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Article

Enhancing the shelf-life of fresh cassava roots: a field evaluation of simple storage bags

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Abstract: Postharvest physiological deterioration (PPD) of fresh cassava roots limits its shelf-life to about 48 hours. There is a demand for simple, cheap, and logistically feasible solutions for extending the shelf life of fresh cassava roots at industrial processes. In this study, three different type of bag materials were tested (woven polypropylene, tarpaulin, and jute as a potential storage solution for cassava roots with different levels of mechanical damages. Microclimate (temperature, humidity, CO2) was monitored to understand the storage conditions up to 12 days. The results showed that fresh cassava roots could be stored for 8 days, with minimal PPD and starch loss (2.4 %). However, roots with significant mechanical damage (cuts, breakages) had a considerably shorter shelf life in the storage bag, compare to whole roots and roots with retained peduncle (stalk where roots are connected to the main plant). Wetting the roots and type of bag material were not significant factors in determining the shelf life and starch loss. Carbon dioxide concentration in the stores significantly correlated with starch loss in fresh cassava roots and is proposed as a possible method for continuously and remotely monitoring starch loss in large scale commercial operations and reduce postharvest losses.

Keywords: Cassava; storage; PPD; starch; shelf-life; postharvest losses.

1. Introduction

The short shelf-life of cassava (Manihot esculanta C.) roots is primarily attributed to the postharvest physiological deterioration (PPD), which is triggered as a wound response shortly after harvest [1]. PPD reduces the quality and quantity of starch and renders the cassava roots unmarketable and inedible. PPD is a complex process and its exact mechanism is still not fully understood [2], however, it is known that it involves enzymatic stress responses to wound and changes in gene expression. PPD can be accompanied by moisture and starch loss [1]. It results in the formation of blue-black internal root discoloration (vascular streaking) because of the combination of insoluble precipitates formed from scopoletin reacting with hydrogen peroxide. Cassava roots can also suffer from fungal rots. Cassava varieties have been reported to differ in storability [1,2] with respect to PPD.

Various attempts have been made in the past to store fresh cassava in various conditions to control PPD and enhance overall shelf life of fresh cassava roots. Several factors appear to be important for storing roots under ambient tropical conditions such as curing, cassava variety, chemical treatments, the container, or bag that the roots are stored in, damage to the roots (due to harvesting and handling), and whether the roots are repeatedly damaged. Curing of the fresh cassava roots is a critical factor; it is the process of wound healing and has been shown to reduce storage losses of slightly damaged roots [3]. The optimum conditions for curing are a humidity of 80-85 % and temperature of 25 to 35 °C [4]. Previous studies on storage of fresh cassava roots have reported durations of 11 days [4], 11 to 21 days [5], 14 days [1], one month [4] and two months under cooler conditions [4]. However, these experiments were undertaken in laboratory conditions with small quantities and lacked practical applications in a commercial setting where tons of roots arrive every day to the processing plant. The limited research at a larger scale, such as storage of 300 kg roots in Colombia [4] and 500 kg in Tanzania [6] indicates that the roots can store well at larger quantities but there was no replication and hence the information is limited.

Since cassava is a low value crop, the challenge is to find a reliable solution but also at low cost. The hypothesis for this study was that PPD in fresh cassava can be restricted at scale by the application of a low-cost simple bag storage method along with control measures that might include bag design, control of moisture, root damage and variety. To test this, we addressed the following questions for storage at scale:

1. Whether the type of storage bag materials used to store fresh cassava roots would influence storability.
2. Whether wetting the roots is important.
3. What is the minimum level of fresh root damage (including the peduncle) while still offering acceptable fresh root quality after storage.
4. Whether cassava root variety affects PPD (in industry roots are often mixed so sorting would be difficult).
5. What is the impact on starch loss (a critical parameter for commercial scale operation) and if methods to continuously monitor starch loss during storage fresh cassava roots can be suggested.

2. Materials and Methods

The research was undertaken during the main harvest period in Nigeria in 2018 and 2019. All experiments were conducted at the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria in an experimental barn for root and tuber crops and at ambient temperature (23°C to 32°C) and humidity (56% to 100%). Due to the need to harvest, sort, weigh, transport and handle large quantities of fresh cassava roots a stepwise approach to minimize logistical challenges was adopted (Figure 1).

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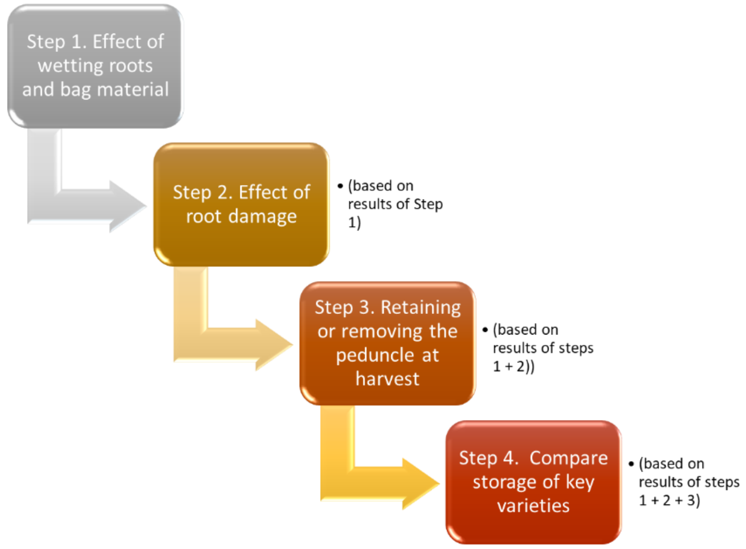


Figure 1. Stepwise progression in experiments to investigate shelf-life at scale.

2.1 Cassava roots

Fresh roots of variety TME 419 were used in the experiments unless stated otherwise. They were manually harvested and sorted. In the field, exposure of the roots to direct sunlight was avoided and roots were transported from the field to the research station within 2-3 hours of harvest. The variety TME 419 was selected to develop the storage method because, it is mostly preferred by farmers and commercial industries in Nigeria. It has high yields, higher starch content and matures early in the growing season [3]. Once the method was developed, two additional varieties were with TME 419 being TMS 0581 and TMS 1632.

2.2 Bag material and effect of wetting

Three types of bag material were compared which were, woven polypropylene (1390 mm long by 789 mm wide by 0.7 mm thick), tarpaulin (1180 mm long by 853 mm wide by 0.6 mm thick) and jute (1083 mm long by 823 mm wide by 2.1 mm thick). These were selected based on previous research (Bancroft and Crentsil, 1995) and availability in Nigeria. Bags were locally purchased. Additionally, fresh roots were either wetted with water (0.7 %) (to provide high humidity) or not wetted. Controls were roots heaped on the ground without using any bag materials. Table 1 illustrates the experimental design for bag material and effect of wetting.

Fresh cassava roots samples were either wetted (dipping in clean water) or not wetted. Roots (50 kg) were placed in three bag types being constructed of either polypropylene, jute and tarpaulin and control roots (wetted and unwetted) were heaped on the floor. All treatments were replicated five times. Roots from each treatment (5 kg) were randomly sampled at 48-hour intervals for weight loss, PPD, fungal rots, and starch content measurements for a duration of up to 12 days.

The carbon dioxide (CO2), temperature (°C) and relative humidity (RH%) levels were measured using a Rotronics CP11 datalogger (Rotronics, UK). They were set to record continuously during the experiments. The dataloggers were fitted inside a ventilated plastic tube (68 mm x 300 mm) which was situated in the centre of each sack or pile of roots.

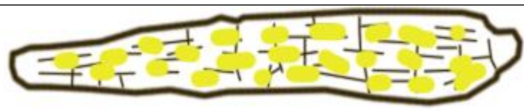
Table 1. Experiment design for bag material and wetting of roots.

Bag type	Wetting (W) Non-Wetting (NW)	Sack material	Replicates	Weight of root for each replicate (kg)
Woven polypropylene (WP)	Wetted	Woven polypropylene	5	50
	Not wetted	Woven polypropylene	5	50
Tarpaulin (T)	Wetted	Tarpaulin	5	50
	Not wetted	Tarpaulin	5	50
Jute (J)	Wetted	Jute	5	50
	Not wetted	Jute	5	50
Control (no bag) (C)	Wetted	No sack	5	50
	Not wetted	No sack	5	50

2.3 Effect of mechanical root damage

Woven polypropylene sacks were filled with 50 kg wetted fresh cassava roots (TME419) with the following treatments being either one break, two breaks, no breaks but slight bruising, no breaks with extensive bruising and roots with no breaks and no bruising. The breaks were obtained by cutting roots with a knife. Cassava roots (5 kg) were sampled at 0, 8 and 12 days. All treatments were replicated five times. Cassava roots (5kg) were sampled at zero, two, four, six and eight days. Table 2 illustrates the categories of mechanical damage categories.

Table 2. Categories of mechanical damage to cassava roots.

Damage class	Definition	Pictorial representation*
One break	One break only and significant proportion of the root remaining	
Two breaks	Two breaks in root but with significant proportion of the root remains	
No breaks	Root is intact and has no visible bruising	
Slight bruising	Surface of root is only slightly bruised and estimated to be 10% or less of the surface area	
Severe bruising	Root is severely bruised and affects most of the visible surface	

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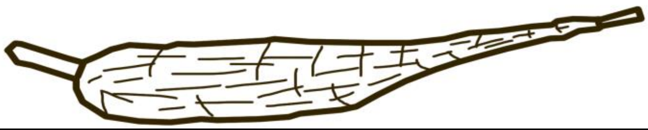
**Where yellow area represents bruising of the surface of the root*

2.4 Harvesting with and without the peduncle

Woven polypropylene sacks were filled with 50 kg wetted fresh cassava roots (TME419) with the following treatments being either roots with the peduncle still attached or root without (Table 3). Control roots were not stored in sacks. All treatments were replicated five times. Cassava roots (5kg) were sampled at zero, two, four, six and eight days.

Table 3. Cassava roots harvested with and without the peduncle.

Damage class	Definition	Pictorial representation
Without peduncle	One break only and significant proportion of the root remaining	
With peduncle	Two breaks in root but with significant proportion of the root remains	

2.5 Varietal comparison

Woven polypropylene sacks were filled with 50 kg wetted fresh cassava roots (TMS 0581, TMS 1632 and TME 419) with the following treatments being either roots with the peduncle still attached or root without peduncle. Control sample cassava roots were not stored in sacks. All treatments were replicated five times. Cassava roots (5 kg) were sampled at zero, two, four, six and eight days.

2.6 Weight loss, PPD and fungal rot measurement

The fresh cassava roots were weighted every 24 hrs. to understand the weight loss during the 12 days storage, for each treatment was measured based on seven transversal slices of 2 cm thickness were cut along the root, starting from the proximal end [7]. A score of 0–1 was assigned to each slice, corresponding to the percentage of the transversal cut surface showing vascular discoloration (0.1 = 10 %, 0.2 = 20 %, etc.). The mean score of PPD for each root was calculated. Fungal rots were defined as the incidence of fungal rotting, roots were visually scored from 0-15, where 0 means no rotting and 5 server rotting.

2.7 Starch content measurement

Starch was measured using the same method as used by the industry in Nigeria being the Reimann Balance (Specific Gravity) Method (1986) (Figure. 2). This is recommended by the International Starch Institute, Science Park, Aarhus, Denmark. The calculated data is in percent, deviates less than 0.05 from values read out of the EU-table enforced by the European Commission covering potatoes with 13% to 23% starch dry matter. A calibrated Kern CH 15K20 weighing balance was used (RS Components, UK).

Figure 2. Reimann Balance (Specific Gravity) Method as constructed at the Federal University of Agriculture, Abeokuta, Nigeria

2.8 Statistical analysis

Data was analysed by Analysis of Covariance (ANOVA) procedures using R Core Team (2013), (Vienna, Austria) and IBM SPSS Statistics, Version 25.0. (Armonk, NY: IBM Corp) statistical packages with a least significant difference (LSD) at P = 0.05 and linear regression.

3. Results

3.1 Comparison of the storage bag materials and wetting

Loading bags with ether dry cassava roots or ones that had been wetted with water did not result in any difference in root quality with respect to PPD, fungal rots, starch content, and root moisture content compared to ones that were not wetted (P<0.05). Therefore, wet, and non-wet scores were combined for the subsequent analyses. This is probably because the humidity within the sacks of cassava roots remained above 85% RH [1] regardless of whether the roots were wetting or not wetting as illustrated in Figure 3. It is speculated that wetting of roots is probably important to maintain a relative humidity above 85% in small scale laboratory due to the small number of roots involved, where larger qualities of roots are involved (in this case 50kg), the natural respiration was probably sufficient to keep the relative humidity above 85% as demonstrated in this study.

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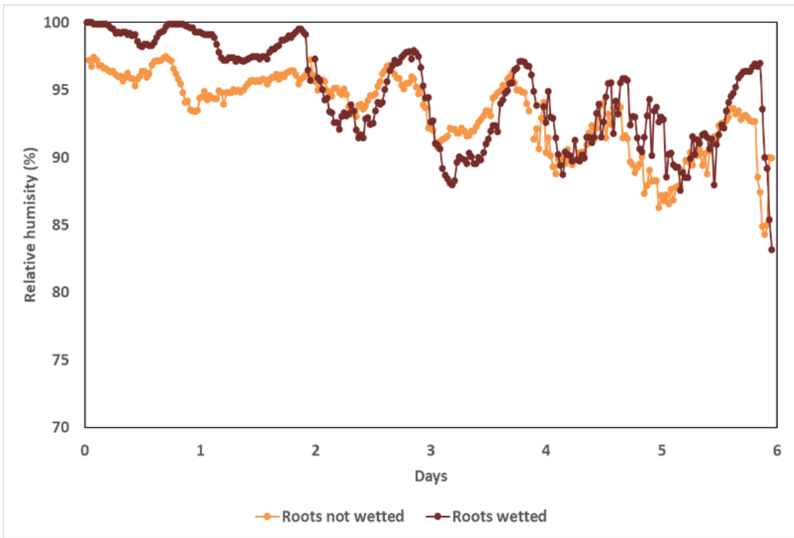
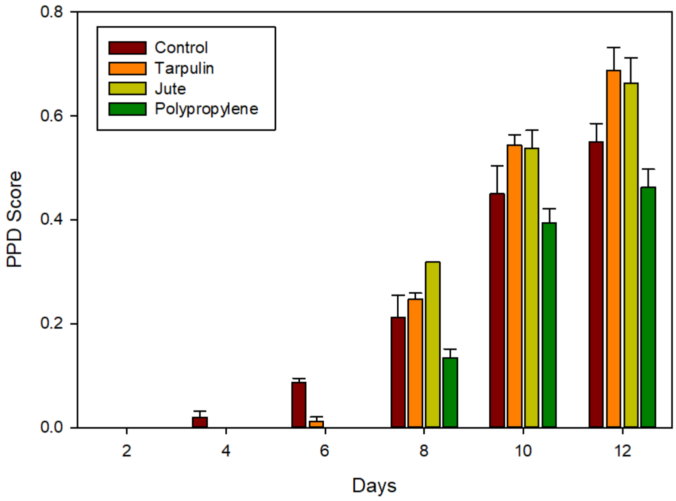
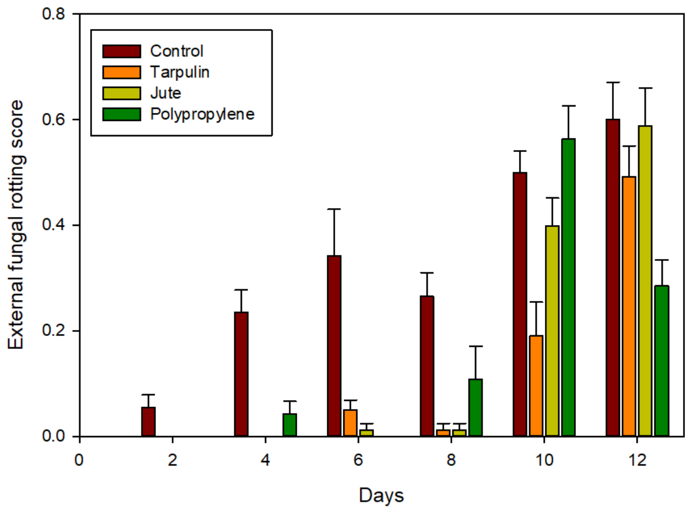


Figure 3. Relative humidity (RH%) within the sacks of cassava roots during storage which were either wetted by adding water or not wetted.

Considering the bag type, polypropylene bags resulted in the least PPD compared to the control, but this was only by 1 day (Figure 4). Considering the fungal rotting, the bags made from tarpaulin resulted in a significant improvement in shelf-life compared to the control such that for just perceptible rots (5 %) the storage time would be 7 days (Figure 4). The other bag types (jute and tarpaulin) did not differ from the control. Regarding the roots moisture content, bags made from tarpaulin resulted in the least reduction in moisture content during storage followed by jute and lastly polypropylene ($P<0.05$) (Figure 4). Most of the decline in moisture content was after 6 to 8 days. Regarding the starch content, storing in bag material types showed that the loss in starch content was less than in the control. Although, there were significant differences between the bags with respect to starch content change, in practice the differences were small and hence the polypropylene bag was used for other experiments as this was already used by the industry to transport cassava roots. In general, the decline in starch content started to occur after 2 days but the loss did not accelerate until after eight days of storage (Figure 4); the loss after two days when stored in bags was about 0.3 % starch and at eight days was 2.4 %. If the roots were not stored in a bag the starch loss was higher at 4.3 %.



(**a**)



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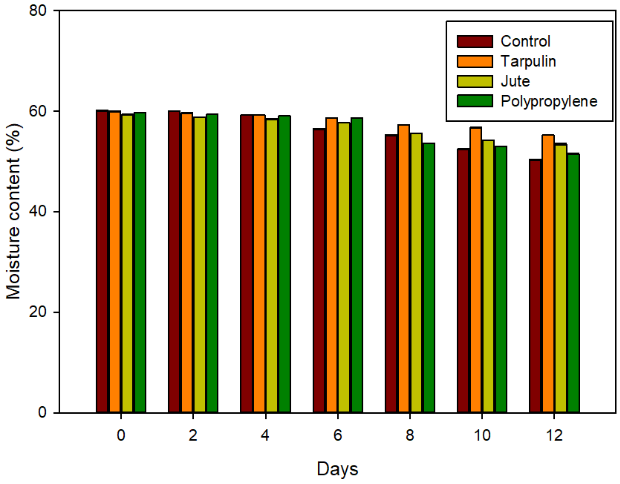

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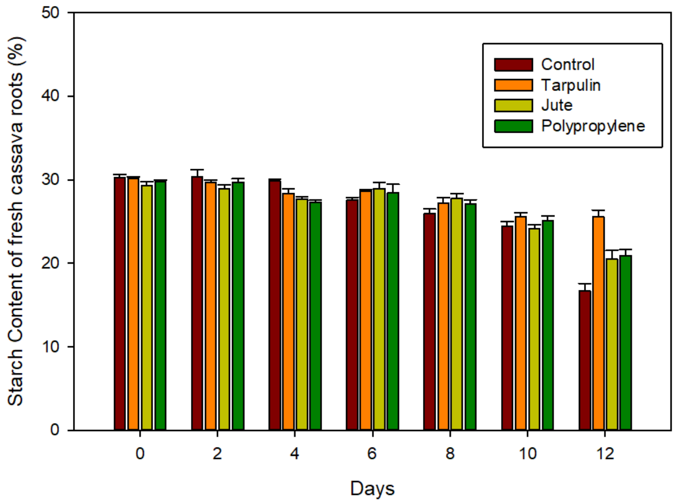

(**d**)

Figure 4. Variation in Fungal rots and PPD score, moisture, and starch content of fresh cassava roots with storage time in different types of bags.

3.2 Effect of root damage on the shelf-life

Considering PPD measurements of the fresh cassava roots, after eight days (Figure 5) only roots with slight bruising or no bruising and no breaks had minimal discoloration. It should be noted that there was a slight increase in discoloration, but this was considered acceptable. However, roots that that were broken (either 1 or 2) or had extensive bruising resulted in significant discoloration. Regarding the extent of fungal rots, after eight days of storage roots with bruising (slight or extensive) and no breaks did not differ from the control sample (no breaks or bruising). However, the inclusion of extensive bruising was probably due to the wide variation between the replicates. Any breaks (either 1 or 2), however, resulted in significant fungal rots. Considering the extent of starch loss after eight days of storage, where the roots are free of breaks or bruising (or have only slight bruising), the starch loss was 2.1 % to 2.3 %. However, if the roots have any break or extensive bruising, the starch loss was higher at 4.4 % to 5.8 % on average.

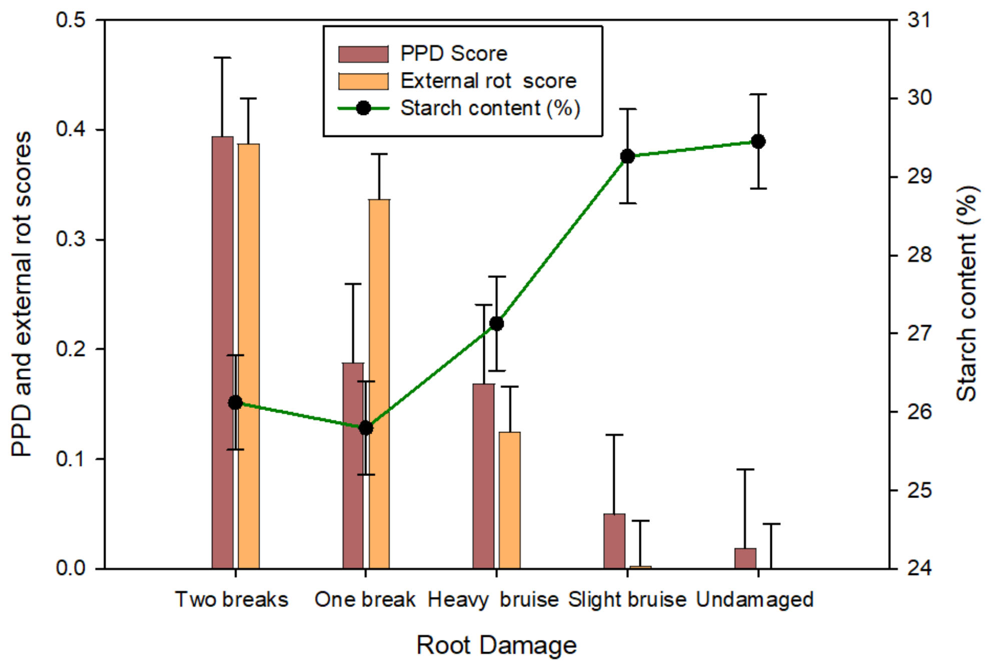

Figure 5. Changes in PPD, fungal rots and starch content of fresh cassava roots with varying degrees of damage after 8 days of storage.

How the root is disconnected from the stem during harvesting might have an impact on storage. Processors of starch prefer to harvest without the peduncle because this part of the root is more fibrous but keeping the peduncle attached is thought to increase the shelf-life (unpublished). Harvesting the roots with the peduncle did not have a significant impact on the starch content. It is speculated that the reason that there was no significant loss in starch content due to cutting without the peduncle might be because the additional damage to the fresh root was relatively minor and as shown in the previous section, minor root damage did not adversely affect the shelf-life when storing for up to eight days.

3.3 Effect of cassava variety

The cassava variety (TME419, TMS0581 and TMS1632) did not have a significant effect on root quality (PPD, fungal rots, starch content, or weight loss). Previously, weight loss occurring during storage was reported to be about 10 % after two weeks storage [1] but this is the first time that comparisons between these varieties has been reported. The starch content of the three varieties did differ due to storage but did differ in their inherent content (Figure. 6). Previously, during the storage of fresh roots, starch loss occurred at a rate of about 1 % per day [1]. This research agrees with the loss in starch of about 1 % per day but also shows that the curve is not linear being little loss during the first 48 hours and then losses increase after this time. Zainuddin et al. [2] reported that starch losses might vary with variety; in this study, variety did not have an effect. A gap in this research was that possible changes in starch gel clarity, swelling power and increases in gel viscosity might occur with variety [1]. This would require further investigation.

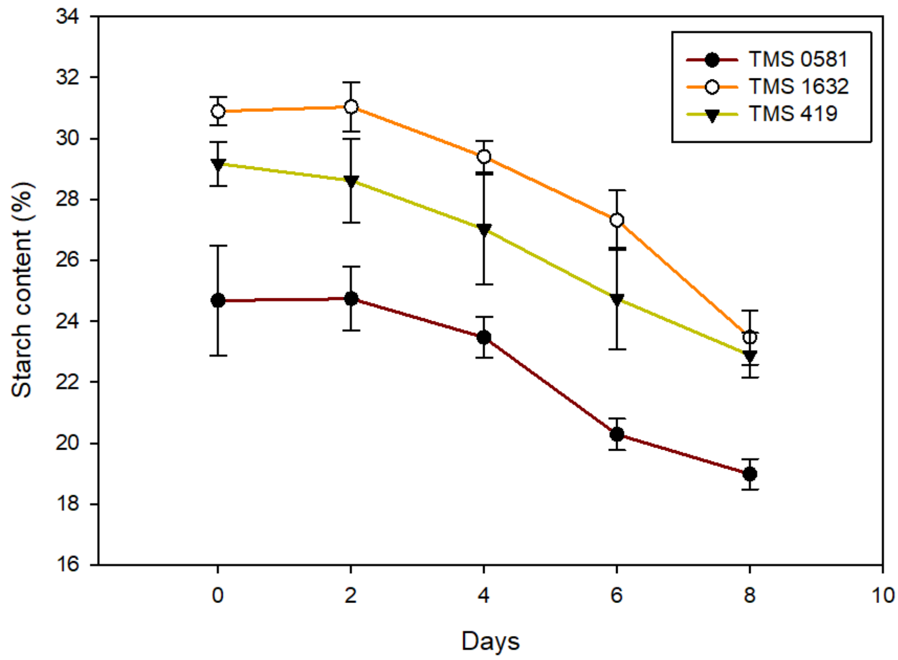

Figure 6. Variation in starch content of three varieties of cassava during storage of 50 kg in sacks.

3.4 CO2 concentration and starch losses

Root damage is known to increase the rate of respiration in fresh cassava roots due to PPD and wound response along with a corresponding loss in starch [9,1]. This increase in respiration is associated with an increase in CO_2 concentration, temperature, and RH%, which if measured during storage, could potentially be used to monitor changes in starch content during storage. While root damage did result in an increase in temperature and humidity in the stored fresh cassava roots, this did not significantly correlate with the extent of starch loss. A significant correlation ($P<0.05$) was found between starch loss (%) and maximum CO_2 concentration measured at eight days (Figure 7). The maximum CO_2 concentration was measured to account for the diurnal effect. While CO_2 is known to be produced by respiration of cassava roots, this is the first time that a relationship between CO_2 concentration and starch loss in fresh cassava roots during storage has been reported. This research suggests that CO_2 concentration in a cassava root store might be a suitable means to measure losses in starch but would require further development.

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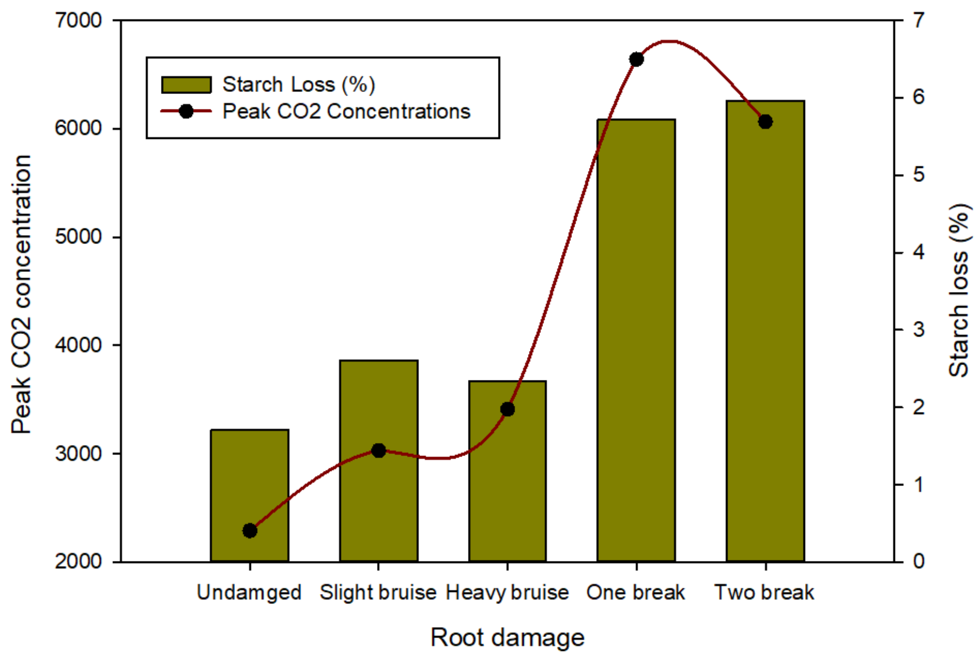

Figure 7. Relationship between starch loss (%) and peak carbon dioxide concentration after eight days of storage.

4. Discussion

Previously, more costly, and logistically challenging chemical treatments (oxidising agents such as calcium hypochlorite, disinfectants such as: ethanol and fungicides such as: benomyl, dicloran and thiabendazole) have been used to increase shelf-life of cassava roots by reducing PPD. Most of these chemicals are probably only preventing relief from secondary deterioration which is microbial (mostly, fungal rotting). Wax coatings [4] were reported to be successful in storing fresh cassava roots, has been tested in Uganda (Naziri unpublished). Edible surface coatings of fresh cassava roots have been found to be effective in preserving the quality of various perishable food products [8]. Using 1.5% xanthan guar/gum as an edible coating, cassava shelf life could be extended by up to 20 days at 25 °C. However, these approaches using chemical treatments were included in this research because at a commercial scale, these methods would only be practical for high value markets. Previous research has demonstrated that during storage of fresh roots, starch loss occurs at a rate of about 1 % per day [1] and might vary by variety and storage conditions [2]. Reported changes in the starch qualities during storage include a reduction in gel clarity and swelling power and increased in gel viscosity; it is not known how these changes in the quality of the starch or its commercial value [1]. In this research, the effect in gel clarity and swelling power was not measured and would require further research.

The temperature, RH% and CO2 in the sacks were similar regardless of the type of bag materials and this supports the findings that the bag material and addition of water had little effect. The average temperature varied between 27.1 and 29.1 oC and was within the range of 25 to 35 oC recommended by [4,9] while the average relative humidity varied between 92 and 98 % which was above the value of 85 % for curing. However, as the ambient conditions for humidity were also high at 74 % the higher humidity's were probably acceptable.Previously, different bag materials have been compared for storing fresh cassava roots being: open weave (manmade fibers), polyethylene (0.13 mm thick), recycled rice/flour sack made of tightly woven polyethylene. Of these, the polyethylene and recycled rice sacks were reported to retard deterioration the most [5]. In this research, it was possible for 50 kg cassava roots to be kept for up to eight days irrespective of whether the roots were wet or dry and irrespective of the bag material. The loss in starch content, a key commercial product requirement, was reduced if the fresh roots were stored in bags and was on average about 2.4% over eight days. This is less than 8% over eight days (i.e., 1 % per day of storage) estimated by [1]. The difference in starch losses, might be because [1] stored only a few roots and each was stored individually rather than in bags.

Root damage had an impact on the quality of the roots with respect to PPD, fungal rots and starch content. Previous research has demonstrated that physical damage to the fresh roots (cuts, breaks and bruising) increased PPD and reduced shelf-life [4]. After 11 days storage, roots with slight damage lost 9.6 % in weight compared to 18.2 % for roots with severe damage [6]. In response to wounding, such as cuts and abrasions, cassava storage roots show early physiological changes, including increased respiratory rate and water loss. Increased respiration induces the conversion of starch to sugar [10,1]. During storage, the starch content of unwounded cassava storage roots gradually decreases. However, starch loss and sugar production during storage is significantly higher if the roots were wounded. This research is new in that, the type of root damage (bruising or breaks) was considered. As the fresh cassava root remains biologically active, PPD is accompanied by an increase in respiration and the root can initiate a wound response and discoloration of the roots (vascular streaking) occurs due to oxidation of secondary metabolites [9]. However, previous research was undertaken on only a few cassava roots and hence, little was known about the response with larger sample sizes or how much root damage was possible before PPD became unacceptable. This research, using larger sample sizes of 50 kg shows that while root damage does reduce the shelf-life, slight bruising of the root is acceptable provided the roots are not cut or broken.

5. Conclusions

Currently, for the processing of cassava roots in the production of high-quality cassava flour or starch, a limitation is the rapid deterioration of the roots within 48 hours after harvesting. It can be concluded that fresh cassava roots (50kg) can be stored in a bag at ambient temperature in West Africa for up to eight days with minimal deterioration or loss in starch. The advantage would be reduced product handling and potentially lower costs when transporting the fresh cassava roots from the farm to the processing factory.

Several control measures would be required to support the management of the process to ensure that roots can be consistently stored. This included minimizing root damage. There was no need to wet the roots, harvest with the peduncle attached or to separate different varieties (TME419, TMS0581 and TMS1632). It is possible that other varieties may have differing storage characteristics, and this would need to be tested.

A new approach to monitoring starch losses in fresh cassava roots during storage using a simple carbon dioxide sensory is suggested but would require further testing. In industrial applications, this could provide a potential way to continuously and remotely monitor large quantities of cassava roots, avoid postharvest losses and maintain profitability.

Author Contributions: K.T, C.O., L. S, A.P and B.B conceived and planned the experiments. C.O., A.R.A and A.A.A. carried out the experiments. K.T. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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