Scientific Research Publishing

American Journal of Plant Sciences, 2023, 14, 89-103
https://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Influence of Harvest Periods on Cassava (*Manihot esculenta* Crantz) Agronomic Traits and Physiological Response to Post-Harvest Physiological Deterioration

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How to cite this paper: Djabou, A.S.M., Ewane, H.P.K., Eyamo, V.J.E., Ketchiemo, F.T., Figueiredo, P.G., Niemenak, N. and Tonfack, L.B. (2023) Influence of Harvest Periods on Cassava (*Manihot esculenta* Crantz) Agronomic Traits and Physiological Response to Post-Harvest Physiological Deterioration. *American Journal of Plant Sciences*, **14**, 89-103.
https://doi.org/10.4236/ajps.2023.141007

Received: November 25, 2022
Accepted: January 28, 2023
Published: January 31, 2023

Abstract

Cassava (*Manihot esculenta* Crantz) is the third largest source of calories in tropical countries and the sixth most important food crop in the World. However, the short shelf life of its storage roots after harvest due to a rapid post-harvest physiological deterioration (PPD) makes the roots to be considered as a risky product to market. The objectives of this work were to investigate the influence of two harvest periods on cassava agronomic parameters and their physiological response to PPD. Three cassava cultivars 96/1414, I070593 and LMR were selected for the experiment and harvested at 10 and 12 months after planting (MAP). The response to PPD was assessed during storage at 0, 3, 8 and 15 days after harvest (DAH). Total proteins content, soluble sugars and starch, total polyphenols compounds, polyphenoloxidase and peroxidase activities were recorded during storage. Results showed large variation among the parameters at the two harvest periods across the cultivars. High number of tubers was recorded in all the cultivars at 12 MAP and a significant increase in storage roots length was observed in 96/1414 and LMR from 10 MAP to 12

MAP (25 ± 5.1 to 41.3 ± 5.9 and 22.6 ± 3.3 to 27.9 ± 4.8) respectively. A reduction of about 49% of tubers weight was observed in I070593 from 10 to 12 MAP while an increase of about 36% and 11% were recorded in LMR and 96/1414 respectively. Tubers from I070593 showed less susceptibility to PPD when harvested at 10 MAP compared to those from LMR and 96/1414 where less susceptibility to PPD were recorded at 12 MAP. An increase in soluble sugars content, total proteins content and peroxidase activity subsequently to a decrease in starch content were recorded during storage from 8 to 15 days after harvest especially at 10 MAP in I070593 and at 12 MAP in LMR and 96/1414. High content of total phenolic compounds and less activity of polyphenol oxidase were correlated to PPD susceptibility. This work opens a new insight issue of the consideration of the appropriate harvest time of the cultivars as a tool to better control the onset of postharvest physiological deterioration.

Keywords

Manihot esculenta, Harvest Period, Post-Harvest Deterioration, Agronomic and Biochemical Parameters

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most valuable roots crops and the second important staple food for energy around the World [1]. It is mainly grown for its tuberous roots, rich in carbohydrates, which account for about 90% of the dry weight of tubers [2]. Cameroon has significant potential as one of the biggest cassava producers in Africa [3]. Cassava accounts for more than 20% of sown land and 46% of national food production [3]. It represents the staple food in the diet of 7 to 8 million Cameroonians and contributes to about 8% of the daily nutritional intake behind the plantain [4]. However, apart from the problem of pest attack especially due to cassava mosaic virus [4], cassava market is constrained by the short shelf-life of cassava roots because of postharvest physiological deterioration (PPD) [5]. Cassava storage root is inevitable predisposed to cell damage due to mechanical injury caused by harvest. Undesirable vascular streaking developed quickly are commonly observed in the place on the site of damage of harvest storage roots and caused deterioration vascular streaking developed quickly within 2 to 3 days and then caused black blue to black discoloration on the parenchyma [6] [7] [8]. Therefore, constitutive defense mechanisms such as physiological and biochemical changes are activated upon harvest as in intact plant subjected to abiotic stress. The process of PPD is considered to resemble a typical wounding response in which the healing process is inadequate. PPD is a complex physiological process which involves many regulatory networks linked with specific proteins modulation and signaling transduction pathways [6]. Several works studying PPD have place reactive oxygen species (ROS) production

as one of the earliest events in the process [9] [10] [11]. In addition, a causal link between cyanogenesis and the onset of the oxidative burst was reported by [12]. Superoxide dismutase in combination with catalase activities was also reported as the first line of defense against PPD to support PPD-tolerant cassava varieties [8]. The accumulation of secondary metabolites such as diterpenic and phenolic compounds during the process of PPD development was also reported [9]. A delay of PPD onset was reported by [13] in yellow-root cassava cultivars with high β-carotene.

Biochemical features of PPD include changes in proteins content and enzymatic activities, genes expression and metabolites [8] [14] [15] [16]. A rapid increase in soluble sugars content coupled with a decrease in starch content and root dry weight were reported by [17]. PPD has been found to be associated with agronomic traits as reported by [18] and [19]. Factors such as cultivar, environmental conditions, and soil preparation and composition are of high importance in PPD sensitive and tolerance considerations [20] [21]. Therefore, PPD is a major challenge in cassava value chain and effort to reduce its negative impact is of great interest for cassava market and industry. Traditional marketing and storage systems have been adapted to avoid root perishability but currently there is no general technique to store and preserve cassava roots commercially [22]. A common way of avoiding root losses due to PPD is to leave the roots unharvest in the soil after the period of optimal root development, until the roots can be immediately consumed, processed or marketed [17]. This strategy has disadvantages because large areas of land are used by the standing crop, unavailable for additional agriculture production. Furthermore, even though the roots may increase in size they become more woody and fibrous, decreasing palatability and increasing the cooking time, respectively, if left longer than the optimal harvest time of 10 - 12 months after planting [17]. In Cameroon as well as in many african countries studies on cassava are concentrated in cassava mosaic virus [23] [24] and very low attention is made on PPD even if losses of about 29% due to PPD were reported in Africa [17].

The purpose of this work was to investigate the influence of two harvest periods on cassava storage roots agronomic parameters and the mobilization of some biochemical variables during postharvest storage in response to PPD among three cassava cultivars highly cultivated in Cameroon.

2. Material and Methods

2.1. Description of the Study Area

The experiment was carried out at the locality of Zamengoe, Centre region of Cameroon (N03˚56.589' E011˚27.388'). The climate according to [25] is tropical with two distinct seasons: the rainy season (from March to June and from August to November) and the dry season (from November to March and from June to August). The average annual temperature is 25˚C, and the average annual rainfall range from 1500 to 2000 mm [25]. The physiochemical composition from 100 g of

soil of the experimental study consisted of pH 5.3, 1.25% of organic matter, 2.76 meq of Ca, 0.58 meq of Mg, 0.1 meq of K, 10.72 mg/kg of P and 1.16 g/kg of N.

2.2. Plant Material

The stem cuttings of 15 cm in length, 20 mm in diameter with at least five buds were taken from 12-month-old plants of three cassava cultivars 96/1414 (white flesh improved cassava), I070593 (yellow flesh improved cassava) and LMR (red flesh local cassava) generously offered by the International Institute of Tropical Agriculture (IITA—Cameroon). According to the information released by IITA, the yield of the cultivars I070593 and 96/1414 are above 35 tons/ha while the yield of LMR is 18 tons/ha. The experiment was set up in a randomized complete block design with three plots of 12 m^2 each containing 20 cassava plants for each cassava cultivars and repeat three time. A 1.5 m wide-open strip separated the blocks; whereas the plots within a block were 1 m apart from each other. The stem cuttings were planted manually in individual spaces measuring 1 m × 1 m (1 m within and among rows) spaced at 1m. The cassava roots were harvested at 10 and 12 months after planting (MAP) which are considered as most appropriated harvest periods for cassava storage roots [15] [16] [17]. Weeds were manually control during the experiment by hoeing.

2.3. Agronomic Parameters at the Two Harvest Periods

Manual harvesting trials were conducted at 10 and 12 months after planting (MAP). Handling of cassava roots was carefully processed to minimize any mechanical damages. Agronomic parameters investigated at harvest include average storage root length (cm), average storage root diameter (cm), average storage root weight, number of storage root per plant at each harvest period using five plants selected at random within the plot as samples per cassava cultivar.

2.4. Visual PPD Assessment

Harvested roots were stored at room temperature on shelves and protected from the sun and rain. The effect of the two harvest periods on the onset of PPD according to cassava cultivar was assessed on storage roots incubated at room temperature for 0, 3, 8 and 15 days after harvest (DAH). At each time of storage, five roots of each genotype were selected randomly for the evaluation of PPD. A sliced section of about 2 cm thickness was photographed for visual observation of PPD development as described by [20]. PPD onset was determined by the observation black blue to black discoloration of the parenchyma, described as characteristics of PPD [26] [27]. The grayscale intensity of the pixels of the images of the tuber sections was assessed using the ImageJ software, version 1.53e (http://rsb.info.nih.gov/ij/, NIH, MD, USA) [28].

2.5. Total Protein Quantification and Peroxidase Activity

Total protein quantification was assessed at different times of storage of each

harvest periods from 0.5 g of cassava flesh crushed in a mortar with 3 ml of protein extraction buffer (0.1 M phosphate, 0.1% (W/V) EDTA, 0.1% (W/V) Ascorbic acid, 0.5% (W/V) NaCl, 0.02% (V/V) Triton X-100, pH = 7.2). Soluble proteins were recorded from the supernatant after centrifugation at 3500 g, 4˚C for 20 min. Total protein concentration was estimated by standard Bradford's method [29]. Peroxidase activity (POX) and Polyphenol oxidase activity (PPO) were both estimated spectrophotometrically from total protein extract using methods described by El-Hadrami & Baaziz and Van Kammen & Brouwer, respectively [30] [31].

2.6. Total Soluble Sugars and Starch Content Quantification

Estimation of total soluble sugars content was done at different time of storage of each harvest periods from 0.4 g of flesh crushing in 4 mL of ethanol 80%. The mixture was centrifuged at 3500 g, 4˚C for 20 min. The supernatant was collected in test tube and constitute the total soluble sugars fraction and the pellet was recorded for starch extraction. Starch extraction was assessed by acid hydrolysis from the pellet of sugar extraction as described by [4]. 2 mL of hydrochloric acid were added to the pellet and the mixture was heated at 70˚C for 3 hours. The reaction was stopped by adding 2 mL of natrium hydroxide 6N and, the mixture was centrifuged at 3500 g, 4˚C for 20 min. The supernatant was collected in a test tube and constituted the starch extract. The concentration of total sugar and starch were estimated using an anthron reagent according to the method described by [32].

2.7. Total Polyphenols Quantification

Phenolic compounds were extracted from 0.4 g of fresh cassava flesh in 3 ml of 80% (v/v) methanol at the different time of storage of tubers from the three cultivars harvest at 10 MAP and 12 MAP [33]. The quantification of the phenolic compounds was made according to [34] using the Folin-Ciocalteu reagent.

2.8. Data Analysis

Statistical analyses were performed in Microsoft Office Excel 2013. For the significance analysis, data were analyzed by a two-factor ANOVA. Means were compared using LSD at 5% using Scott-knott test through R software version 3.6.3. Analyses were done in three biological replicates.

3. Results

3.1. Agronomic Parameters of Tubers at Harvest

Cassava storage roots were evaluated at 10 MAP and 12 MAP by tubers length, tubers weight, tubers diameter and number of tubers per plants (**Table 1**). The results indicated a significant difference among cultivars following the evaluated parameters according to the two harvest periods. The number of tubers per plant of cassava cultivars 96/1414 and LMR at 10 MAP were 6.9 ± 1.7 and 6.4 ± 1.07

respectively. The lowest number of tubers per plant 3.2 ± 1.13 was recorded in I070593 cultivar at this same harvest period. At 12 MAP, the average number of tubers increased significantly in all the cultivars with a great increase observed in I070593 where the number of tubers doubled from 3.2 ± 1.13 at 10 MAP to 7.3 ± 2.7 at 12 MAP. A decrease in tubers length and diameter was observed in 96/1414 and LMR storage roots from 10 MAP to 12 MAP. The average tubers length drop of 39% (from 41.3 ± 5.95 cm to 25.3 ± 5.07 cm) and 19% (from 27.9 ± 4.8 cm to 22.6 ± 3.34 cm) was observed in cassava storage roots 96/1414 and LMR cultivars respectively from 10 MAP to 12 MAP. No significant difference was observed in the average tubers length of I070593 at 10 MAP and 12 MAP. However, a decrease in tubers weight was observed in cassava storage roots of I070593 cultivar at 12 MAP where the cultivars 96/1414 and LMR showed an increase in tubers weight at this harvest period (Table 1).

3.2. Effect of Harvest Period on Morphological Changes of Tubers during Storage

Morphological observations of postharvest physiological deterioration (PPD) on cassava storage roots stored at 0, 3, 8, and 15 DAH for the two harvest periods are reported in Figure 1. Visual observation by transverse section of the roots showed differences in PPD onset according to the harvest periods and the cultivars. Delay of PPD development for about 15 days was observed in cassava storage roots from I070593 cultivar harvested at 10 MAP while PPD symptoms were observed in cassava storage root from LMR and 96/1414 cultivars at 3 DAH and 8 DAH respectively. However in cassava storage roots harvested at 12 MAP, PPD symptoms were observed in all the cultivars with diverse severity at 3 DAH. The grayscale intensity relative to PPD development analyzed by ImageJ give more appreciation of response of the cultivars to PPD under the two harvest periods (Figure 1). The analysis of grayscale intensity in tubers from I070593 at 10

Table 1. Effect of harvest period on agronomic parameter of storage roots at harvest.

Agronomic traits	Harvest periods	Genotypes		
		96/1414	I070593	LMR
Number of tubers	10 MAP	6.9 ± 1.7^{c}	3.2 ± 1.13^{d}	6.4 ± 1.07^{c}
	12 MAP	10.2 ± 2^{a}	7.3 ± 2.7^{c}	8.6 ± 1.6^{b}
Lenght of tubers (cm)	10 MAP	25 ± 5.1^{d}	32.3 ± 4.7^{b}	22.6 ± 3.3^{e}
	12 MAP	41.3 ± 5.9^{a}	32.8 ± 5.4^{b}	27.9 ± 4.8^{c}
Weight of tubers (kg)	10 MAP	0.6 ± 0.25^{b}	0.69 ± 0.1^{b}	0.5 ± 0.22^{c}
	12 MAP	0.76 ± 0.1^{a}	0.35 ± 0.1^{d}	0.8 ± 0.25^{a}
Diameter of tubers (cm)	10 MAP	17.5 ± 2.9^{a}	17 ± 3.5^{a}	17.2 ± 3.1^{a}
	12 MAP	14.6 ± 1.6^{b}	15.1 ± 2^{b}	15.8 ± 1^{b}

Values with same letters from line and for one parameter are not significant different according to the Scott-knott test at 5% threshold. MAP= months after planting.

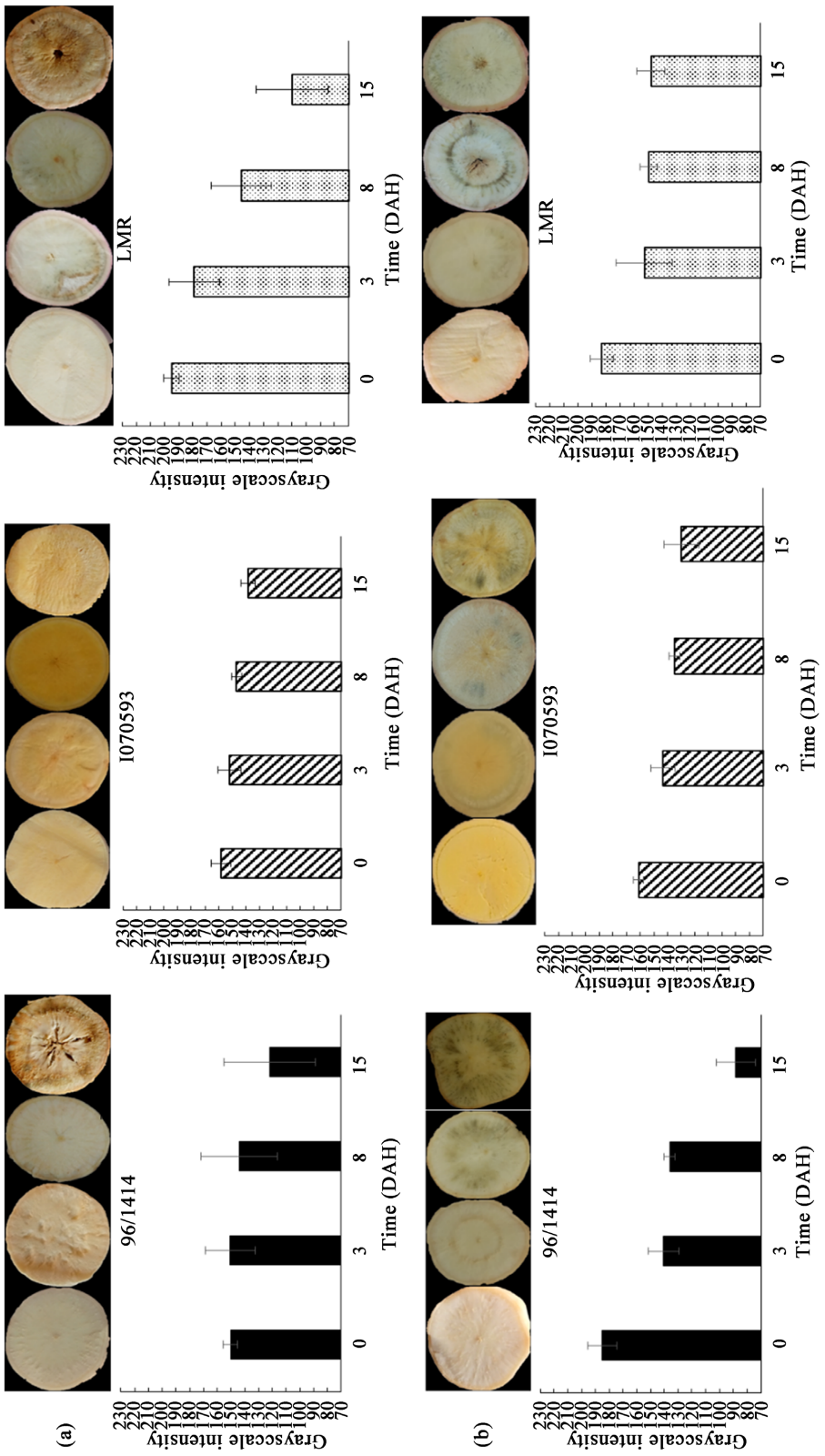

Figure 1. Morphological visualization of post-harvest physiological deterioration on tubers at the two harvest periods and Means ± standard deviations of pixel grayscale values of images of tuber sections by ImageJ software. (a) Tubers harvest at 10 months; (b) tubers harvest at 12 months.

MAP showed low variation from 0 to 15 DAH while a continuously decreased was observed in tubers from LMR at 10 MAP and in tubers from 96/1414 at 12 MAP.

3.3. Physiological Response of the Tubers to Postharvest Physiological Deterioration during Storage at the Two Harvest Periods

A significant variation in total proteins content during storage was observed for the two periods of harvest (Table 2). In general, the tolerance to PPD of the cultivars at a specific harvest period was correlated to an increase in proteins content following the duration of storage. At 10 MAP, an increase in total proteins content was observed in tubers from I070593 following the duration of storage. This increase was correlated to the delay of PPD development of tubers from this cultivar harvest at 10 MAP compared to the tubers from LMR and 96/1414 where the total proteins increased from 0 to 3 DAH and decreased from 8 to 15 DAH. At 12 MAP, the amount of proteins gradually increased in tubers from LMR during storage while a decreased in total proteins was observed in tubers from I070593 and 96/1414 at 8DAH and 15DAH respectively.

The increase in total proteins was also associated with an increase in peroxidase activity especially in tubers from I070593 at 10 MAP and in tubers from 96/1414 at 12 MAP. In fact, at 10 MAP the peroxidase activity slowly increases in all the cultivars from 0 DAH to 8 DAH and decreases in 96/1414 and LMR at 15 DAH while it continue to increase in I070593 (Table 3). At 12 MAP two burst of peroxidase activity were in I070593 and LMR at 3 DAH and 15 DAH while in 96/1414 the activity gradually increases following the duration of storage.

The effect of the two harvest periods on soluble sugars content is presented in Table 4. An increase in total sugars content following the duration of storage

Table 2. Effect of harvest period on total proteins content of tubers during storage.

Harvest periods	Days after harvest (DAH)	Genotypes		
		96/1414	I070593	LMR
10 MAP	0	1.7 ± 0.03^{d}	1.17 ± 0.03^{f}	1.9 ± 0.01^{c}
	3	2.28 ± 0.09^{b}	1.4 ± 0.07^{e}	2.6 ± 0.02^{a}
	8	1.86 ± 0.02^{c}	1.7 ± 0.04^{d}	1.77 ± 0.2^{d}
	15	0.64 ± 0.19^{g}	2.2 ± 0.06^{b}	1.48 ± 0.03^{e}
12 MAP	0	1.7 ± 0.03^{e}	1.43 ± 0.01^{f}	1.23 ± 0.04^{g}
	3	1.96 ± 0.06^{c}	1.76 ± 0.04^{e}	1.84 ± 0.09^{d}
	8	2.54 ± 0.12^{a}	1.53 ± 0.12^{f}	1.8 ± 0.04^{d}
	15	1.78 ± 0.06^{d}	0.04 ± 0.06^{h}	2.25 ± 0.06^{b}

Values with same letters from line and column and for each harvest period are not significant different according to the Scott-knott test at 5% threshold. MAP = months after planting.

Table 3. Effect of harvest period on peroxidase (POX) activity of tubers during storage.

Harvest periods	Days after harvest (DAH)	Genotypes		
		96/1414	I070593	LMR
10 MAP	0	0.3 ± 0.1^{f}	1.8 ± 0.7^{e}	4.8 ± 0.5^{d}
	3	2 ± 0.1^{e}	2.5 ± 0.6^{e}	4.4 ± 0.4^{d}
	8	4.6 ± 0.8^{d}	7.1 ± 0.9^{b}	6.7 ± 0.2^{b}
	15	1.6 ± 0.6^{e}	14 ± 0.1^{a}	5.7 ± 0.5^{c}
12 MAP	0	5 ± 0.8^{f}	6.6 ± 0.6^{e}	5.2 ± 0.6^{f}
	3	6 ± 0.2^{e}	6.3 ± 0.2^{e}	14.8 ± 0.6^{c}
	8	8.6 ± 0.2^{d}	6.3 ± 0.1^{e}	6.7 ± 0.1^{e}
	15	9 ± 1^{d}	62 ± 1^{a}	30.5 ± 0.5^{b}

Values with same letters from line and column and for each harvest period are not significant different according to the Scott-knott test at 5% threshold. MAP = months after planting.

Table 4. Effect of harvest period on soluble sugars content of tubers during storage.

Harvest periods	Days after harvest (DAH)	Genotypes		
		96/1414	I070593	LMR
10 MAP	0	9.1 ± 2.4^{g}	16.8 ± 0.74^{f}	19.8 ± 1.3^{e}
	3	20.8 ± 0.35^{e}	27.5 ± 0.47^{d}	21.6 ± 0.48^{e}
	8	34.6 ± 1.2^{c}	37 ± 1.2^{c}	35.9 ± 1.26^{c}
	15	42.9 ± 2.5^{b}	49.8 ± 0.6^{a}	25.9 ± 0.7^{e}
12 MAP	0	25.5 ± 1.7^{c}	24.4 ± 0.66^{d}	23.1 ± 1.37^{d}
	3	25.4 ± 0.28^{c}	26.6 ± 0.57^{c}	23.6 ± 0.9^{d}
	8	30.8 ± 1.75^{b}	27.1 ± 1.63^{c}	24.5 ± 1.9^{d}
	15	33.8 ± 0.47^{a}	26 ± 1.8^{c}	23.97 ± 0.8^{b}

Values with same letters from line and column and for each harvest period are not significant different according to the Scott-knott test at 5% threshold. MAP = months after planting.

was observed in all the cultivars at the two harvest periods with an exception of tubers from I070593 and LMR where a decrease in sugars content was observed at 15 DAH at 10 MAP and 12 MAP respectively.

The increase in soluble sugars was subsequent to the decrease in starch content in all the cultivars at the two harvest periods following the duration of the storage (Table 5).

The analysis of total phenolic compound in I070593 at 10 MAP showed a decrease from 0 to 8 DAH following by a slight increase at 15 DAH while in 96/1414 a gradually increase in total phenolic compounds was observed from 0 to 8 DAH with a peak at 15 DAH (Table 6).

Table 5. Effect of harvest period on starch content of tubers during storage.

Harvest periods	Days after harvest (DAH)	Genotypes		
		96/1414	I070593	LMR
10 MAP	0	188.7 ± 35.4^{c}	324.8 ± 16.4^{a}	211.6 ± 35^{c}
	3	226.4 ± 19.7^{b}	197.5 ± 26.4^{c}	254.6 ± 26.5^{b}
	8	191 ± 29.7^{c}	188.7 ± 49.3^{c}	134 ± 26.2^{c}
	15	156.7 ± 11.6^{c}	245 ± 45^{b}	250.9 ± 25.2^{b}
12 MAP	0	348 ± 29.8^{a}	170.3 ± 16.8^{b}	148.3 ± 3.4^{c}
	3	194.4 ± 23.4^{b}	189.9 ± 29.1^{b}	138.3 ± 18.9^{c}
	8	167.1 ± 18.1^{b}	154.5 ± 13.2^{c}	195 ± 20.4^{b}
	15	149.4 ± 39.8^{c}	161.2 ± 27^{b}	99.5 ± 17.5^{d}

Values with same letters from line and column and for each harvest period are not significant different according to the Scott-knott test at 5% threshold. MAP = months after planting.

Table 6. Effect of harvest period on phenolic compounds of tubers during storage.

Harvest periods	Days after harvest (DAH)	Genotypes		
		96/1414	I070593	LMR
10 MAP	0	3.77 ± 0.02^{f}	6.1 ± 0.46^{c}	4.8 ± 0.05^{e}
	3	5.5 ± 0.5^{d}	4.5 ± 0.1^{e}	4.9 ± 0.24^{e}
	8	6 ± 0.2^{c}	2.5 ± 0.18^{h}	3 ± 0.18^{g}
	15	10.6 ± 0.02^{a}	4.1 ± 0.33^{f}	7 ± 0.26^{b}
12 MAP	0	8.32 ± 0.17^{a}	4.75 ± 0.36^{e}	6.15 ± 0.29^{d}
	3	3.66 ± 0.12^{f}	2.93 ± 0.34^{g}	2.64 ± 0.26^{h}
	8	2.45 ± 0.54^{h}	7.45 ± 0.12^{b}	3.2 ± 0.34^{g}
	15	6.87 ± 0.27^{c}	6.35 ± 0.46^{d}	2.18 ± 0^{h}

Values with same letters from line and column and for each harvest period are not significant different according to the Scott-knott test at 5% threshold. MAP = months after planting.

The opposite trend was observed at 12 MAP where the total phenolic compounds was found to be decrease in 96/1414 and LMR from 0 to 8 DAH. The decrease in total phenolic compounds was followed by an increase in polyphenol oxidase according to the harvest period and the cultivars (Table 7).

Table 7. Effect of harvest period on polyphenol oxidase (PPO) activity of tubers during storage.

Harvest periods	Days after harvest (DAH)	Genotypes		
		96/1414	I070593	LMR
10 MAP	0	6.4 ± 0.3^{c}	3 ± 0.2^{g}	1.4 ± 0.2^{h}

Continued

	3	4 ± 0.5^{f}	3.2 ± 0.3^{g}	4.8 ± 0.5^{d}
	8	3.7 ± 0.1^{f}	6.9 ± 0.1^{b}	4.2 ± 0.1^{e}
	15	4.9 ± 0.5^{d}	10.3 ± 0.1^{a}	3.7 ± 0.6^{f}
12 MAP	0	0.4 ± 0.1^{h}	9 ± 0.2^{a}	2.1 ± 0.1^{f}
	3	1.6 ± 0.2^{g}	5.9 ± 0.2^{b}	4.8 ± 0.4^{c}
	8	3 ± 0.3^{e}	4.1 ± 0.3^{d}	6.2 ± 0.2^{b}
	15	2.2 ± 0.1^{f}	5.9 ± 0.1^{d}	1.7 ± 0.1^{g}

4. Discussion

Cassava postharvest physiological deterioration is a truly global challenge for cassava producers since it reduces the shelf life in cassava value chain. Investigations on response of diverse cultivars to PPD in order to discriminate susceptible to tolerant cultivars have been previously made by many authors [8] [35]. Farmers' practices such as the appropriate harvest period in relation to the cultivars need to be take into consideration since cassava can stay on the ground more than two years [36]. In this study we investigate the correlation between cultivars, agronomic parameters, harvest periods (10 MAP and 12 MAP) in response to cassava postharvest physiological deterioration. The results showed that agronomic parameters at harvest are significantly affected by harvest period according to the cultivar. Increase in tubers numbers was observed in all the cultivars from 10 MAP to 12 MAP. [36] has reported a continuity in tuber formation up to 24 MAP in cassava. The cultivar I070593 showed for almost all the parameters evaluated best performance at 10 MAP compared to LMR and 96/1414 cultivars which performed well at 12 MAP. However newly formed tubers at 12 MAP showed a decrease in tubers diameter and length compared to those harvested at 10 MAP. This could be explained by the re-assimilation of reserves in the previous formed tubers to promote the formation of new tubers at later stages of development [37]. Cultivars showed diverse response to PPD according to the harvest period. A PPD delay was observed in the tubers from I070593 the yellow flesh cassava cultivar at 10 MAP. [38] has reported a delay of more than 40 days in the implementation of PPD in three cassava cultivars with high carotene contents. The effect of carotenes as a quench of reactive oxygen species in response to PPD development was previously reported by [13]. Tubers from LMR and 96/1414 cultivars showed less susceptibility to PPD when harvested at 12 MAP. Differentially expressed levels in PPD susceptibility cassava cultivars harvested sequentially in two years was reported by [18].

The increase in total proteins content was correlated to the delay in PPD development according to the cultivars and the harvest period. Increase in total proteins content was observed in I070593 at 10 MAP while in LMR and 96/1414 at 12 MAP. Qualitative and quantitative changes in protein profiles as a mechanism of resistance to PPD development depending on the cultivars were re-

ported by many authors [7] [8]. The increase in proteins content may be due to the high activity in proteins synthesis mainly involved in cells repair as a response in PPD development as reported by [39]. The activity of peroxidase was high in I070593 at 10 MAP while in LMR and 96/1414 at 12 MAP. This suggest the scavenging of hydrogen peroxide which burst initiated PPD development [10] is more scavenging in I070593 when the tubers are harvest at 10 MAP than at 12 MAP. In fact, high activity of peroxidase were observed in tubers undergoing PPD compared to freshly harvest tubers [10].

The peak of soluble sugars was correlated to the appearance of morphological discoloration in LMR at 10 MAP and I070593 at 12 MAP. The increase in sugars content has been reported by [40] as mechanism of resistance to PPD development in tolerant cultivars. In fact, sugars promote the increase of phenylpropanoid metabolism in immature potato plants [41]. The increase in total phenolic compound was associated to an increase in PPD development at 10 MAP in LMR and 96/1414 and I070593 at 12 MAP. In addition, PPD tolerance was associated to high amount of polyphenol oxidase activity. In fact, PPD development induces the conversion of phenolic compounds into quinones which are more reactive molecules to stress [17].

5. Conclusion

This work shows that harvest time and cultivar have a significant influence on the agronomic performance of cassava cultivars at harvest as well as on their response to PPD. In addition, it provides new guidance on the appropriate harvest time which is reported for cultivar I070593 at 10 MAP and for LMR and 96/1414 at 12 MAP for better performance of tubers at harvest and less susceptibility to PPD.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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