing treatment, only five (namely Nyaraboke, Kirimumpale, Bukalasa, NASE14 and TME14) of the nine varieties were considered depending on their availability, market value, preference to farmers and logistical arrangements for their collection from farmers in at least three different times. Cassava roots were treated according to the method described by CIAT et al. (2012). The roots were washed with potable water using a soft bristled brush to remove adhering soil and allowed to drip dry for 10min at room temperature. They were then dipped for one minute in a solution of Ridomil fungicide and a surfactant (Silverwelt). The roots were air dried and subsequently dipped in hot wax pre-heated to temperature of 140-160 ^{0}C.

2.3. Relative humidity treatment

Harvested roots were left moist and placed in polyethylene bags of 2-5mm gauge. The bags were sealed and roots were kept under ambient conditions in the sealed bags. Four roots were sampled every 7 days for PPD scoring and biochemical analysis.

2.4. Scoring for postharvest physiological deterioration

The roots were scored for PPD according to the method described by Wheatley, Lozano, & Gómez (1985). Roots of each cultivar with a minimum size of 18 cm length, without mechanical damage or pre-harvest rot were selected. The distal and proximal ends were cut off with a stainless steel knife, so that the remaining root section is about 15 cm long. Crosswise sections 2, 4, 6, 8, 10, 12 and 14 cm from the proximal end were cut. A total of 7 sections were evaluated. Numerical values were assigned according to a scale of 0-10 on the proximal surface of each cut slice. The scale values correspond to 0-100% PPD. The average of the sum of the numerical values in the 7 sections evaluated was obtained and expressed as "Percent of deterioration".

The percentage increase in Shelf Life (SL) after waxing was determined as the mean PPD of waxed roots subtracted from the mean PPD of non-waxed roots as shown in the formula below.

$$(SL\ Increase) \quad = \frac{(PPD\ unwaxed - PPD\ waxed)x100}{PPD\ unwaxed}$$

2.5.Dry matter content determination

The dry matter content was determined using the method by Uarrota et al. (2016). Roots of each cultivar were randomly selected, cut into 2cm slices using a stainless steel knife, mixed thoroughly and triplicates of 100g samples (W_1) were dried at 60 °C for 48 hours in an oven drier (Leader, Leader Engineering Widnes, United Kingdom). After removal from the oven drier, samples were weighed immediately. It was then taken back to the oven drier for 2 hours until a constant weight (W_2) was obtained. Percent dry matter content (DM %) was calculated as follows:

Dry matter content = 100 * (W_2/W_1)

2.6.Determination of starch yield

Cassava starch was extracted by a modified method described by Nuwamanya et al. (2009). Roots were peeled and cleaned with distilled water. Then, the roots (500g) were blended with distilled water (500g of tuber in 1000ml of water) using a Waring blender (Waring® Commercial Blender, HBB2WTG4, USA). The pulp was stirred for 2min and filtered using a triple cheese cloth. The filtrate was allowed to stand until the starch sedimented and the top liquid decanted and discarded. The starch sediment was again washed with distilled water, and the top water discarded. The starch produced was oven-dried on aluminum pans at 60 ºC until a constant dry weight was obtained. The starch extract is weighed and then stored at room temperature in dry plastic air tight containers.

2.7. Determination of starch content

Distilled water (0.1ml; blank), standard corn starch (98%; 0.1g) and cassava starch (100mg), were transferred to a clean test tube and 10% sulphuric acid (5ml; Lobachemie® Reagents and Fine Chemicals, 1830, India) added. The test tube was placed in a water bath (Grant Instruments Ltd, TXF200, UK) at 80 ˚C for 30min. The supernatant (0.5ml) was transferred into a clean dry test tube as well as 5 serial dilutions for the standard solution; distilled water (1ml), phenol (0.5ml, 5%; VWR® Chemicals, France) were added to the contents in the test tube and vortexed (Labonet® International, 50200, United Kingdom) for 5s. Concentrated sulphuric acid (1ml) was added to the contents in the test tube, shaken for 5s, allowed to cool at room temperature for 15min and then absorbance was recorded with a spectrophotometer (WPA Biowave II+, England) at a wavelength of 490nm. The spectrophotometer was zeroed by reading absorbance of the blank then the absorbance of the prepared sample. The standard sample and serial dilutions of known concentrations were also measured. A graph of the data obtained from the readings obtained from the standard sample was plotted with the solution concentration on the x-axis and the absorbance on the y-axis. The equation of the "best-fit" straight line was determined using MS Excel© 2013. This equation gave the mathematical relationship between solute concentration and absorbance.

Finally, the equation was used to derive the concentration of digestible starch in the cassava starch sample.

$y = 0.418x - 0.43$

Where,

y is the absorbance
x is the concentration

2.8. Determination of amylose content of cassava starch

Cassava starch (100mg) was transferred into a volumetric flask, wetted with ethanol (95%, 1ml; VWR® Chemicals, UN1170, France) and distilled water (10ml), followed by NaOH solution (10%, 2ml; Lobachemie® Reagents and Fine Chemicals, 0589800500, India). The contents were heated in a water bath (Grant Instruments) at 60 ºC until a clear solution was formed. The flask with its contents was cooled at room temperature and diluted to the mark (100ml) with distilled water. A portion of distilled water (5ml) was added and acidified slightly with HCl (6M, 3 drops; Sigma-Aldrich®, UN1789, Germany). The contents were homogenized by shaking for 5s and Iodine solution (10%, 5ml) was added. Absorbance of the solution was read at 640nm against and amylose content quantified spectrophotometrically.

2.9. Determination of reducing sugar content

Cassava flour (500mg) was mixed with ethanol (1ml, 95%) and distilled water (2ml) in a centrifuge tube. Hot ethanol at 60 ºC (10ml, 95%) was added to the resultant solution followed by vortexing for 5min. and centrifugation (Labofuge 400R, Thermo Electron Corporation, Germany) for 10min. The supernatant was decanted into a volumetric flask and made up to 100ml with distilled water. This solution (10ml) was used for quantification of reducing sugars. The supernatant, distilled water (blank) and serial dilutions of 99% glucose (standard) (0.5ml each) were pipetted into separate clean dry test tubes. Distilled water (1ml) and 5ml phenol (5%; UNILAB®, 1159, Ajax Finechem, Australia) were added to the contents in each of the test tubes and vortexed for 3-5s. Concentrated sulphuric acid (1ml) was added to the contents in the test tubes, shaken for 3-5s. and allowed to cool for 15min. and then the reducing sugar content was quantified using a spectrophotometer at a wave length of 490nm.

2.10. Determination of total cyanide content

Linamarase enzyme solution was prepared according to a modified method described by Haque & Bradbury (1999). Sap (1ml), was squeezed from the end of the petiole (stalk) of cassava leaves and mixed with orthophosporic acid (0.1M, 10ml; Unilab® 372-2.5L GL, Ajax Finechem, Australia) to give a solution of enzyme. This solution was stored at room temperature for 1 hour until it was utilized.

The peeled cassava root (50g) was added to orthophosphoric acid (160ml, 0.1M) and finely ground in a blender. The mixture was centrifuged at 129,000 RCF for 30min. at 4 ˚C. Triplicate samples (0.1ml) of the supernatant were added to separate clean dry test tubes. Standard solutions of Potassium Cyanide (1g/ml) as well as its serial dilutions and 1ml of distilled water (blank) were also added to test tubes. To each of these test tubes, orthophosphoric acid (0.1M, 0.4ml, pH

7.0) and linamarase enzyme solution (0.1ml) were added and incubated at 30 ^{0}C for 15min. Sodium hydroxide (0.2M, 0.6ml) was added to the above sample and incubated at room temperature (25±5 ºC) for 5 min. Orthophosphoric acid (2.8ml, pH 6) and of *N*-chlorotosylamide (Chloramine-T; 0.1ml) were added to the sample, shaken for 5 s. and incubated for 5min. at room temperature. Pyridine-barbituric acid (coloring reagent; 0.6ml) was added to the sample, shaken for 3-5s. and left for 10min. at room temperature after which absorbance was read at 605nm in the spectrophotometer.

2.11. Sensory analysis

Rating was done on a 9-point hedonic scale with anchors ranging from 1 (dislike extremely) to 9 (like extremely) according to Ubbor & Akobundu (2009). Sensory analysis of all steamed cassava samples involved the participation of 20 untrained panelists who comprised of staff at National Agricultural Research Organization, Kawanda. Panelists consisted of 7 males and 13 females and their age ranged from 24 to 50 years. Availability, willingness and having eaten cassava were some of the factors considered for participating in the session. Each individual evaluated five sensory characteristics (appearance, taste, aroma, texture and mouthfeel) which were consequently averaged as overall acceptability. For waxing analysis, three of the candidate varieties which were accessible for use for this study were evaluated. These included NASE14, NAROCas1, and Nyaraboke.

Upon arrival at the sensory laboratory, each panelist read an explanation of the study and gave their informed consent. Cassava samples were steamed for 30min. and served 15min. later. Steamed cassava samples were placed onto disposable plastic plates and labeled with randomly selected three digit numbers. The coded samples were presented under normal lighting conditions, in a randomized manner across panelists to ensure that the order did not introduce bias into the results. Each individual evaluated the five aforementioned sensory characteristics. Each panelist was presented with the test sample and a bottle of drinking water to rinse out their mouths before and after each taste. The panelists were asked to evaluate the product and record their perception of each sensory characteristic using a nine-point hedonic scale. The ratings on the 9-point hedonic scale used were (9="like extremely"; 8="like very much"; 7="like moderately"; 6="like slightly"; 5="neither like nor dislike"; 4= "dislike slightly"; 3="dislike moderately"; 2="dislike very much"; 1="dislike extremely").

2.12. Data analysis

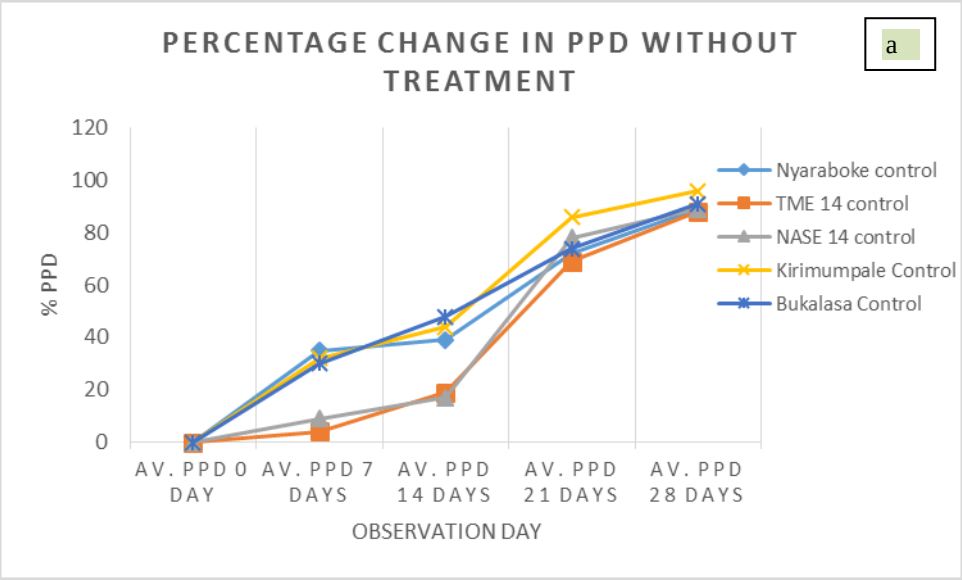
Averages for the sampled varieties were taken to be the representative values of particular varieties in each of the treatments at a particular sampling time. The variations between the averages for the different sampling times and the differences between the test varieties were evaluated using a one way ANOVA. All the specific analyses were carried out using GENSTAT Discovery Edition 2013 analysis software.

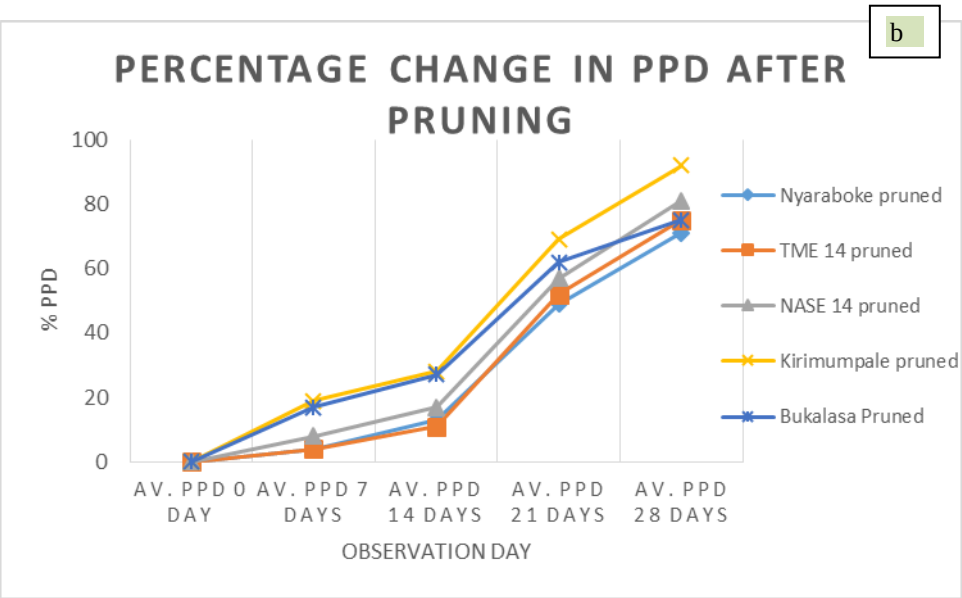
3. RESULTS

3.1. Effect of waxing on shelf life and biochemical properties of cassava roots

3.1.1. Variation in levels of PPD of waxed roots compared to pruned roots and the control (unpruned and not waxed)

There were differences in levels of PPD among the varieties after waxing with reduction in PPD and increased shelf life for all varieties compared to untreated controls (Figure 1). Much as differences were observed among treatments, it was observed that deterioration increased with time. The rate of deterioration was however different for the two treatments and both treatments slowed down PPD significantly compared to the control.





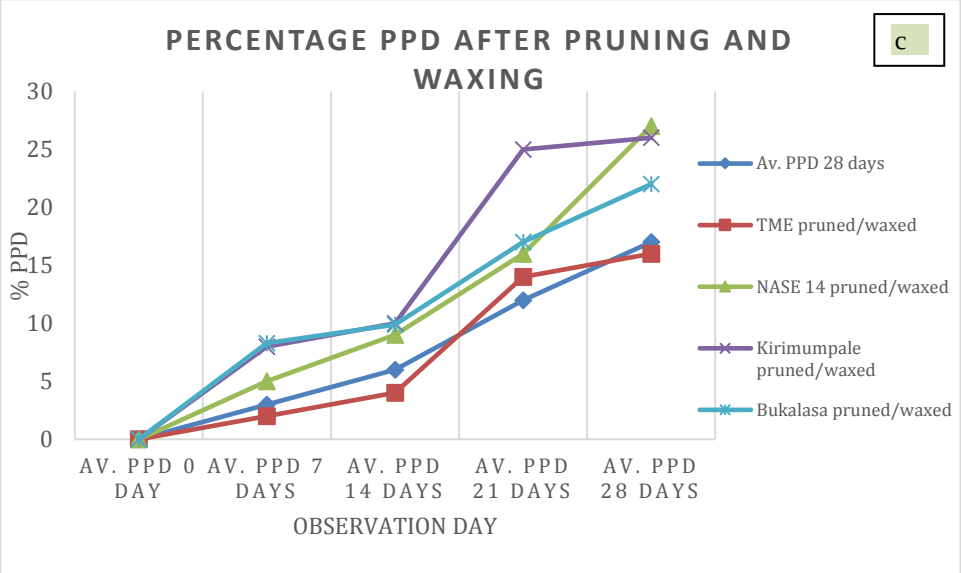


Fig. 1: Percentage PPD among the different varieties and treatments

The variations observed in Figure 1 indicated that the varieties responded in different ways to the waxing technology. TME14 and two popular local varieties (Bukalasa and Nyaraboke) responded well to waxing and therefore have major potential for shelf life extension. Conversely, NASE14 had the lowest percentage reduction in PPD rate and the lower response to waxing.

Waxing was also more appropriate for longer storage times (Figure 2) while cheaper options such as high relative humidity storage would be appropriate for shorter storage times.

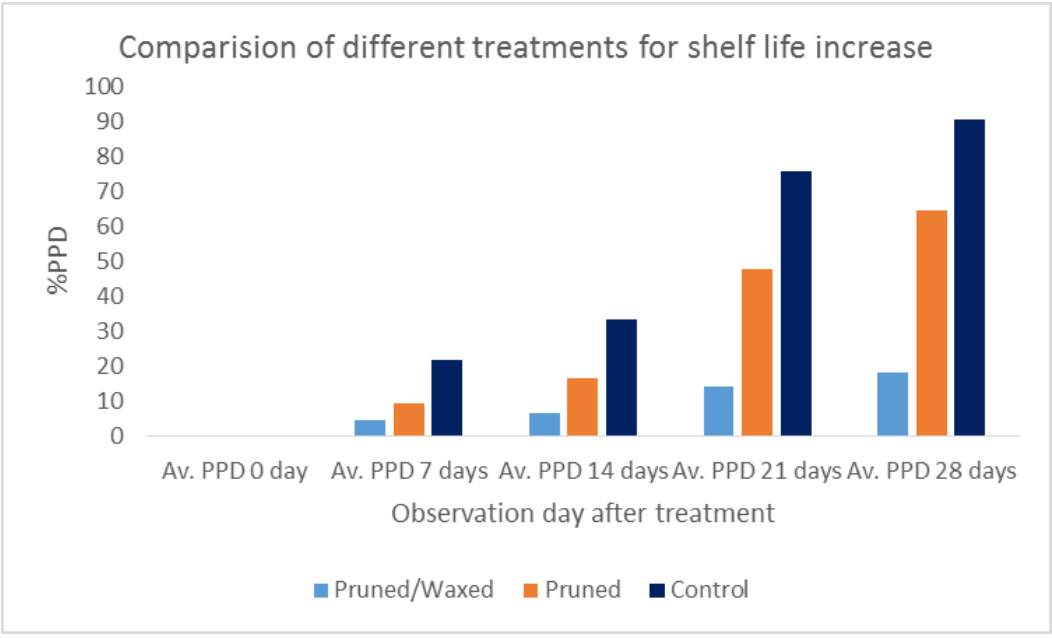


Fig. 2: Average percentage PPD during storage of cassava varieties subjected to two treatments

The average PPD increased rapidly in the control and pruned treatment compared to the pruned-and-waxed samples. In the case of waxing, the deterioration rate for all varieties was lower than 30% after 28 days of storage compared to about 90% and 80% deterioration for the control and pruned samples, respectively. From the above, it is evident that the shelf life of cassava can slightly be improved by pruning while shelf life can be extended for significantly longer when pruning is combined with waxing. Pruning alone cannot offer extended shelf life over 14 days while combined pruning and waxing can. Given the fact that marketing of cassava can take a long time, extended marketing period can be achieved by combining waxing with pruning.

3.1.2. Dry matter content

The dry matter (DM) content at day zero (Day 0) ranged from 31 to 36%. The lowest dry matter contents were observed in the local varieties Kirimumpale and Nyaraboke (average 31 and 32%, respectively) while the highest DM contents were observed for the elite variety TME14 (average 36%). Changes in DM contents were observed after storage increasing significantly by between five and 10 percentage points in the first seven days in the control (Table 1). Such increments were sustained reaching the highest level at 28 days and ranging between 42-53%. Similar observations were made for the pruned roots with no significant differences observed between the pruned experiment and the control. However in the waxed roots, lower increments in DM content were observed. The DM content, which ranged from 31 to 35% at harvest, increased with storage days and was in the range of 36-43% at 7 days and 40-48% at 28 days. The DM content in waxed roots during storage period was consistently lower than in pruned only and control roots. Nevertheless significant variability ($P<0.05$) was observed among the different varieties. The increase in DM over time could be as a result of moisture loss that occurs in the roots during storage. Such losses in moisture may contribute to deterioration of the root by execrating the production of reactive oxygen species (ROS), the main predisposing factors of PPD.

Table 1: Specific changes in dry matter content of the cassava across different treatments

Variety	Treatment	Day 0	Day 7	Day 14	Day 21	Day 28
Nyaraboke	Control	32.73±0.033	36.44±0.827	39.37±1.647	44.21±1.435	42.12±3.111
	Pruned	31.77±0.438	38.35±0.572	41.37±1.400	44.82±0.077	45.09±0.198
	Pruned/ Wax	31.48±0.587	35.73±1.520	38.72±1.725	40.88±0.700	39.69±1.675
TME 14	Control	36.21±0.728	45.72±2.114	47.09±0.049	51.45±1.103	50.74±0.869
	Pruned	35.62±0.559	44.76±3.966	47.19±0.487	50.27±0.247	53.18±1.492
	Pruned/ Wax	35.43±0.615	42.27±5.395	45.25±1.492	44.45±0.834	45.66±2.743
NASE 14	Control	34.48±0.693	42.29±0.975	45.09±0.304	49.15±0.544	53.49±0.268
	Pruned	34.83±0.262	42.74±0.127	45.98±0.346	49.87±0.113	53.09±0.912
	Pruned/ Wax	34.07±0.283	39.32±2.093	43.69±1.859	42.59±1.223	47.97±0.466
Kirimumpale	Control	31.41±0.665	41.52±0.735	41.82±1.385	45.72±0.530	46.87±1.371
	Pruned	31.53±0.198	42.01±0.091	42.42±0.855	45.49±1.187	47.26±0.685
	Pruned/ Wax	31.53±0.693	36.72±1.245	39.07±0.947	42.47±1.576	40.69±2.107
Bukalasa	Control	32.55±0.651	39.12±0.734	41.74±2.453	44.36±1.810	43.42±7.240
	Pruned	32.68±0.354	42.32±0.742	43.18±0.516	46.86±0.044	48.00±0.028
	Pruned/ Wax	32.61±0.099	42.95±0.063	41.32±2.517	43.66±1.442	43.40±0.148

Note: DM 7, 14, 21, 28 denote DM content at 7,14,21, & 28 days storage time.

3.1.3. Starch yield

Starch is one of the key ingredients of cassava roots. Loss in starch does not only lead to loss in caloric value of the root but also affects other nutrient related aspects of the root. Therefore changes in starch yield from different varieties undergoing storage after waxing were determined and these results are presented in Table 2. Reduction in starch yield was observed during storage. Reduction in the amount of extractable starch could be linked to hydrolysis and break down processes that occur in roots during storage. Reduction in starch yields over time were more pronounced in pruned and control samples which were significantly different (P <0.05) from waxed root as from day 14 of storage. However, it should be noted that there were no significant differences between the pruned treatment and the control after 7 days. This further indicates that pruning as a technology is crucial for extending the shelf life for only about 7 days after which the cassava should be marketed.

Table 2: Variations in starch yield across the test varieties and treatments over the storage days

Variety	Treatment	Day 0	Day 7	Day 14	Day 21	Day 28
Nyalaboke	Control	22.69±1.51	16.28±0.21	15.17±0.08	14.30±0.16	14.28±0.76
	Pruned	21.29±2.16	17.45±0.37	15.12±0.09	15.09±0.01	12.77±0.62
	Pruned/ Wax	20.83±1.43	17.32±0.18	16.79±0.22	16.11±0.40	15.10±1.29
TME 14	Control	25.31±1.59	19.49±0.41	15.62±0.60	16.63±1.08	14.14±0.95
	Pruned	23.76±1.25	20.26±0.21	17.65±0.09	14.82±0.19	13.77±0.01
	Pruned/ Wax	22.80±1.54	20.04±0.04	18.48±0.61	18.02±0.06	17.32±0.53
NASE 14	Control	22.00±1.03	19.09±0.04	17.28±0.05	16.18±0.13	16.49±0.71
	Pruned	23.73±0.40	20.11±0.05	16.71±0.04	15.68±0.04	14.32±0.00
	Pruned/ Wax	20.76±1.27	19.85±0.93	18.17±0.86	17.72±0.09	17.54±0.01
Kirimumpale	Control	20.30±1.09	16.03±1.26	14.45±0.40	13.60±0.40	13.24±0.04
	Pruned	21.55±0.46	18.29±1.48	15.77±0.08	14.39±0.31	11.29±0.24
	Pruned/ Wax	21.48±2.52	17.44±1.80	16.66±0.74	16.97±0.59	15.96±0.24
Bukalasa	Control	23.81±1.48	15.02±0.00	12.15±0.06	13.24±0.04	11.06±1.15
	Pruned	24.84±0.11	18.02±0.00	13.72±0.06	13.67±0.27	10.41±1.09
	Pruned/ Wax	21.49±0.06	16.41±0.00	13.43±0.05	13.39±0.06	12.87±0.01

Note: Starch yield 7, 14, 21, 28 denote starch yield content at 7,14,21 & 28 days storage.

Decrease in starch yield over time of storage can be attributed to respiration of the root (Zidenga, et al., 2012). The rate of decrease in starch yield in this study however was lower than that found by Sanchez et al. (2013) who stated that starch yield decreases by 1% per day when cassava roots were stored under ambient humidity. This is because cassava roots have a lower respiration rate when held under high humidity compared to low humidity storage conditions (Marriot,et al., 1979) found in the tropics like Uganda.

3.1.4. Variation in reducing sugar content

There were significant differences (P>0.05) in reducing sugar contents of different varieties before storage (day 0), indicating that the amount of sugars in cassava is variety specific (Table 3). The reducing sugar contents of both waxed and non-waxed roots increased with storage time. Indeed for both the pruned and the control samples, rapid increases in sugar contents were observed over the storage days but no significant differences (P>0.05) were observed for specific storage day. However, the increases observed in pruned-and-waxed sample were lower than in the pruned roots and was significantly different (P>0.05) from the control samples (Table 3). In most of the varieties, reducing sugars increased significantly (P>0.05) during storage. Such results indicate progression in the physiological changes occurring as the starch is remobilized in the root. The remobilization coupled to no utilization of sugars in such a system leads to

accumulation of a number of non-structural carbohydrates that on analysis constitute the reducing sugars.

Table 3: Variation in mean reducing sugar content on dry matter basis of waxed and non-waxed cassava root samples over a 28-days storage period.

Variety	Treatment	Day 0	Day 7	Day 14	Day 21	Day 28
Nyaraboke	Control	1.79±0.13	6.34±0.76	9.29±0.97	15.66±0.15	18.62±0.31
	Pruned	1.84±0.16	7.13±1.04	10.17±1.73	11.82±0.10	12.09±0.21
	Pruned/ Wax	1.34±0.21	6.37±1.08	10.22±0.17	10.76±0.09	11.76±0.22
TME 14	Control	2.46±0.04	9.54±0.93	14.25±2.34	20.49±0.18	23.96±0.63
	Pruned	2.17±0.06	13.75±0.74	15.46±1.74	19.45±0.45	22.95±0.43
	Pruned/ Wax	2.34±0.21	10.93±2.16	12.24±1.18	13.15±0.04	14.64±0.33
NASE 14	Control	2.13±0.07	7.20±0.29	9.72±0.59	8.43±0.03	10.03±0.18
	Pruned	2.18±0.05	7.96±0.38	10.63±0.74	11.88±0.02	13.04±0.24
	Pruned/ Wax	2.06±0.15	7.26±0.21	9.61±1.00	10.57±0.06	9.02±0.16
Kirimumpale	Control	1.53±0.21	3.62±0.03	5.49±0.41	7.92±0.09	9.42±0.16
	Pruned	1.75±0.11	4.99±0.47	7.21±0.72	8.92±0.05	10.47±0.20
	Pruned/ Wax	1.34±0.50	3.46±0.93	4.78±1.67	5.64±0.06	5.28±1.52
Bukalasa	Control	1.46±0.33	7.71±1.56	12.53±0.32	16.52±0.06	19.86±0.37
	Pruned	1.92±0.27	7.66±0.37	12.47±2.47	13.61±0.21	15.71±0.31
	Pruned/ Wax	1.22±0.04	7.26±0.93	10.89±0.83	11.99±0.07	12.97±0.94

Note: the reducing sugar contents in this case refer to available sugar as released after hydrolysis of starch rather than glucose.

Note: Sugar 7, 14, 21, 28 denote reducing sugar content at 7,14,21,& 28 days storage.

3.1.5. Effect of waxing on cyanogenic potential in cassava roots

Waxing was carried out on known "sweet varieties" and hence of lower cyanogenic potential (CNP). Table 4 shows that the CNP of untreated (control) and treated samples (pruned, and pruned-and-waxed) before storage (Day 0) were lower than the recommended safe levels by FAO of 50 ppm. Significant differences (P>0.05) were observed among the different varieties with the elite clones maintaining higher CNPs. These values reduced with storage time in the pruned and the control samples by more than 90% by day 28 of storage. Apart from Nyaraboke, there were increases in CNP in the waxed samples of all the other varieties up till 14 days of storage. After day seven, reductions in the cyanogenic potential was recorded from an average 80ppm for all varieties and all treatments to an average of 4.4ppm by day 28 in the non-waxed roots. This was a significant reduction compared to losses in the waxed roots which ranged from an average 127.14ppm at day 7 to an average 28.73ppm at day 28. The reductions imply that waxing does increase CNP of cassava although the CNP reduces to safe levels after 21 days.

3.1.6. Changes in starch content

Starch content ranged from 73-84% and varied across the different varieties. Lower starch contents were observed for Nyaraboke (73.14%) while higher starch contents were observed for TME14 (84.4%). During storage, the starch content reduced with time dropping by between 10-40% depending on the variety and the treatment method (Table 5). Reduction in starch content in the pruning samples was comparable to the control samples after 14 days of storage. However, no specific reductions were observed for the pruned-and-waxed samples with starch content increasing with time instead.

Table 4: Variation in cyanogenic potentials (CNP; ppm) of waxed and non-waxed cassava root samples during storage

Variety	Treatment	Cyanide 1	Cyanide 7	Cyanide 14	Cyanide 21	Cyanide 28
Nyaraboke	Control	36.50±5.24	33.56±0.13	23.10±1.09	17.12±2.40	4.08±2.63
	Pruned	39.09±3.18	32.92±0.06	26.29±2.23	15.85±2.15	5.40±0.62
	Pruned/ Wax	36.58±3.24	37.27±2.18	33.39±0.57	16.41±2.50	7.32±1.28
TME 14	Control	32.63±1.44	84.58±0.93	30.84±5.17	15.36±0.54	8.56±7.45
	Pruned	36.65±1.42	48.81±0.23	33.89±1.32	17.65±0.04	6.72±1.07
	Pruned/ Wax	33.37±1.77	153.77±0.38	76.60±2.91	16.01±1.39	12.11±4.33
NASE 14	Control	30.09±13.36	64.80±1.90	55.20±1.46	19.08±0.81	11.30±3.37
	Pruned	35.53±3.27	46.18±1.29	33.29±0.43	16.72±1.26	8.01±0.91
	Pruned/ Wax	31.25±6.51	76.07±3.49	67.68±2.54	35.70±12.66	21.36±4.42
Kirimumpale	Control	44.89±8.53	91.50±1.66	15.71±7.37	20.52±3.29	7.32±5.81
	Pruned	46.07±5.9	76.47±0.18	19.54±0.12	21.61±2.78	8.52±3.74
	Pruned/ Wax	46.09±3.45	122.62±1.69	82.81±2.35	22.14±0.10	11.25±2.79
Bukalasa	Control	28.76±1.30	53.65±1.27	44.27±5.09	14.23±0.86	7.03±2.35
	Pruned	31.68±4.16	68.60±1.65	31.73±0.79	15.67±1.75	8.11±4.64
	Pruned/ Wax	30.08±4.70	114.66±2.37	63.88±3.21	14.47±2.57	9.19±1.28

Note: CNP at 7,14,21& 28 days after waxing.

Table 5: Changes in starch content across treatments and for different cassava varieties

Variety	Treatment	Starch content day 0	Starch content day 7	Starch content day 14	Starch content day 21	Starch content day 28
Nyaraboke	Control	73.65±0.57	70.55±0.29	70.27±0.57	69.00±0.21	66.16±0.57
	Pruned	73.14±1.06	71.19±0.11	70.18±0.24	69.03±0.13	66.11±0.33
	Pruned/ Wax	74.21±0.26	72.68±0.40	73.77±0.17	75.09±0.28	78.90±0.03
TME 14	Control	82.81±0.38	79.31±0.06	74.04±1.99	68.91±0.11	66.56±1.29
	Pruned	83.85±0.25	79.31±0.11	72.2±0.62	68.01±0.16	67.31±1.93
	Pruned/ Wax	84.40±0.24	82.51±0.19	83.18±1.44	82.91±1.37	82.36±0.52
NASE 14	Control	77.62±0.39	75.62±0.57	71.23±0.31	68.58±0.62	65.69±1.13
	Pruned	78.14±0.31	74.46±0.33	70.18±0.24	68.67±0.61	65.88±1.43
	Pruned/ Wax	78.48±0.34	79.19±1.51	75.32±0.11	78.18±1.70	81.28±0.58
Kirimumpale	Control	79.28±0.09	77.88±0.45	72.99±0.42	71.45±0.28	67.52±1.24
	Pruned	80.81±0.76	77.94±0.41	74.42±0.79	70.72±0.72	66.12±0.49
	Pruned/ Wax	80.84±0.11	80.92±1.21	82.23±0.76	82.13±0.96	81.75±0.17
Bukalasa	Control	80.49±0.36	78.04±0.25	74.97±0.97	71.89±0.31	66.26±0.39
	Pruned	81.05±0.16	79.19±0.49	75.33±1.33	72.02±0.21	67.86±0.11
	Pruned/ Wax	79.68±0.55	80.03±0.23	82.26±0.07	83.31±1.35	82.80±3.62

Note: starch content 7, 14, 21, 28 denote starch content at 7,14,21& 28 days after waxing.

3.1.7. Changes in amylose content

The amylose contents of samples ranged from 14% to 16% and were not significantly different (P>0.05) among test varieties (Table 6). There were significant differences (P>0.05) in amylose content for the different treatments at day 14 and 21. The differences reflect the losses in starch content earlier observed which was related to hydrolytic reduction and production of non-structural carbohydrates. However, amylose was not a significant indicator of the level of deterioration since it is a function of available starch rather than total available carbohydrate.

Table 6: Variations in amylose content across treatments and varieties

Variety	Treatment	Day 1	Day 7	Day 14	Day 21	Day 28
Nyaraboke	Control	15.90±0.06	16.70±0.17	15.12±0.01	13.94±0.11	14.24±0.12
	Pruned	15.98±0.00	16.62±0.24	15.25±0.13	14.53±0.19	14.56±0.07
	Pruned/ Wax	15.27±0.08	16.56±0.03	15.86±0.18	15.03±0.27	16.10±0.03
TME 14	Control	15.61±0.05	16.37±0.15	15.26±0.05	14.63±0.36	14.77±0.16
	Pruned	15.71±0.05	16.40±0.03	15.13±0.17	14.37±0.08	14.49±0.52
	Pruned/ Wax	15.39±0.03	16.12±0.08	15.88±0.16	15.80±0.03	15.67±0.13
NASE 14	Control	15.87±0.16	15.96±0.04	15.20±0.13	14.07±1.30	14.22±0.01
	Pruned	15.79±0.07	15.74±0.17	15.18±0.13	15.09±0.11	13.95±0.11
	Pruned/ Wax	15.46±0.16	15.93±0.09	16.28±0.22	16.80±0.08	16.47±0.05
Kirimumpale	Control	14.88±0.06	15.40±0.47	14.60±0.11	14.61±0.38	13.87±0.01
	Pruned	14.91±0.11	15.18±0.02	14.32±0.25	14.93±0.08	13.69±0.13
	Pruned/ Wax	14.65±0.06	15.36±0.08	15.89±0.07	15.57±0.11	15.63±0.51
Bukalasa	Control	15.53±0.13	16.59±0.18	15.11±0.14	14.06±0.42	14.23±0.15
	Pruned	15.55±0.24	16.53±0.06	15.11±0.06	13.82±0.09	13.78±0.16
	Pruned/ Wax	15.59±0.11	16.92±0.04	15.81±0.04	16.26±0.40	15.49±0.05

Note: Starch content 7, 14, 21, 28 denote starch content at 7,14,21& 28 days after waxing.

3.1.8. Protein content

Changes in protein content are presented in Table 7. Significant differences (P>0.05) were observed for protein contents at day zero or among the different cassava varieties. This is an indication that different cassava varieties accumulate different levels of protein. These differences were observed across the storage time although there were no significant differences due to treatment effects. Particularly, the protein contents reduced from an average 0.75% at day zero to an average 0.54% by day 28 of storage. These losses were higher in the control and the pruned samples and this can be attributed to degenerative hydrolysis of the components of the root. ON the other hand, waxing does not significantly affect protein content and hence it is appropriate for maintaining the nutritional quality of the roots.

Table 7: Variation in protein contents of cassava varieties across treatments

Variety	Treatment	Day 1	Day 7	Day 14	Day 21	Day 28
Nyaraboke	Control	0.716±0.09	0.792±0.01	0.717±0.01	0.667±0.05	0.563±0.01
	Pruned	0.774±0.02	0.776±0.01	0.759±0.01	0.658±0.05	0.570±0.01
	Pruned/ Wax	0.832±0.02	0.856±0.01	0.828±0.01	0.835±0.06	0.811±0.01
TME 14	Control	0.914±0.00	0.846±00	0.848±0.01	0.841±0.06	0.755±0.01
	Pruned	0.932±0.00	0.855±0.01	0.819±0.01	0.821±0.06	0.745±0.01
	Pruned/ Wax	0.906±0.02	0.976±0.00	0.956±0.00	0.953±0.00	0.951±0.01
NASE 14	Control	0.935±0.00	0.891±0.00	0.871±0.01	0.902±0.06	0.854±0.02
	Pruned	0.922±0.05	0.881±0.02	0.873±0.01	0.892±0.04	0.866±0.02
	Pruned/ Wax	0.927±0.05	0.973±0.00	0.957±0.01	0.952±0.00	1.009±0.02
Kirimumpale	Control	0.674±0.00	0.641±0.02	0.556±0.00	0.596±0.05	0.553±0.01
	Pruned	0.667±0.00	0.649±0.01	0.557±0.00	0.607±0.05	0.552±0.01
	Pruned/ Wax	0.656±0.00	0.670±00	0.611±0.00	0.623±0.05	0.645±0.02
Bukalasa	Control	0.615±0.01	0.437±0.00	0.465±0.00	0.480±0.03	0.459±0.01
	Pruned	0.629±0.01	0.541±0.00	0.449±0.01	0.515±0.04	0.450±0.01
	Pruned/ Wax	0.611±0.01	0.565±0.01	0.576±0.00	0.624±0.04	0.574±0.00

Note: Protein 7, 14, 21, 28 denote protein content at 7,14,21 & 28 days after waxing.

From the observations presented in previous sections, it is possible to conclude that pruning improves the shelf life of cassava by an average 7-14 days after harvest. Thus it is only applicable for short term storage and marketing. On the other hand, waxing can extend shelf life for at least 28 days. Its potential for use in the fresh cassava export market is huge. It is therefore recommended for long term storage that may involve transportation of roots over long distances and for extended marketing period.

3.2. Efficacy of high relative humidity treatments

3.2.1. Effect of pruning combined with high relative humidity storage on PPD

There was variation in mean PPD of roots with variety and storage time (Table 8). As earlier observed with the waxing treatment, high relative humidity storage (RH), reduced PPD by 30-40% depending on the variety. Such reductions are plausible if the storage technique is used for specific varieties that respond to this method.

Table 9 shows that the dry matter content of cassava roots did not change with storage time under high relative humidity conditions (inside the polyethylene bags) over the storage period. This can be attributed to the control of moisture losses from the storage chamber. Therefore the maintenance of dry matter in this shelf life improving method is important attribute for fresh cassava marketing. According to Van Oirschot et al. (2000) pruning of cassava plants does not affect the dry matter content of cassava roots.

Table 8: PPD (%) of fresh cassava roots pruned seven days prior to harvest and stored under high relative humidity

Variety	Storage time (Days)				
	0	7	14	21	28
Bufumbo	0	1.49±0.21	21.86±3.09	21.40±3.03	49.50±7.00
Hoima	0	5.00±0.71	4.00±0.57	5.00±0.71	7.00±0.99
Kigita	0	1.42±0.20	18.60±2.63	31.40±4.44	51.80±7.33
Kirimumpale	0	12.50±1.77	38.30±5.42	51.00±7.21	69.00±9.76
NASE 14	0	1.00±0.14	5.20±0.74	12.80±1.81	30.00±4.24
Njule	0	7.64 ±0.08	7.80±1.10	10.00±1.41	35.00±4.95
Nyaraboke	0	3.00±0.42	10.00±1.41	30.00±4.24	30.90±4.37
TME 14	0	1.00±0.14	1.80±0.25	5.20±0.74	6.00±0.85
Mean		4.13	13.4	20.8	34.9

Table 9: Dry matter content of cassava roots pruned seven days prior to harvest and stored under high relative humidity conditions

	% dry matter content with time (days)				
Variety	0	7	14	21	28
Bufumbo	34.75 1.66	32.64 ± 2.77	33.09 ± 2.32	33.61 ± 2.70	32.33 ± 1.75
Hoima	32.87 ± 0.47	34.42 ± 1.15	31.41± 2.05	32.61 ± 1.12	32.61 ± 0.54
Kigita	30.38 ± 2.53	35.91 ± 1.96	32.85 ± 1.60	35.31 ± 2.43	34.12± 2.17
Kirimumpale	30.24 ± 2.33	35.93 ± 1.34	33.94 ± 3.15	31.49 ± 2.13	30.16 ± .44
NASE 14	32.66 ± 1.24	30.03 ± 4.02	32.01 ± 0.74	31.76 ± 2.88	30.71 ± 3.03
Njule	33.56 ± 2.60	32.71 ± 2.68	34.08 ± 3.47	32.96 ± 3.51	34.72 ± 2.89
Nyaraboke	33.85 ± 0.41	30.74 ± 1.90	30.45 ± 1.02	30.71 ± 1.55	30.72 ± 1.81
TME 14	34.06 ± 0.11	35.50 ± 0.24	35.58 ± 0.83	35.16 ± 0.10	35.50 ± 0.35
Mean	32.8	33.5	32.9	32.9	32.6

The results for starch content are presented in Table 10. Significant differences ($p<0.05$) were observed among the test varieties and the starch content ranged from 71 to 86%. Elite varieties had higher starch contents compared to local varieties. No significant differences were observed for starch content across the storage time and among different varieties over the storage time. The starch content observed in this study was within the range recorded by Nuwamanya et al. (2009) which varied from 50 to 90%. Starch digestibility is a major focus for improvement of cassava because it ensures maximum output of total solid utilizable from the solid matter. The inferences above show that potential digestibility of the cassava starch remains unchanged in pruned, unpruned cassava and roots stored under high RH which highlights that RH treated roots retain their potential digestibility.

Table 10: Percentage of starch content of crude starch obtained from fresh cassava roots pruned seven days before harvest and subsequently stored under high relative humidity conditions

Variety	Storage time (Days)				
	0	7	14	21	28
Bufumbo	80.37±3.53	82.88±2.82	80.88± 1.40	81.38± 3.53	83.37±2.11
Hoima	81.87±2.82	82.88±7.06	84.37±0.71	84.87± 2.82	84.37±2.12
Kigita	70.99±1.55	70.94±1.34	69.39±0.71	71.39± 2.12	71.89±0.00
Kirimumpale	82.88±1.41	83.37±2.12	83.87± 1.41	85.87±0.00	83.38± 2.11
NASE 14	78.87±4.24	80.38±7.78	75.39±4.94	79.38±2.12	80.87±1.41
Njule	86.37±0.71	86.37± 7.78	83.38±4.94	82.38± 2.12	82.38±1.42
Nyaraboke	74.39±0.70	72.39±4.94	73.89±1.41	74.89±4.24	74.88±0.00
TME 14	86.37± 0.71	84.88±4.25	85.88± 4.25	85.87±1.41	84.87± 2.82
Mean	80.3	80.5	76.6	80.8	80.8

3.2.2. Amylose content

The amylose content of fresh cassava roots did not vary significantly among the cultivars ($p>0.05$). Kirimumpale had amylose content of 14.6% while NASE14 had 16.9% on the upper side of the values. Kigita, Nyaraboke, NASE-14, Hoima and Njule had amylose contents of 14.8, 15.33, 15.8, 15.5 and 15.85%, respectively. Storage of cassava roots under high RH did not reveal statistical differences in amylose content (Figure 4).

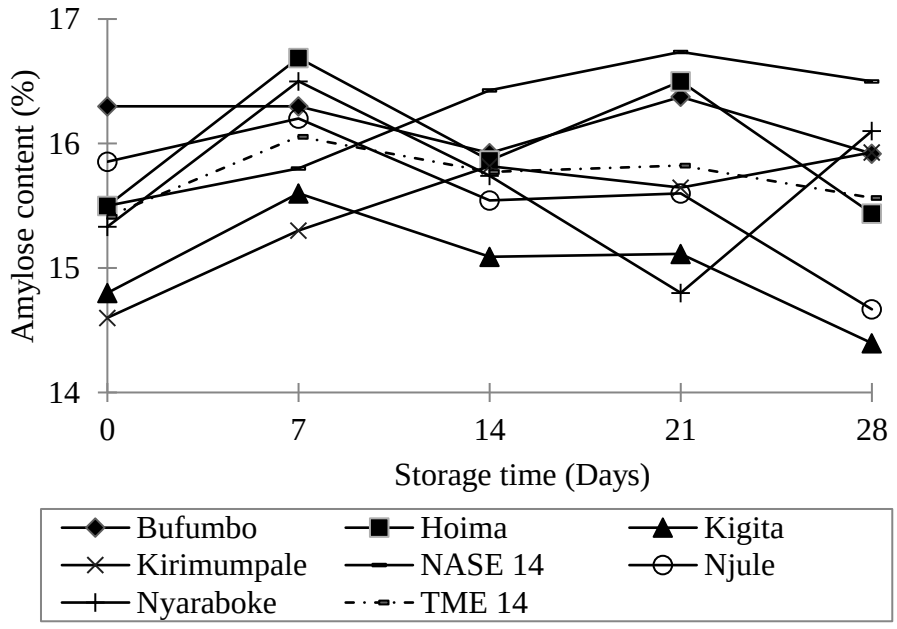


Fig. 4: Amylose content of cassava roots pruned seven days prior to harvest and subsequently stored under high relative humidity

The amylose content (14.6-16.9%) of the cassava cultivars were within the range found by Nuwamanya et al. (2009). Van Oirschot et al. (2000) also found that pre-harvest pruning does not affect the content of amylose in cassava starch.

Most of starch functionalities and physical properties of starch such as gelatinization temperature and time are dependent on the amylose content (Charles et al., 2005). All the cassava cultivars used in this study contained amylose but Getzin & Fellman (2012) utilized a cassava cultivar (AM206-5) characterized by amylose-free starch. Amylose-free "waxy" starch is more susceptible to gelatinization and glucoamylase digestion and has great advantages when used in food industry (Howeler et al., 2013).

3.2.3. Content of reducing sugars in cassava flour

Reducing sugar content of flour made from freshly harvested cassava obtained from pruned cassava plants ranged from 7.49 in Hoima to 13.14% in TME14. Unpruned cassava plants yielded roots with reducing sugar content varying between 7.28% in Hoima to 12.78% in TME14. Pruning did not have a significant effect ($p>0.05$) on the reducing sugar content of the cassava roots. However, all cassava roots showed an increase in reducing sugar content over storage time regardless of treatment. After 28 days under RH storage, the reducing sugar content in cassava ranged from 13.82% to 29.61% for NASE14 and TME14 cultivars, respectively. There was an average increase in reducing sugar content of cassava roots under high RH storage of 0.34% per day. Increase in reducing sugar content of cassava over time is attributed to breakdown of polysaccharides like starch into glucose during respiration (Zidenga, et al., 2012). Increase in reducing sugars in cassava gives a desired organoleptic quality in terms of sweetness (Nuwamanya et al., 2009).

Table 11: Reducing sugar content of cassava roots for selected cultivars pruned seven days prior to harvest and stored under high relative humidity

Variety	% reducing sugar with storage time (days)				
	0	7	14	21	28
Pruned					
Bufumbo	7.63±0.08	9.45 ±0.1	11.85±0.13	14.15±0.1	17.84±0.19
Hoima	7.49 ±0.08	9.44 ±0.1	11.89±0.13	13.91±0.15	17.94±0.19
Kigita	10.77±0.12	11.84±0.13	13.75 ±0.15	14.70±0.16	16.40±0.18
Kirimumpale	7.90±0.08	9.54±0.1	11.70±0.13	14.15±0.15	17.80±0.19
NASE 14	8.18 ±0.09	11.62 ±0.12	15.31±0.16	11.61±0.12	13.82±0.15
Njule	7.64 ±0.08	9.53 ±0.1	11.92±0.13	14.22±0.15	17.97±0.19
Nyaraboke	10.43±0.11	11.74 ±0.13	13.52±0.14	13.91±0.15	16.69±0.18
TME 14	13.14±0.14	17.09 ±0.18	21.76±0.23	25.74±0.28	29.61±0.32
Mean	9.1	11.28	13.96	15.3	18.5

3.2.4. Protein content

Protein content ranged between 0.52% in Kigita and 0.96% in NASE14 for cassava roots from pruned cassava plants. Fresh roots obtained from unpruned cassava had a protein content ranging from 0.53 to 0.95% (Figure 5). There was no significant differences in the protein content of pruned and unpruned cassava roots ($p>0.05$). The protein content in the high RH treated roots (0.52-0.96%) did not change significantly throughout the 28 days of storage ($p>0.05$). It was observed that improved cassava varieties had higher protein content (0.93% for TME14 and 0.96% for NASE14) than the local cultivars (0.52% in Kigita to 0.82% in Nyaraboke) ($p<0.05$).

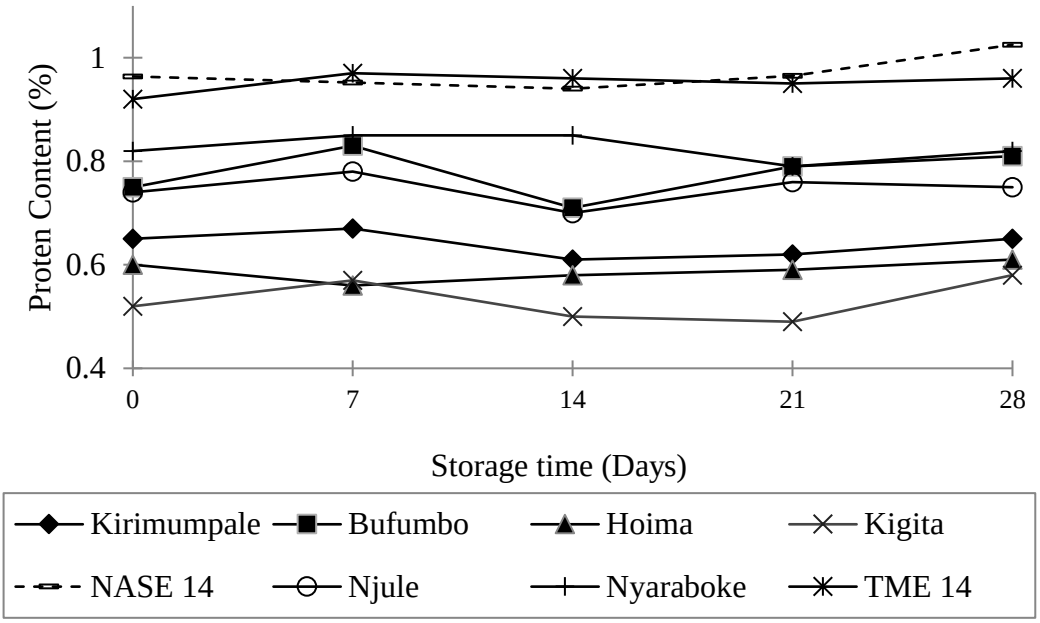


Fig. 5: Protein content of cassava roots pruned seven days prior to harvest and stored under high relative humidity

Cassava cultivars in this study had protein content lower than that documented by USDA (2014) where the protein content ranged between 1 and 2%. This can be attributed to the fact that variation in nutritional composition occurs among different cultivars, locations and environmental conditions (Burns et al., 2012). Inferences by Van Oirschot (2000) also showed that protein content is not affected by pruning or prolonged storage at ambient temperature and humidity.

3.2.5. Total cyanogenic potential

There were significant differences ($p<0.05$) in cyanogenic potential among the eight cultivars examined. Cyanogen levels in fresh cassava roots from pruned cassava plants varied between 27.8 and 53.2ppm (Figure 6). Roots obtained from pruned cassava plants of NASE14, TME14, Nyaraboke, Kirimumpale, Kigita and Bufumbo cultivars had cyanide contents of 31.12, 32.16, 36.79, 44.86, 47.89 and 50.41 ppm, respectively. Njule had 53.2 ppm before storage while Hoima had 28.42 ppm. Pruning alone did not have a significant effect ($p>0.05$) on cyanogen content of cassava roots. Pruning followed by high RH storage also did not have a significant effect on the cyanogenic content of cassava ($p>0.05$). However, overall decrease in level of total cyanogens was observed with time among all the cultivars of pruned and unpruned cassava stored at ambient humidity as well as pruned, high RH stored cassava after seven days.

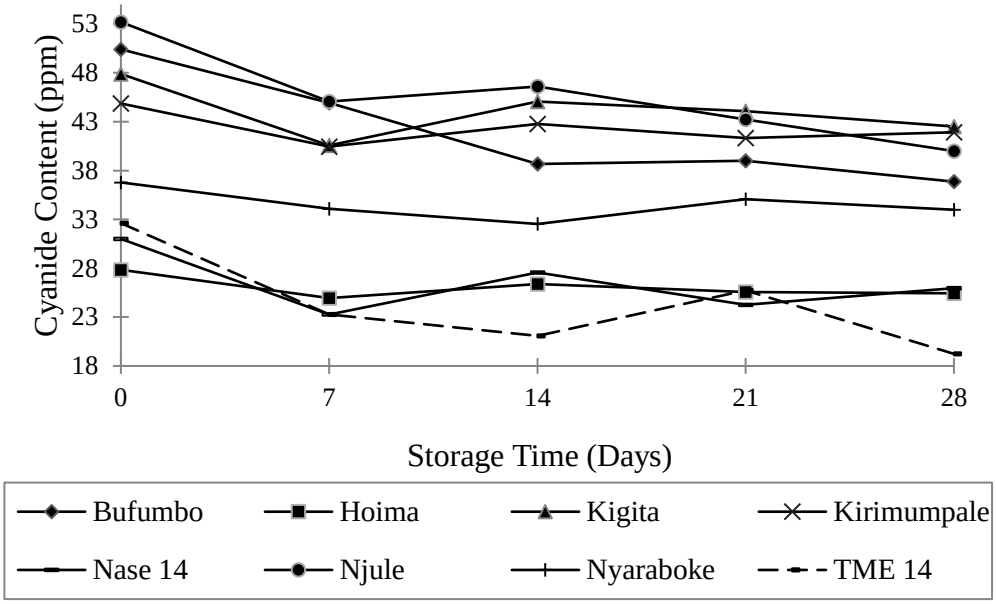


Fig. 6: Total cyanogen content of cassava roots pruned seven days prior to harvest and then stored under high relative humidity

All the cultivars in the study are characterized as low cyanide/sweet cassava according to Cereda & Mattos (1996) who reported that low cyanide cassava has a cyanide level below 50 ppm. Njule exceeded the aforementioned level by 2.3 ppm and this slight variation, according to Burns et al. (2012), could be attributed to variations in location and environmental conditions.

Overall decrease in cyanide levels in cassava seven days after harvest could be attributed to volatility of free cyanide and prolonged interaction between the enzyme linamarase and the cyanogenic glucoside in the cassava root (Padmaja, 1995). The level of cyanide however remained constant after seven days. Further reduction in levels of cyanide could only occur by crushing or pounding the plant material to increase enzyme-substrate interraction (Montagnac, 2009). The cultivars in this study are categorised as sweet cassava and consumption of these varieties, therefore, does not pose a risk of cynide toxicity (Creda & Mattos, 1996).

3.3 Sensory acceptability of pruned, pruned+high relative humidity, and pruned+waxing cassava roots

The overall sensory acceptability of steamed cassava freshly obtained from pruned cassava plants at 0 days ranged from 8 (like very much) for Hoima, Bufumbo and Nyaraboke to 6 (like slightly) for Kigita, Njule, TME14 while NASE14 scored 7 (like moderately). For Hoima, Bufumbo and Nyaraboke, all the sensory attributes of taste, appearance, aroma, texture and mouthfeel were highly rated at 8 (like very much). Njule, TME 14 and NASE 14 were highly rated for taste, appearance and mouth feel (averaged at 8) but were rated lower for aroma (5: Neither like nor dislike). Kigita was scored high for taste (7 like) but with low rating for texture (4: dislike slightly). Kigita was found to be very soft, which was not appealing to most of the panelists. There was no significant difference ($p>0.05$) between the overall sensory acceptability of steamed roots obtained from pruned and unpruned cassava plants. At seven days of storage under ambient humidity, overall acceptability decreased for pruned and unpruned cassava roots respectively. The overall sensory acceptability of high RH treated roots, on the other hand increased at 7 days and 14 days.

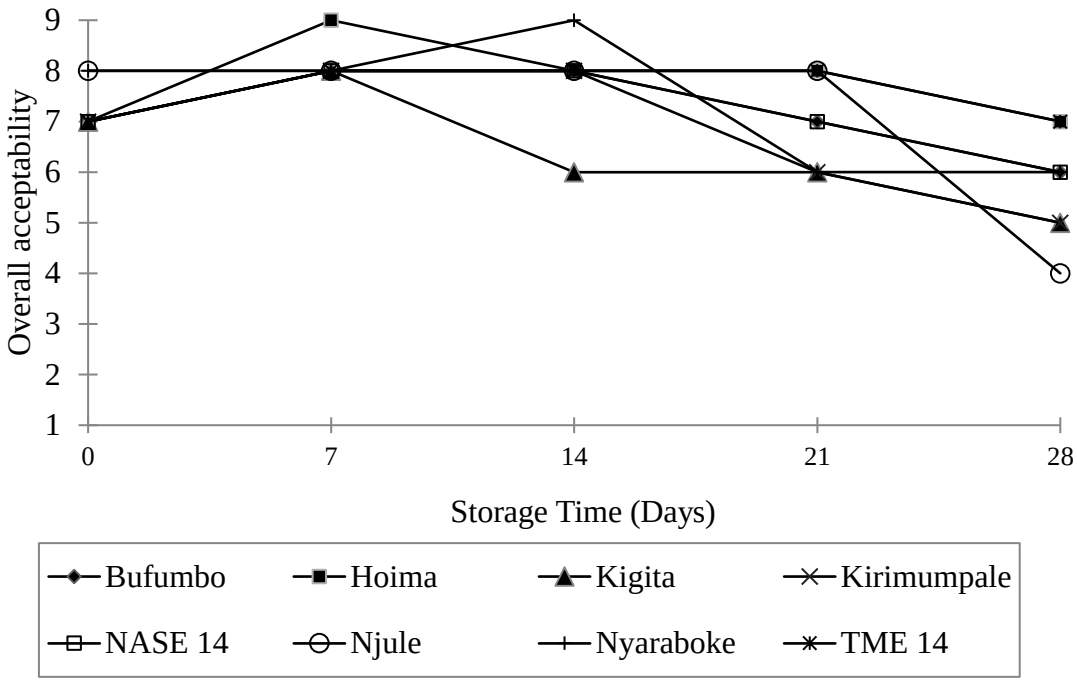


Fig. 7: Overall sensory acceptability of cassava roots pruned seven days prior to harvest and kept at high relative humidity

Figure 8 shows that the sensory acceptability of cassava roots decreased with storage days. After seven days, the average scores of pruned and unpruned roots were 5 (neither like nor dislike) and 3 (dislike moderately), respectively. This shows that cassava roots are rendered unpalatable shortly after harvest (Ofor, 2011). The least favorite cultivar for freshly harvested cassava (Kigita: 6) was due to its low score for texture (4) (hence its name that means *ghee* in the local Western Uganda dialect). This is an indicator that very soft cassava is not liked by most consumers. Increase in overall acceptability of high RH treated cassava roots is linked to the increase in content of reducing sugars in the root, which, according to Nuwamanya (2009) is desired by consumers. Reducing sugars are a by-product of respiration of the root so they increase in the roots during storage. The decrease in overall sensory acceptability at 28 days was due to a low average score for the flavor (5) and taste (4) of cassava. The stored samples were also too sweet for the panelists' liking. However, nearly all the varieties were rated above 6.5 average for overall acceptability at day 7 and 14 (Figure 8)

For waxing the three varieties tested included NAROCas1, Nyaraboke and NASE14. Waxing did not negatively affect the acceptability of roots. Waxed roots remained acceptable and did not differ from freshly harvested roots up to 14 days of storage (Figure 9). Thus waxing can easily be adopted for marketing of cassava roots with extended shelf life.

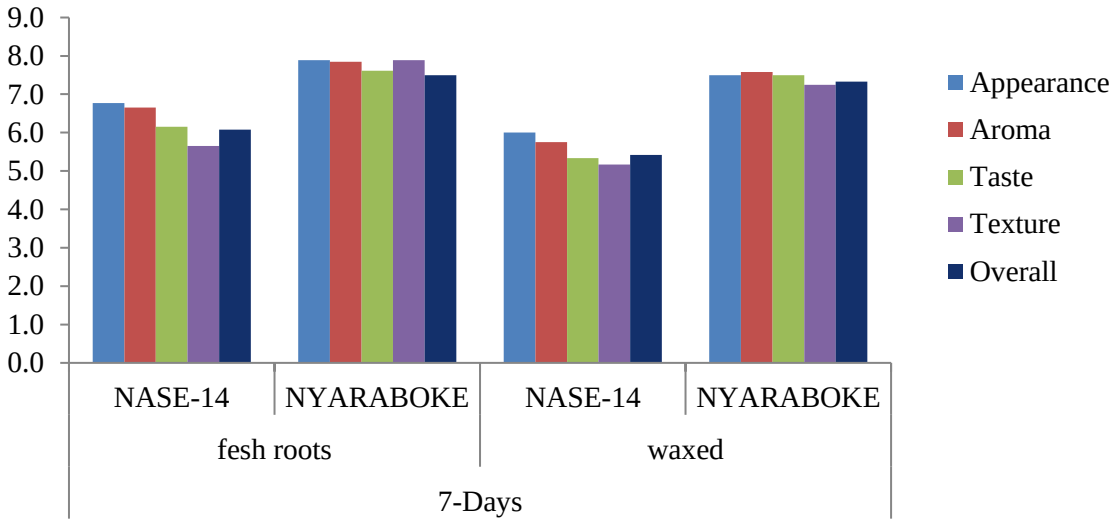


Fig. 8: Variation in acceptability of the roots at 7 days

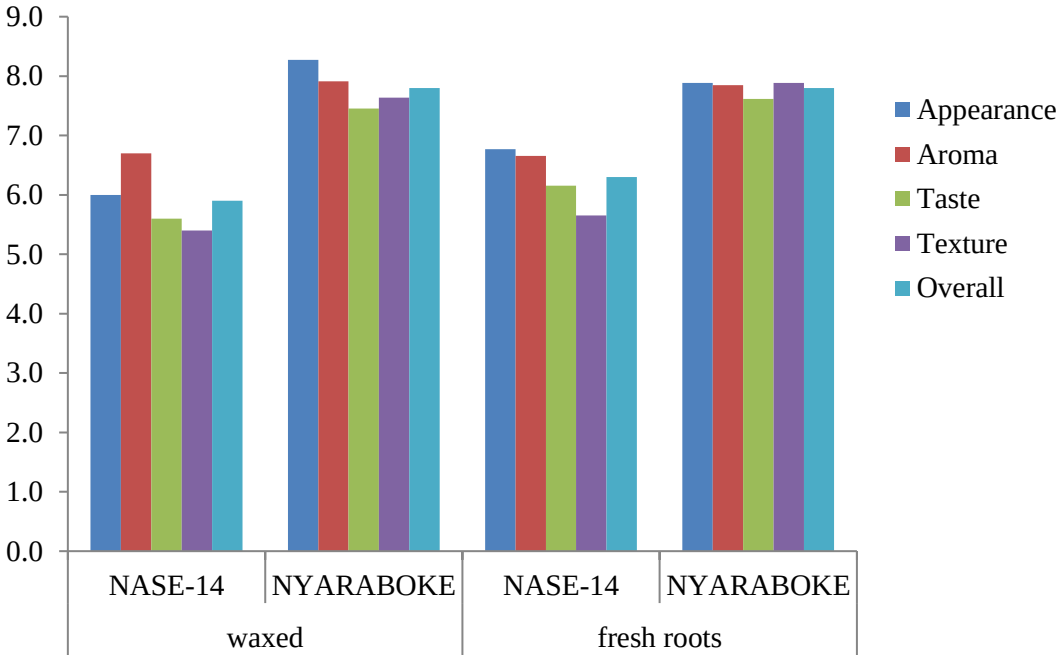


Fig. 9: Variation in acceptability of waxed roots at 14 days compared to fresh roots

4. CONCLUSIONS AND RECOMMENDATIONS

Pruning alone can be used to extend shelf life of cassava roots to four to seven days. However, pruning followed by high RH storage could be used to extend the shelf life of fresh cassava roots to 28 days with % PPD less than 51 among all the cultivars. The technology shows promise for commercial exploitation in eastern and southern Africa where consumption of fresh cassava is widespread. Pruning seven days prior to root harvest and storage at high RH does not significantly affect the starch yield, dry matter, starch digestibility, amylose, protein and cyanide content of the cassava roots implying the root quality characteristics are not compromised by the treatments examined in the study.

Similarly, pruning of cassava seven days prior to harvest did not affect the sensory characteristics of fresh cassava roots. In fact, storage of pruned cassava under high RH conditions increases the time over which cassava remains organoleptically acceptable to consumers (up to 21 days) but not up to 28 days of storage due to excessive sweetness and lack of aroma. These results highlight the prospects of employing pruning followed by high RH storage for maintaining the quality attributes of fresh cassava roots in a commercial setting.

Further studies are required to understand the interaction of high RH storage and pruning on enzymatic function of cassava root. Effectiveness of other methods of storage under high RH such as storage in moist wood dust, soaking in water and burying in the soil can be further studied and compared with storage in plastic bags.

Waxing similarly resulted in longer shelf life of cassava across in all the tested varieties. It can thus be a viable PPD management option for end-users such as supermarkets and other up-end markets of fresh cassava. Although the technology requires some investments in terms of facilities for waxing and other tools, the cost can be recouped quickly through the longer shelf stability of roots on the market that will reduce economic losses from PPD. PPD in unpreserved roots triggers postharvest qualitative deterioration which at times results in complete loss of the roots. Thus the benefits of better cassava marketability will outweigh the costs associated with use of the technology.

Relative humidity on the other hand is cheap and could be recommended for use by traders who often have small or no investment capital. Indeed it can be used concurrently with waxing in a business pack house as designed during this study. But its benefits may be tapped by retailers in road side markers which can easily store roots in polyethylene bags as they wait to sell the roots.

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