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Changes in extended shelf life of cassava roots during storage in ambient conditions

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ABSTRACT

Cassava roots have a short shelf life due to a process known as post-harvest physiological deterioration (PPD). Within 2–3 d undesirable vascular streaking in the root develops. Tolerance to PPD was recently reported in different cassava genotypes, opening up new opportunities to analyze biochemical changes in stored roots and in the functional properties of their starches. Roots from PPD-susceptible (HMC-1) and tolerant (AM 206-5) clones were harvested and stored for up to 14 d in ambient tropical conditions. AM 206-5 is also characterized by amylose-free starch. Roots and starch were analyzed each day. PPD levels differed significantly between the two clones (35% and 8% at day 14) and showed a relation to scopoletin synthesis, which reached maximum levels around day 3 or 4 of storage. Roots lost weight consistently during storage (≈10% in two weeks). Starch loss per day of root storage was estimated at about 1%. This could be the result of consistent increases in total sugars and respiration of root tissue. Important changes in starch properties were observed. Gel clarity decreased gradually during storage, with more pronounced changes occurring in starches from HMC-1. Swelling power decreased only in the case of AM 206-5. Gel viscosity increased in both genotypes. Improved tolerance to PPD could significantly reduce the economic impact of the short shelf life of ordinary cassava root processing. It remains to be seen, however, whether changes in stored roots positively or negatively affect the quality of the final product.

1. Introduction

Cassava contributes vitally to global food security and is likely to play an even more significant role in the near future (Rosenthal and Ort, 2012), as demand grows for cassava roots to produce starch, food, animal feed and ethanol (Balagopalan, 2002; Buitrago, 1990; Chauynarong et al., 2009; Moorthy, 2004; Sriroth et al., 2010) as well as to make bread (Pasqualone et al., 2010) and snacks (Vitrac et al., 2002).

Several factors affect the ability of cassava to satisfy new and increasing demands. Cassava is generally grown in marginal environments that are often far from processing centers and have poor roads. In addition, cassava roots are bulky, containing approximately 65% water. They also have a very short shelf life because of a process known as post-harvest physiological deterioration (PPD), which rapidly renders the roots unpalatable and unmarketable (Reilly et al., 2003, 2007; Wheatley, 1982; Wheatley and Gomez, 1985). Consequently, cassava roots need to be consumed soon after harvest (van Oirschot et al., 2000). The processes involved in PPD resemble changes typically associated with the plant's response to wounding and trigger a cascade of biochemical reactions, in which reactive oxygen species are central. Specific genes involved in PPD have been identified and characterized, and their expression evaluated (Reilly et al., 2007). Several secondary metabolites, particularly hydroxycoumarins, accumulate in the process (Bayoumi et al., 2010; Blagbrough et al., 2010; Gnonlonfin et al., 2012).

Several approaches have been developed to preserve cassava roots, such as underground storage, storage in boxes with moist sawdust, storage in bags combined with the use of fungicides, pruning plants before harvest, cold storage (2–4 °C) for up to two weeks, freezing or waxing the roots to prevent access to oxygen, and even chemical treatments (Ravi et al., 1996). However, these methods are too expensive or complicated for handling large volumes of roots, and have been restricted mostly to high-value product chains such as the consumption of fresh cassava roots.

Cassava is the second most important source of starch after maize, and cassava starch is traded more in international markets

Abbreviations: PPD, post-harvest physiological deterioration; DMC, dry matter content; PT, pasting temperature; PV, peak viscosity; HPV, hot paste viscosity; CPV, cool paste viscosity; FV, final viscosity; DSC, differential scanning calorimeter; ΔH, gelatinization enthalpy; ϕ, volume fraction of the dispersed phase.

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than any other starch source (Stapleton, 2012). New root quality traits that offer particular advantages for the starch industry are likely to strengthen and widen the industrial applications of cassava in the near future (Rolland-Sabaté et al., 2012; Sánchez et al., 2010). Genetic transformation is an important tool for developing cassava cultivars with such traits (Liu et al., 2011; Koehorst-van Putten et al., 2012; Zhao et al., 2011).

The recent report of genetic variation for tolerance to PPD (Morante et al., 2010) has created a new opportunity for the starch sector. However, further analysis is required to determine whether the properties of starch from roots not affected drastically by PPD change during the storage period. Changes in the physicochemical and/or functional properties of root and tuber starches in storage have been reported for potato (Ooraikul and Moledina, 1981; Singh et al., 2008; Golachowski, 1985; Kaur et al., 2007), sweet potato (Zhang et al., 2002) and yams (Akissoe et al., 2004; Aishat et al., 2007). Idowu and Akindele (1994) reported qualitative changes in cassava gari and fufu after storage of roots for up to four days. Ihedioha et al. (1996) reported that properties of stored cassava roots change long before PPD can actually be observed. However, with the exception of studies by Osunsami et al. (1989), little is known about changes in cassava starch functional properties occurring during root storage as a result of limitations imposed by PPD.

The short shelf life of cassava roots severely limits marketing options by increasing losses and overall marketing costs. Vlaar et al. (2007) estimated that the development of a cassava variety whose roots could be stored for up to 45 d would generate benefits valued at about US$35 million per year for Thai cassava farmers and factory owners.

The objective of this study was to monitor PPD, changes in the weight and biochemical properties of stored roots, and in the functional properties of the starches extracted from them. Roots from two contrasting genotypes (PPD tolerant or susceptible) were stored for up to 14 d. Such a study was not possible previously, because PPD prevented storage of roots beyond a few days after harvest.

2. Materials and methods

Roots from two different cassava genotypes (AM 206-5 and HMC-1) were harvested for this study. AM 206-5 has been reported to be tolerant to PPD (Morante et al., 2010), whereas HMC-1, a commercial variety grown in the mid-altitude valleys of Colombia, is susceptible. AM 206-5 is also the source of a spontaneous mutation for amylose-free (waxy) starch (Ceballos et al., 2007). Root samples were obtained from plants grown at the CIAT Experimental Farm in Palmira, Colombia, which is approximately 1000 m above sea level and where cassava is harvested 11 months after planting. The two genotypes were grown under standard cultural practices, with fertilizer and irrigation provided as required.

Commercial-size roots were harvested and weighed individually. On harvest day, eight roots from each clone were processed for biochemical characterization. Starch and flour were extracted from them as explained below. Remaining roots were stored on shelves under a roof but without walls. Air, therefore, circulated freely through the shelves. During the experiment, the average maximum temperature (day) was 29.6 °C with a maximum value of 32.1 °C. The average minimum temperature (night) was 18.9 °C with a minimum value of 16.5 °C. Relative humidity was 94.7% at 7:00 AM, 61.3% at 1:00 PM and 76.7% at 7:00 PM. Every day four roots from each genotype were randomly selected, weighed again and scored for PPD. Roots were then processed for biochemical characterization and starch and flour extraction. The study continued through the day 14 of storage. Roots were not sampled, however, on days 5, 11 and 13.

2.1. PPD score

Scoring the reaction to PPD is a destructive process developed initially by Booth et al. (1976) and based on the storage of intact roots (also Booth, 1976, 1977). A new method for quantifying PPD was described by Marriott et al. in 1978 and 1979 and later modified by Wheatley in 1982. With this method, the proximal and distal ends of the root are removed to accelerate the process and avoid microbial contamination, which occurs during long storage periods. The distal open section of the root is covered with cling film to prevent further flow of oxygen. Roots are then stored for 3 d. To score for PPD reaction, seven transversal slices are cut along the root, starting at the proximal end. A score ranging from 1 to 10 is assigned to each slice, corresponding to the percentage of the cut surface showing discoloration (1 = 10%, 2 = 20%, etc.). The mean PPD score for each root is calculated by averaging the scores for the seven transversal sections. Roots showing symptoms of microbial rotting (very different from those related to PPD) or affected by insects were discarded. In this study, roots were left intact following the methodology used by Booth, but PPD assessment was done on seven root slides as suggested by Wheatley in 1982. The results obtained resemble more closely the conditions of the roots in storage at a starch factory.

2.2. Root processing

After the roots were weighed and the PPD score taken, the seven root slices from each root were peeled and chopped into small pieces. The four roots from each treatment (genotype × duration of storage period) were randomly paired in two replications (with each replication made up of two roots combined). The two roots from each replication were ground together using a food processor with stainless steel tools into a uniform mash (SKYMSEN Food Processor MODEL PA-7SE), from which sub-samples were taken for dry matter content measurement and flour production.

2.3. Dry matter content

Two independent samples (5×10^{-2} kg aliquots) were taken from the homogenous paste of each replication for quantification of dry matter content (DMC) after measurement of PPD. For this purpose, the samples were dried in an oven (Thelco Oven Model 28, Precision Scientific Subsidiary of GCA Corporation, Chicago, USA) at 105 °C for 24 h. Dry matter was expressed as the percentage of dry weight relative to fresh weight.

2.4. Flour production

Another sample (approximately 0.1 kg) was taken from the ground roots for flour production. Samples were dried for 2 d at 40 °C and ground with a Glen Creston cross beater mill (Stanmore, England). There was a single flour sample per replication for each treatment (genotype × duration of storage period). Flour analyses were done twice.

2.5. Cassava starch isolation

The homogeneous mash of root tissue from each replication (left after samples were taken for dry matter quantification and flour production) was further crushed in a 4 L capacity Waring Commercial blender (New Hartford, CT, USA). The slurry was filtered through a market grade 100 mesh (0.149×10^{-3} m) sieve. The starch was allowed to settle and the supernatant decanted off. Solids were washed with distilled water twice and centrifuged at 133.3 s^{-1} for 600 s (Aristizábal and Sánchez, 2007). The sample was then dried in an oven with fan-forced ventilation at 40 °C