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Effects of expanding cassava planting and harvesting windows on root yield, starch content and revenue in southwestern Nigeria

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ABSTRACT

Cassava (*Manihot esculenta* Crantz) is an important staple crop in Nigeria. It provides approximately 80 % of the caloric intake in Nigeria. High starch content and fresh root yields are important for the commercialization of cassava. Cassava is a perennial crop, and it can be produced all year round. However, cassava fresh root yield and starch content are strongly influenced by environmental conditions such as rainfall. Therefore, it is important to identify planting and harvest periods to attain maximum yields and starch content and to increase profitability. The present study aimed at (i) comparing changes in fresh root yields and starch contents of cassava planted and harvested at different times around the year (ii) identifying the cassava harvest phase attaining maximum fresh root yields and starch content (iii) assessing how price fluctuations and root yields affect the revenue and income generation across the year. This study was carried from 2017 to 2019 in southwestern Nigeria. Existing cassava fields planted at different months were visited and the planting dates were recorded. Harvesting for each planting month was done at 9, 11 and 13 months after planting (MAP). Fresh root yield and starch content varied across planting months. For all crop ages, the highest fresh root yields were recorded when planted in September and December. The highest root starch content was observed in 9- and 13-months old cassava when planted in March and November, respectively. Cassava fresh root yield and starch content varied across Julian day of harvest with lowest yields obtained between Julian day 60–120 (March and April) which coincides with the beginning of rainfall. Highest fresh root yields and starch content were attained between Julian day 180–330. Revenue showed seasonal variation and was dependent Julian day of harvest. Gross revenue was lowest between Julian day 60 and 120 (March and April) and highest from Julian day 180 (July). Lowest incomes or profits were recorded when cassava was harvested between Julian day 60 and 120 (March and April). About 9.1 % of farmers had negative revenues or lost income when they harvested at 9 MAP hence losing between 150 and 200 USD ha^{-1} compared with 2.8 % of farmers that lost income when harvesting was done at 11 and 13 MAP losing between 100 and 150 USD ha^{-1}. Thus, farmers' income generation critically depends on cassava planting and harvest dates. Choosing the right time to plant and harvest cassava is one of the most important decisions farmers can make to maximize profit.

1. Introduction

Cassava (*Manihot esculenta* Crantz) is a perennial plant belonging to the family Euphorbiaceae. It is largely grown in tropical and subtropical regions (Alves, 2002; Li et al., 2016; Wang et al., 2018). Cassava is relatively drought tolerant and has been predicted to be highly resilient to future climatic changes, which makes it an important crop for food security (Duque and Setter, 2019; Jarvis et al., 2012). It is a major source of starch and is dominantly locally processed into food items. However, it is increasingly utilized in various ways in the food and non-food industries. In the food industry it is used to produce bread, sweetening agents in confectioneries and animal feed. The non-food industries produce, amongst others, natural adhesives, coating agents for the paper industry and fabric firmer for the textile industry (Howeler, 2012; Wang

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et al., 2018). In Nigeria an estimated 30 million farmers are producing approximately 60 million tons of fresh cassava roots annually (FAOSTAT, 2020). Yet, despite being the largest cassava producer in the world, the processing industry still faces major problems of procuring sufficient amounts of roots year-round. Ugwu and Okereke (1985) reported variations in root supply to processing factory across the year with the lowest root supplies observed in January, February, April, May and August in south-eastern Nigeria. This insufficient supply may prevent processing factories from operating at maximum efficiency at certain periods in the year. Furthermore, it was reported that approximately 44 tonnes of cassava per day is required, however, due to scarcity of cassava root only 16 tonnes of roots per day are available to processors hence factories do not get enough roots for processing. To address the growing demand for households' food consumption and the processing industry there is need to investigate measures ensuring a continuous supply of cassava roots.

One option shown in researcher managed trials is an expansion of the planting and harvesting phases (Enesi et al., 2022). In Nigeria, cassava growers continue to harvest and plant cassava at the onset of rains (April-May) because of adequate soil moisture and availability of planting materials. In southwestern Nigeria, (Enesi et al., 2022) reported that cassava planted later in the year can produce more competitive cassava root dry matter yields than those planted early. In Thailand, (Janket et al., 2020) showed that when cassava was planted late (October and December) starch content and yields were higher than when planted early.

Cassava fresh root yield and starch content are fluctuating with changes in rainfall. Water shortage at early growth stages or at the end of the growing season can reduce yields and starch content in cassava roots (Moreno and Gourdji, 2015; Santisopasri et al., 2001). The starch in mature storage roots is remobilized for the expeditious production of new leaves at the onset of rains, which reduces starch content (El-Sharkawy and Cock, 1987). In contrast, during drought, a fully developed cassava plant will reduce its canopy growth by shedding its leaves, however, translocation of starch to storage root continues and maximum dry matter partitioning to storage root is achieved thus preventing starch reduction in the roots (Alves, 2002; Sriroth et al., 1999). In Thailand, 10 months old cassava, harvested shortly after the beginning of the rainy season after drought, had lower starch contents in storage roots when compared with 14 months old cassava (Sriroth et al., 1999). Similarly, (Mtunguja et al., 2016) in a study conducted in Tanzania obtained highest starch content at 12 MAP, when harvesting before the rainy season, while starch content was lowest at 15 MAP, shortly after the onset of rains, because stored carbohydrates were used for the synthesis of new leaves. Seasonal patterns of fresh root yield, starch and dry matter content have been reported by (Howeler et al., 2007; Sagrilo et al., 2003a, 2003b), with higher fresh root yields obtained when cassava was planted early in the rainy season, irrespective of crop age at harvest, while higher starch contents were observed in when cassava was harvested in dry phases.

Different studies have attempted to determine the optimum crop age for harvesting cassava, but variations exist in their recommendations (Benesi et al., 2007). In south-west Nigeria, Kayode (1983) showed that starch content in cassava roots declined when crop age was prolonged beyond 18 MAP. Wholeya and Booth (1979) found no notable decline in cassava root starch content with increasing crop age at harvest. Alves (2002) stated that maximum dry matter (DM) and starch accumulation in storage roots can occur between 6 and 10 MAP. However, this is also dependent on variety because some varieties can attain maximum dry matter accumulation at 6 MAP and others at 12 MAP (Adjebeng-Danquah et al., 2016). Chipeta et al. (2016) observed that there is no specific maturity time for cassava, implying that the harvest can be scheduled for periods when prices are high. For all 16 varieties tested there was an increase in yields with prolonged crop ages and the highest yields were attained with Mulola variety with yields ranging from 9.3 t ha^{-1} when harvested at 6 MAP to 27.9 t ha^{-1} when harvested at 12 MAP. Generally, cassava initiates the formation of storage roots between 60 and 90 days after planting (DAP) and storage roots continue to bulk from 90 to 180 DAP with high rates of carbohydrate translocation to storage root occurring between 180 and 300 DAP and maximum dry matter partitioning to the roots attained between 300 and 360 (Alves, 2002). Furthermore, starch quality is also influenced by variety, crop age at harvest and rainfall. Sriroth et al. (2001) reported that the peak paste viscosity of starch extracted from cassava roots harvested shortly or immediately after a prolonged dry period is always lower than that of starch extracted from cassava roots harvested in dry periods. Teerawanichpan et al. (2008) in a study conducted in Thailand for varieties KU50 and R1 observed that the size of starch granules increased with increasing crop age. Also, variations in amylose content in relation to planting periods was dependent on variety, such that amylose content of R1 increased consistently when planted in the rainy season and was stable when planted in the dry season while amylose content of KU50 irrespective of planting date decreased with crop age. The harvest time at 12 MAP in Nigeria, of cassava planted early (April-May), usually coincides with the transition from dry to rainy season (March-April) and in this phase, starch content declines because a new canopy is grown, using starch from the roots. The fact that many farmers harvest concurrently creates a saturated market in March, April, and May, causing root prices to become unattractive to farmers, while the roots are unattractive to processors due to their low starch content. Furthermore, it is possible that in these phases post-harvest losses increase if harvested roots do not find buyers.

In Nigeria, some production constraints have hampered the commercial expansion of the cassava sector, such as unavailability of planting material of improved varieties, farmers' reluctance to invest in fertilizer and the high cost of mechanized farm services. Maintaining a low input approach renders the cassava production system inefficient (Koyama et al., 2015).

Many studies have explored factors impacting prices of crops such as soybean, maize and sugarcane but little consideration has been given to cassava, despite its relevance (Treesilvattanakul, 2016). Cassava root prices are extremely unstable. For this reason, it is crucial to investigate different pricing scenarios in which farmers can maximize profit (Psaltry and Ltd, 2018). Cassava prices and availability vary seasonally because production tends to go through cycles of glut and scarcity, which is problematic for processors and farmers (Koyama et al., 2015; Treesilvattanakul, 2016). Singvejsakul et al. (2021) also reported in Thailand that other factors such as government policies and foreign exchange rates can affect cassava root price volatility. Starch prices peaked at $540/t when supply of roots was limited and was as low as $315USD/t in phases of high supply (Newby and Thuy, 2018). The reduction in supply was linked to a reduction in cultivated land area due to unattractive root prices in the preceding year, flooding and diseases (Newby and Thuy, 2018). A study conducted in Columbia by (Moreno and Gourdji, 2015) looking at seasonal fluctuations in starch content versus rainfall, showed a seasonal pattern in starch content but did not report price fluctuations over the study period. There is a dearth of information on seasonal variations in cassava root and starch prices in Nigeria.

Farmers need easy to follow science-based guidance to support their decisions on how to schedule their cassava planting and harvesting to generate higher incomes. This study was conducted to verify results obtained in researcher managed trials in farmers' fields, using existing cassava fields, that were planted all year round and managed by staff of two large scale cassava processing companies and their contract farmers. We also used data on starch content from the starch factory provided across the year. The study aimed to (i) compare changes in fresh root yields and starch contents of cassava planted and harvested at different times around the year. (ii) identify the best phase to harvest cassava to attain maximum fresh root yields and starch content. (iii) assess how price fluctuations, root yields and starch content affect the gross- and net revenue across the year.

2. Materials and methods

2.1. Study areas

The study was conducted in Oyo state, a leading cassava producing area in Nigeria. Within Oyo state, we focused on Niji-Farms (Kajola local government area) and Psaltry-Farms (Iseyin local government area) (Fig. 1), where cassava is planted and harvested year-round. Both farms have industrial processing factories and process the entire harvest from their own land. Average rainfall in Oyo state is approximately 1200–1600 mm per year with a bimodal distribution, allowing for expansion of planting dates throughout most of the year. To estimate rainfall throughout the growing season, the meteorological data for the years 2017–2020 were obtained from Climate Hazards Group Infrared Precipitation (CHIRPS, 2020). The first rainy season starts in April and lasts to the end of July, followed by a dry period in August. The second rainy season lasts from early September to mid-November, followed by a dry season from December to the end of March. The amount of rainfall received by each crop planted in a particular month, was calculated as the sum of monthly rainfall amounts from the first day of the planting month to the end of the 9th, 11th, and 13th month after planting (Fig S1, supplementary information). The mean annual temperature is 30 °C. Soils are predominantly sandy. Niji-Farms have about 400 ha of cassava at any time of the year. Psaltry-Farms has about 1000 ha of cassava at any time of the year and many out-growers, who produce cassava under a contract for the Psaltry-Farms processing facility on their own land. Paltry-Farms supports the out-grower cassava production with tractor services and loans for inputs. Farmers are typically entrepreneurial, use hired labour and dominantly sell roots to Psaltry-Farms or other nearby processing factories, however the crop is mostly grown with little external inputs. Data were collected between 2017 and 2019. All crops were grown under rainfed conditions.

2.2. Selection of fields and sampling plots

The approach was to select fields of at least 0.75 ha, planted with variety TME419, the most common variety planted in the area and recording the planting dates. Technicians visited farmers through the year to identify a maximum of fields planted in different months over the longest possible phase to attain a situation in which cassava would be harvested in every month of the year. The harvesting dates at 9, 11 and 13 MAP dates were calculated for all fields and in each field 3 sampling plots were delineated. The sampling plot size was 39.2 m^2 and 49 cassava pants were harvest per plot at a spacing of 1 m × 0.8 m which is the recommended planting density of 12,500 ha^{-1}.

2.3. Data collected at harvest

At harvest the net sampling plot plants were uprooted, the roots cut from the planning stake and cleaned of attached soil. The roots considered fit for processing and those unfit for processing (diameter <2 cm, too small [<120 g estimated], misshaped, rotten) were counted and weighed separately. Of the fit for processing roots a sample of 5 kg was taken to determine starch content by the gravimetric method. The starch content of the roots was calculated using the formula of (Fukuda et al., 2010):

$$\text{Fresh root} Starch \quad Content = \frac{SG - 1.00906}{0.004845}\%$$

The specific gravity (SG) was calculated as

$$SG = W0/(W0 - (Wu + BC))$$

Where:
W0 = weight of the cassava sample in air.
Wu = weight of the cassava sample under water.
BC = nylon net compensated weight (BC = weight in air – weight under water).

2.4. Factory root starch content data

The processing factory of Psaltry-Farms is paying for cassava roots by the starch content and has been collecting data on starch content of

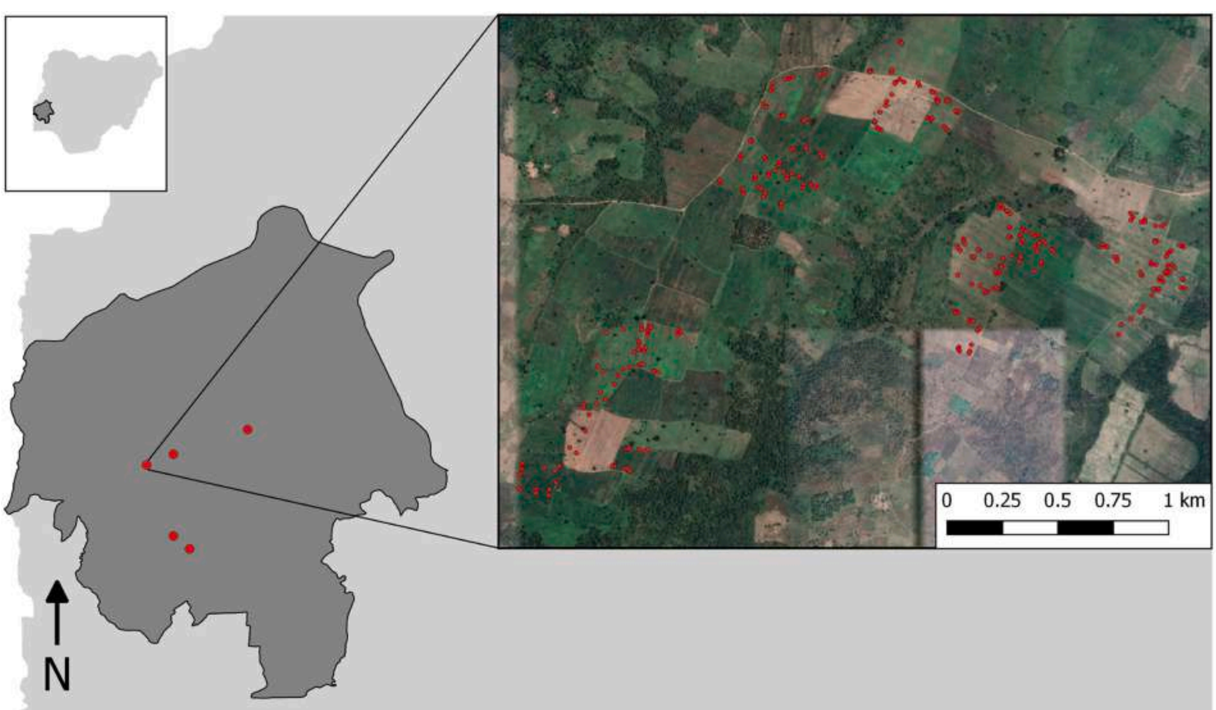

Fig. 1. Map of Nigeria showing Oyo state and the study area in Kajola and Iseyin local governments in Oyo state. Red dots on the Oyo map indicate locations of fields in which sampling plots were delineated and red dots on the satellite image indicate plots that were harvested.

cassava roots delivered by farmers for the purpose of adjusting the root prices. As a result, the factory holds a large dataset of starch contents of roots delivered at different times throughout the year, determined with the gravimetric method. For this study, Psaltry-Farms released the data of several years; these were digitized and the starch content data over time as date of delivery, were used to compare with the data obtained in our field measurements.

2.5. Production cost and root price data collection

We conducted interviews with a total of 73 farmers to obtain data on root prices and production costs between 2017 and 2020. Key production costs such as for ploughing, planting, weeding and harvesting and others relevant to cassava production were collected. Farmers in Oyo state were asked to recall the fresh root prices of cassava per tonne between 2017 and 2020, and the price of weeding, ploughing and harvesting per hectare. Fresh root prices obtained from farmers were used to calculate revenue based on yield. Root prices are averages for Oyo state and can differ between markets within Oyo and from those in other states in Nigeria.

2.6. Gross- and net revenue calculations

The gross and net revenues were calculated based on fresh root prices. The gross revenue was calculated as a product of the average root yield within a month and crop age and the average fresh root price of the corresponding month. The net revenue was calculated as gross revenue minus the cost of production. The percentage of negative net revenue was calculated by counting the number of negative values for each crop age divided by the total number plots and multiplied by 100.

2.7. Field management

Field sites were mostly flat, and most of the fields had been cropped over several years to cassava before they were used to collect the yield data. Before planting, most farmers slashed the previous vegetation, dominantly weeds of the previous cropping phase. Where vegetation was short and sparse it was directly incorporated into the soil by ploughing. Fertilizer was not applied due to the high cost. Very few farmers used herbicides before planting their fields. Weeding during the cropping phase was mainly done manually. The differences in crop management can be attributed only to farmers effectiveness and availability of labour. Only monocrop cassava fields were considered in yield assessment.

2.8. Data analysis

The R software version 3.6.0 was used for all statistical analysis (R Core Team, 2020). Multiple comparisons based on post-hoc Tukey tests, were done using R statistical computing language to assess significant difference between planting months and crop ages for fresh root yield and starch content. The distribution of fresh root yield and starch content at different crop ages were also investigated. A simple financial analysis was done to evaluate the profitability of scheduling planting and harvest throughout the year by calculating the net revenue as the difference between the gross revenue and the cost of production for each month throughout the year. Relationships between net revenue, starch content and fresh root yield with Julian day of harvest were analysed using polynomial regressions. Cumulative probability was used to determine the percentage of farmers who lost income due to the choice of the day of harvest. Figures for data visualizations were made using ‘ggplot2()’ data visualization package in R.

3. Results

3.1. Rainfall conditions

The rainfall pattern in the four years were similar (Fig. 2). Rains mostly commenced in March and ended in November. The heaviest rainfall was observed in June 2017 (196 mm), September 2018 (237 mm), October 2019 (280 mm) and October 2020 (355 mm). Total rainfall in the four years was 2017 (910 mm), 2018 (1293 mm), 2019 (1491 mm) and 2020 (1126 mm).

3.2. Cassava fresh root yield

Cassava storage fresh root yield varied significantly between the planting months in each crop age (Fig. 3 A). For all crop ages, fresh root yields were higher when planted late (September and December). Increasing crop age increased yields regardless of planting month. At 9 months crop age, fresh root yields did not differ significantly when cassava was planted in April and October. Also yields did not differ significantly between cassava planted in June and August. The lowest yields were observed when cassava was planted in August (7.5 t ha^{-1}) and in June (9.7 t ha^{-1}). Significantly higher yields of 9 months old cassava were observed when planted in December (24.9 t ha^{-1}) and September (22.6 t ha^{-1}). At a crop age of 11 months, root yields were significantly lower when planted in June (16.8 t ha^{-1}) than when planted in March (19.5 t ha^{-1}), April (19.3 t ha^{-1}), July (18.2 t ha^{-1}), August (23.2 t ha^{-1}), September (37.6 t ha^{-1}), October (21.8 t ha^{-1}) and December (37.1 t ha^{-1}). Similar yield trends over the year were observed in 13-month-old cassava, with highest root yields attained when planted in September (42.8 t ha^{-1}) and December (28.8 t ha^{-1}), however, yields did not differ significantly between cassava planted in all other months. Cassava fresh root yields were significantly affected ($p = 0.001$) by the Julian day of harvest with an of $r^2 = 0.08$ (Fig. 4A). High cassava root yields were attained when harvesting between Julian day 240 and 300 (September and October). Lowest yields were attained when harvesting between Julian day 60 and 90 (in March) (Fig. 4A). At 9 MAP, most yield values were between 0 and 20 t ha^{-1}; at 11 and 13 MAP, most yield values were between 20 and 40 t ha^{-1} (Fig. 5A).

3.3. Cassava starch content

Cassava starch content was significantly affected by planting month and crop age (Fig. 3B). At 9 MAP, root starch content attained when planted in March (29.7 %) was significantly higher than when planted in April (23. 6 %), June (16.8 %), July (18.2 %), August (19.8 %), September (21.8 %), October (22.2 %) and December (20.5 %). The lowest starch content was observed when cassava was planted in June (16.8 %). In 11-months old cassava, the lowest starch content was found when planted in April (17.6 %), significantly different from all other planting months. Planting after April caused higher starch contents, reaching a maximum when planted in September (25.7 %) and October (25.1 %). At 13 MAP, cassava root starch content determined in our field study was significantly lower in cassava roots when planted in March (18.3 %) and April (19.1 %) than when planted in all other months except December. Highest starch contents were attained when planted in November (29.9 %). (Fig. 3B). The starch content was lowest in cassava roots when harvested between Julian day 60 to around 120 (March and April) (Fig. 4B & C). Thereafter starch content increased up to around Julian day 300 (end of October) (Fig. 4B & C). Cassava root starch content determined in our field study was significantly correlated with the Julian day of harvest and could best be described by a third order polynomial function ($r^2 = 0.24$; $p = 0.001$) (Fig. 4B). The Psaltry-Farm factory starch content data followed the same pattern yet had a closer correlation with the Julian day of harvest or delivery ($r^2 = 0.88$; $p = 0.001$) (Fig. 4C). Most starch content values when harvested at 9 and 13 MAP were between 20 % and 25 %; when harvested at 11 MAP

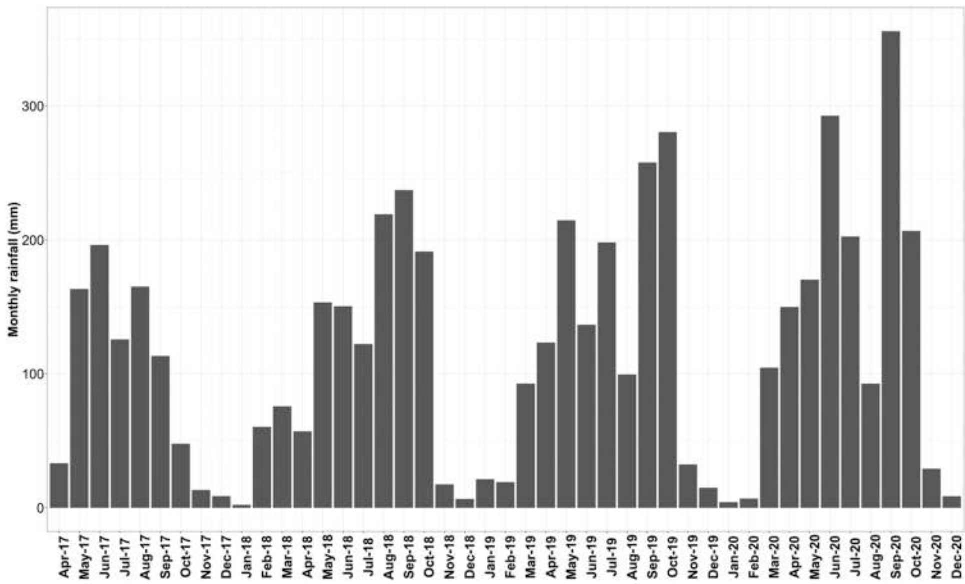

Fig. 2. Total monthly rainfall in field sites from April 2017 to December 2020.

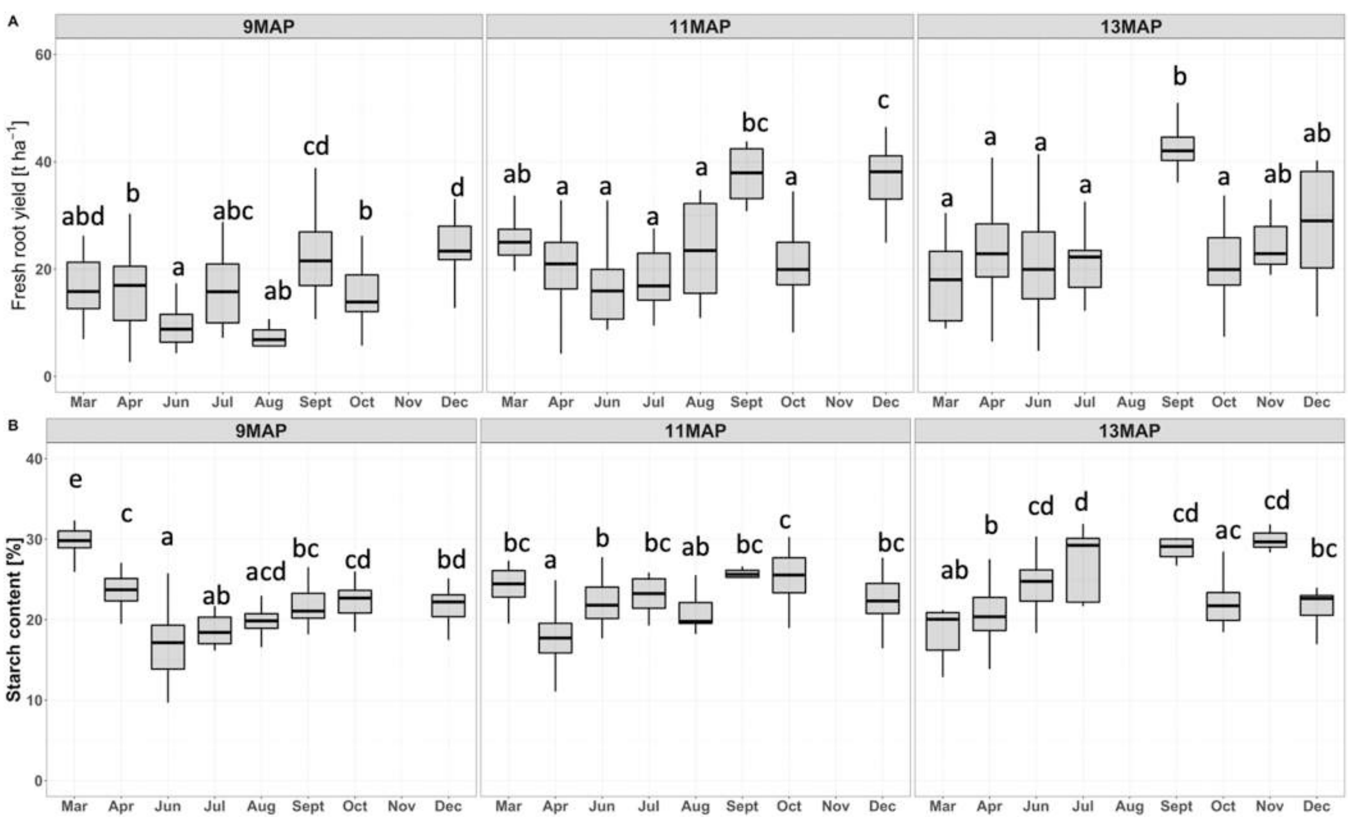

Fig. 3. A) Cassava fresh root yield (t ha^{-1}) as affected by planting month (March-December) and crop age (9, 11 and 13 Months After Planting (MAP). B) Cassava starch content (%) as affected by planting month (March-December) and crop age (9, 11 and 13 MAP). Boxplots with the same letter do not differ significantly by Tukey HSD post hoc tests. The horizontal line in the middle of the box is the median yield or starch content value and the lower and upper boundaries indicate the 25th and 75th percentiles, respectively. For all crop ages, there are no fields planted in the months of January and February hence no data presented. Note: 9- and 11-months old cassava fields planted in November were not available for harvest and 13-month-old cassava fields planted in August were also not available for harvest hence missing in the graph.

most values were between 15 % and 25 % (Fig. 5B).

3.4. Monthly price variation across the year (USD per ton)

Cassava fresh root prices varied across months (Fig. 6). The highest root prices were observed in February (52.2 USD/t) and June (53.6 USD/t) and the lowest prices in April (28.1 USD/t) and May (35.1 USD/t).

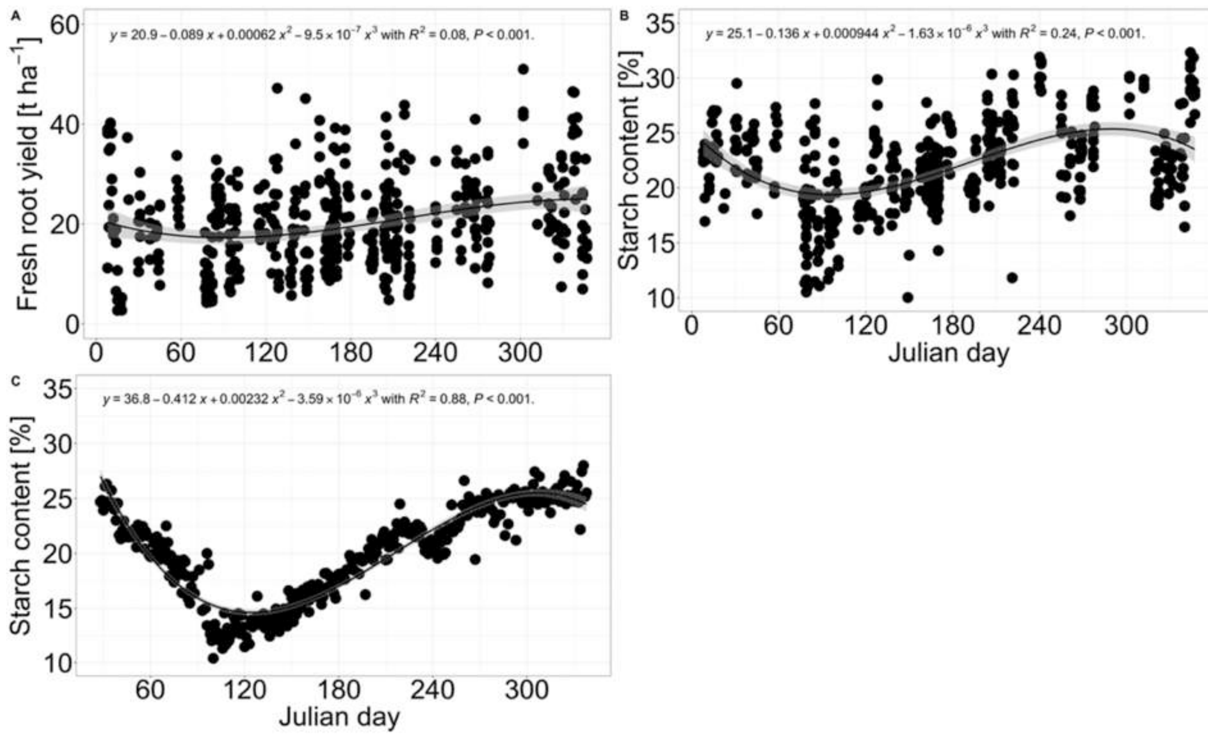

Fig. 4. A) The effect of Julian day on cassava fresh root yield (t ha^{-1}) B) The relationship between the Julian day of harvest and the cassava starch content (%) on farmer's field C) The relationship between the Julian day of delivery to the Psaltry-Farms factory and the cassava starch content (%). Note: cassava roots are generally delivered within 2 days after harvest.

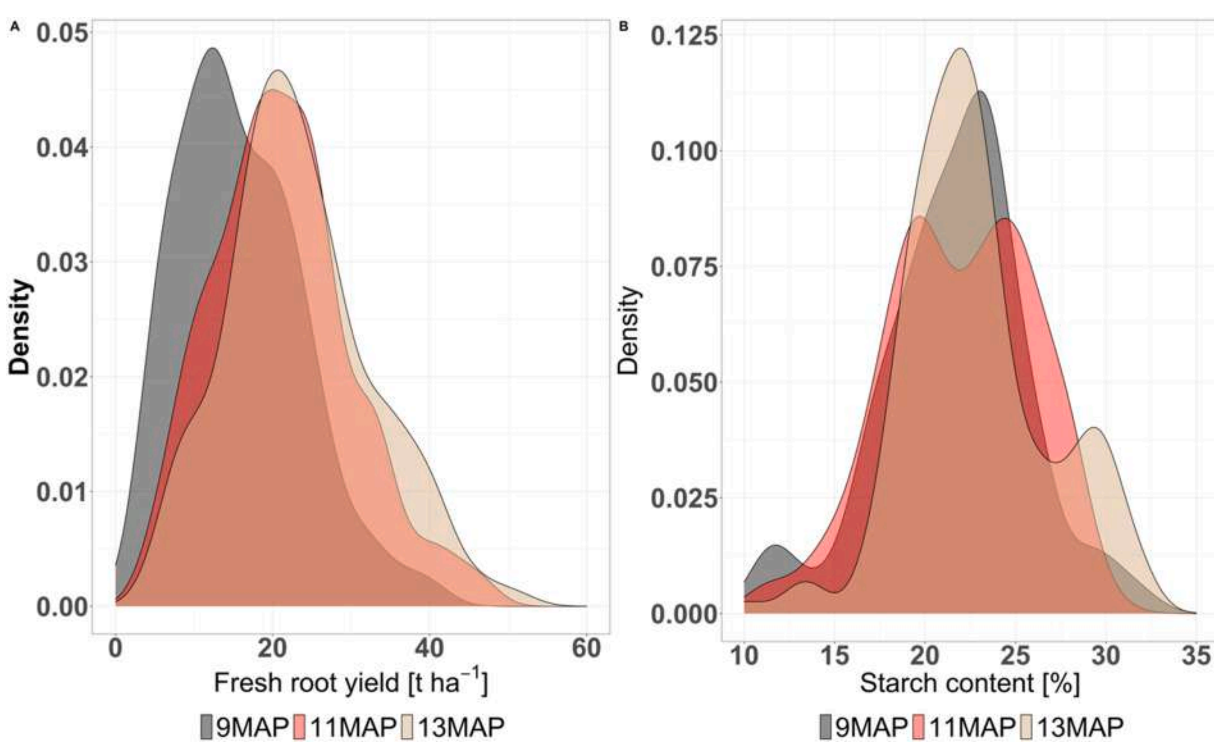

Fig. 5. (A) The distribution of cassava fresh root yield (t ha^{-1}) and (B) distribution of starch content (%) as affected by crop age at harvest (9, 11 and 13 months after planting).

3.5. Gross revenue USD ha^{-1}

Gross revenue varied across Julian day of harvest due to changes in cassava fresh root yield and root prices (Fig. 7A). Lowest gross revenue was observed when cassava roots were harvested between Julian day 60 and 120 (March and April). From Julian day 180 (July) net revenues started to increase (Fig. 7A). Harvesting at 9 MAP significantly reduced gross revenues ($p = 0.01$) and produced the lowest gross revenues

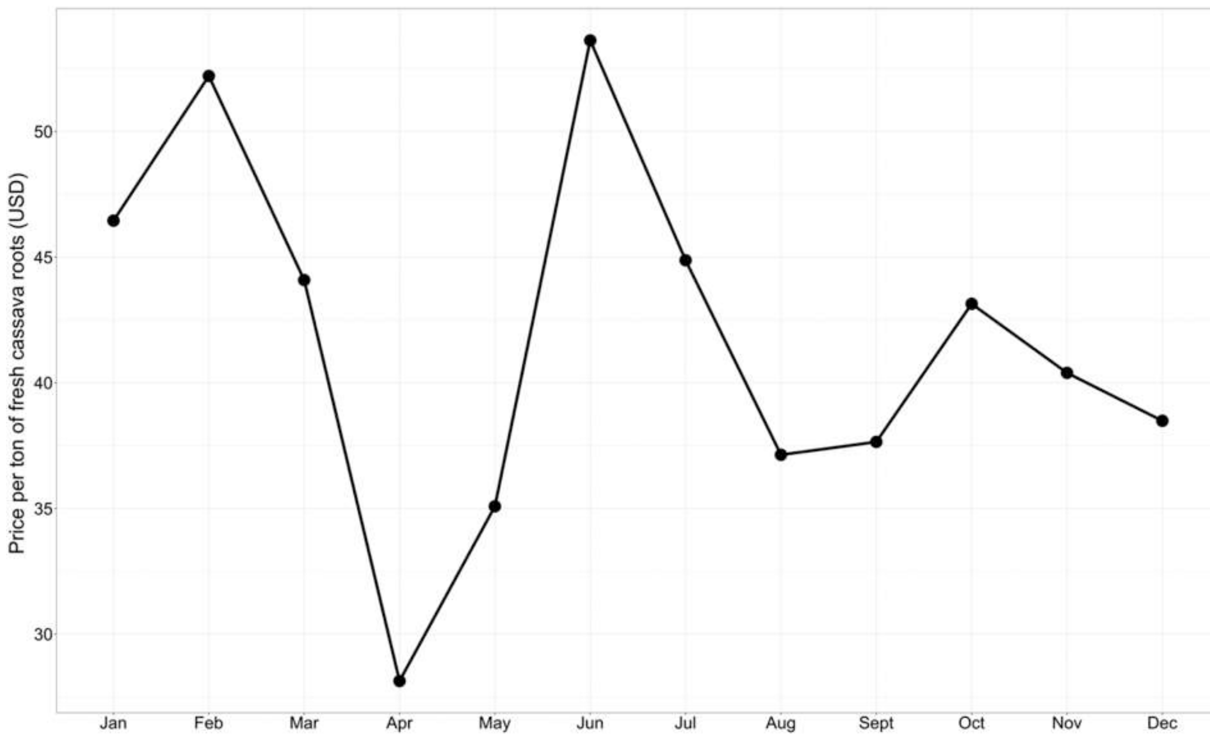

Fig. 6. Cassava fresh root price in (USD ha^{-1}) as affected by harvest month (January-December).

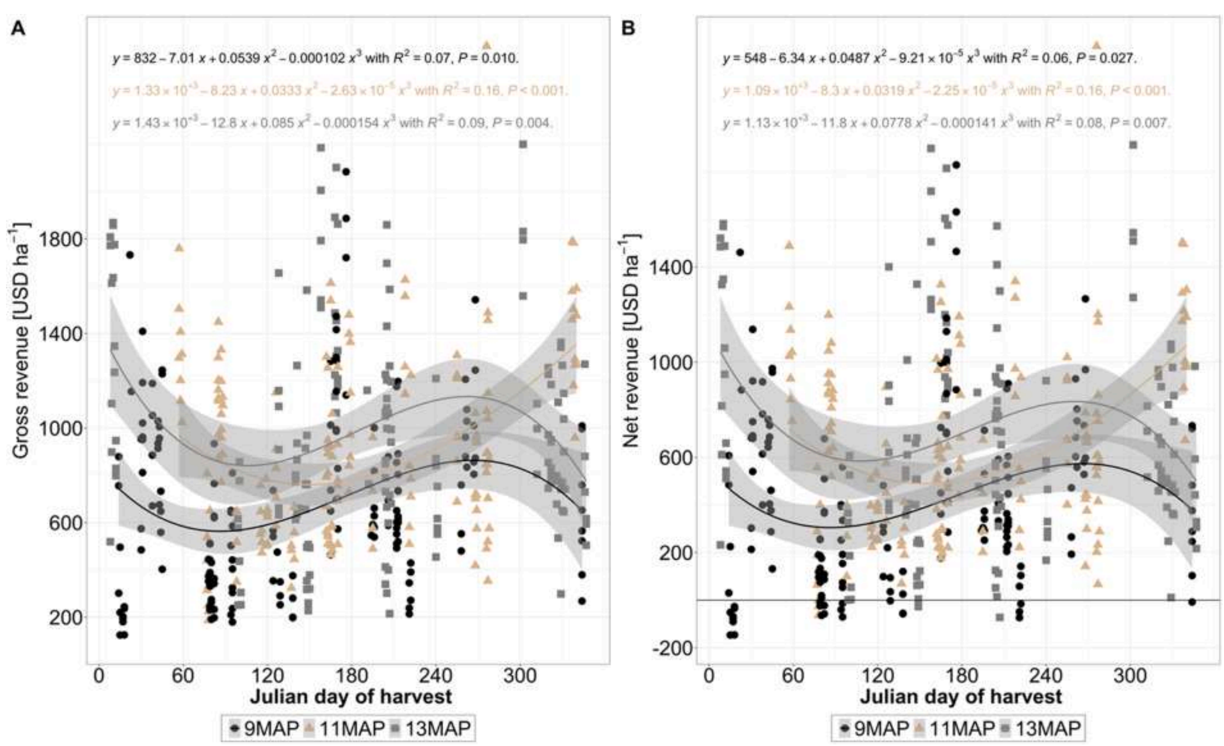

Fig. 7. A) The relationship between the Julian day of harvest and cassava gross revenue based on fresh root yield (USD ha^{-1}) when harvested at crop ages 9, 11 and 13 Months After Planting (MAP). (B) The relationship between the Julian day of harvest and net revenue based on fresh root yield (USD ha^{-1}) when harvested at crop ages 9, 11 and 13 Months After Planting (MAP).

accounting for 7 % of the variation. While harvesting at 11 MAP also significantly affected gross revenues ($p = 0.0010$) accounting for 16 % of the variation. Harvesting at 13 MAP produced the highest net revenues ($p = 0.004$) accounting for 9 % of the variation observed.

3.6. Net revenue USD ha^{-1}

Net revenue varied across the Julian day of harvest for all crop ages (Fig. 7B). Lowest net revenue was observed when cassava roots were harvested between Julian day 60 and 120 (March and April). From

Julian day 180 (July) net revenues started to increase (Fig. 7B). Harvesting at 9 MAP significantly reduced net revenues ($p = 0.02$) and produced the lowest net revenues accounting for 6 % of the variation. While harvesting at 11 MAP also significantly affected ($p = 0.001$) net revenues accounting for 16 % of the variation. Harvesting at 13 MAP produced the highest net revenues ($p = 0.007$). Negative net revenues were calculated for 9.1 % of the cases when cassava was harvested at 9 MAP (9.1 %) and for 2.8 % when harvested at 11 MAP and 13 MAP (Fig. 8).

4. Discussion

4.1. Effects of planting month, Julian day of harvest and crop age on starch content and fresh storage root yields

The cassava sector in Nigeria has a substantial potential for industrialization if production in sufficient quantity is delivered uninterrupted all year round (Koyama et al., 2015). To achieve a constant supply, the cassava planting and harvesting windows must be expanded throughout the year. Higher fresh root yields and starch contents were observed with late planting months in this study (Fig. 3 A&B). This agrees with earlier studies of cassava storage root yields and starch content reported by (Janket et al., 2020) and (Enesi et al., 2022). As observed in our study, (Janket et al., 2020) reported that water stress at early growth stages did not adversely affect storage root yields and starch content. They reported that under rainfed conditions cassava storage root yields and starch content can be increased by planting late in the rainy season (October-November) when growing conditions were favourable and under good management. Another study by Phoncharoen et al. (2018) revealed that planting date significantly affected storage root dry matter with CMR38–125–77 variety producing higher storage root dry matter when planted in May, June, October and November and lowest when planted in April. However, there are studies reporting higher yields when cassava is planted early in the season (Akhtar et al., 2013), yet such results were from environments with different climatic conditions and other varieties. Howeler (2007) reported that in tropical regions with bimodal rainfall patterns, planting late or at the onset of the second rainy season will produce high yields because plants would have established well in the last months of rains, with gradual growth in dry periods and a continuous rapid growth in the later raining season. In this study, cassava planted late received sufficient rainfall before the dry season to fully establish. Apparently, any water shortage encountered by relatively young cassava at early growth stages when planted between September to December was not detrimental to final root yield formation and starch content.

In this study, fresh root yield and starch content reductions were observed when cassava was harvested between day 60 and 120 (March and April), which coincides with the onset of rains after a 3–4 months long dry season and the formation of a new canopy. Similar storage root yield reductions at the onset of rains were reported by (Sriroth et al., 2001). Fresh root yields and starch content started to increase after Julian day 120 to reach a maximum around Julian day 330 (end of November), which shows that starch synthesis and accumulation in storage roots commences after the recovery of the canopy, leading later in the growth period to high starch contents and root yields. Cassava grows continuously, yet has different phases of vegetative growth, sink formation, carbohydrate accumulation in and mobilization from roots as well as phases of dormancy caused by drought (Alves, 2002). This study shows that cassava can be planted at any time in the year if soil moisture is sufficient to allow the crop to establish. However, farmers should avoid harvesting cassava in periods that coincide with the commencement of rains after long dry seasons. As in our study, (Bakayoko et al., 2009) and (Adjebeng-Danquah et al., 2016) stated that increasing crop age of cassava had a major positive effect on storage root yield and starch content. They reported significant storage root yield increases as crop age increased between 12 and 18 MAP, when cassava was planted in June and September in southern Côte d′Ivoire for 14 different improved varieties, which has a similar rain regime as southern Nigeria. (Adjebeng-Danquah et al., 2016) reported higher fresh storage root yield when crop age was increased from 6 to 12 MAP for 20 different varieties in Ghana. In addition, Enesi et al. (2022) in researcher managed trials conducted in southwestern Nigeria also observed higher dry matter root yields with increasing crop age from 9 to 13 MAP for TME419 and TMS581. As observed in our study, Sagrilo et al. (2003a), (2003b) in a study conducted in Brazil with five different varieties, reported an increase in starch content in cassava root yields when crop age was increased up to 21 MAP. However, they observed a reduction in starch content during periods of regrowth of vegetative parts of cassava plants. In addition, (Adeola et al., 2020) reported prolonging the crop age at harvest between 12 and 18 MAP had a significant effect on the proximate composition of cassava storage roots. However, it is imperative to note that increasing crop age may not always lead to higher cassava root yields and starch content if the time of harvest in the year is inappropriate, i.e., coincides with periods of canopy regeneration. There is a strong correlation between starch and dry matter content in cassava storage roots (Fukuda et al., 2010). This study shows that high starch contents can be attained as early at 9 MAP, such as when cassava was planted in March and harvested at 9 MAP in January. In such cases

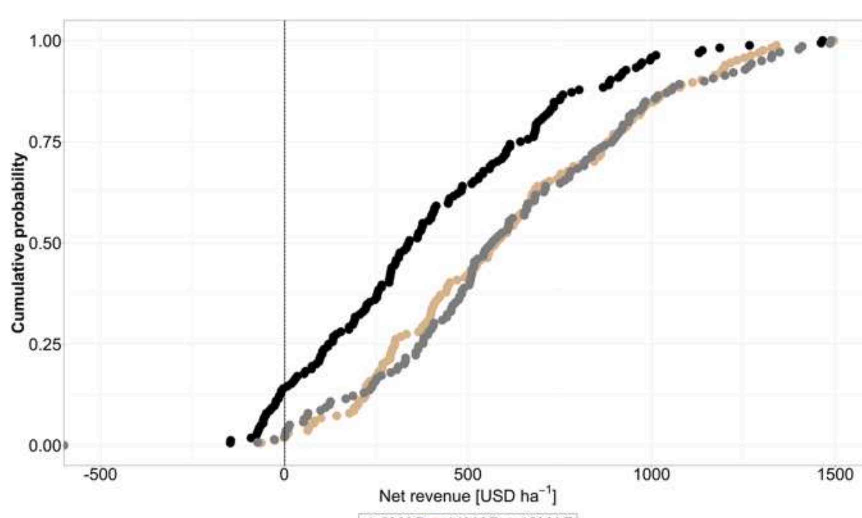

Fig. 8. The cumulative probability of the net revenue based on fresh root yield (USD ha^{-1}) when harvested at crop ages 9, 11 and 13 Months After Planting (MAP).

starch content at 9 MAP was higher than at other crop ages. If harvesting of storage roots coincides with a physiological state of dormancy (rest phase) of the crop, after a long rainy season, Sagrilo et al. (2003a), (2003b) reported that the physiological resting period signifies the optimum harvest time, due to high storage root starch accumulation and dry matter content. Studies by Enesi et al. (2022) have shown that TME419 is an early bulking i.e., partitioning of dry matter into storage roots occurs early. Early bulking varieties have been known to sustain vegetative growth and storage root bulking concurrently (Okogbenin et al., 2013) hence such a variety as can attain high starch content at 9 MAP. Furthermore, factors such as poor field management and soil fertility can significantly influence cassava storage root yields. In studies conducted by (Kintché et al., 2017) in Kongo central and Tshopo of the DR Congo, poor soil fertility accounted for 6.2 t ha^{-1} fresh root yield reduction and poor field management resulted to 5.5 t ha^{-1} fresh root yield reduction in Kongo central while in Tshopo poor soil fertility accounted for 4.5 t ha^{-1} fresh root yield reduction and poor field management resulted to 6.5 t ha^{-1} fresh root yield reduction. Hence farmers must take into consideration good management practices and different soil replenishment strategies to account for mining of nutrients caused the continuous harvesting of cassava. Differences in management practices such as weeding, tillage, quality of planting and soil fertility status across fields may have strongly contributed to the variability observed in the dataset from this study (Fig. 4A & B) hence the reason for the low r-square observed as these factors influences yields. A good understanding of the variations of starch content across the year can guide farmers' decision on best harvest dates for high starch contents and yields. Most farmers may be reluctant to harvest in dry periods because soils are hard, and they would face difficulties in harvesting, although starch contents are high. Farmers are aware that they would likely have more frequent root breakage, causing yield losses or additional labour to recover root pieces. They would as well lose all cassava stems as planting materials because the time may not be suitable to plant. Thus, the root prices would need to be sufficiently high to compensate for additional labour cost and root losses. Decision making by farmers on the appropriate date of the cassava harvest would therefore require good estimates of the expected fresh root yield, the root starch content, and eventual additional costs for additional labour to harvest under dry conditions. The cropping calendar, management and provision of planting materials may need to be adjusted to ensure farmers have access to quality planting material whenever they need to plant.

4.2. The effect of the harvest date on gross- and net revenue

In this study, the changes in gross- and net revenue across the year showed a seasonal pattern. We observed that the lowest gross and net revenues were obtained between Julian day 60 and 120 (March and April) (Fig. 7A & B). In March and April most farmers harvest cassava and cause a glut driving the prices down (Fig. 6). Industrial processors are not keen on the roots harvested in March and April due to their low starch content, which renders the processing less efficient than at high starch contents. Similar trends were observed in Thailand (Treesilvattanakul, 2016), where low cassava root prices were observed in June and July, which coincided with period of low starch content. Therefore, in Nigeria, unless farmers are desperate for money, it is not advisable to harvest and sell or process roots in March and April. Farmers can delay the harvest until after April to take advantage of additional root yield through a longer growing phase, higher starch contents and potentially higher root prices (Fig. 6). Ezedinma et al. (2007) reported that seasonal fluctuations in root prices are typical in Nigeria and that root prices are lower in the rainy season because the cost of harvesting is low due to ease of harvest. Nevertheless, there is still a dearth of quantitative data on seasonal cassava root price fluctuations and the net revenue cassava farmers can attain across the year in Nigeria.

Cassava production is labour intensive and many activities such as land clearing, soil tillage, planting, weeding, and harvesting cause high production cost (Hoback et al., 2015). In this study, after accounting for production costs, more farmers would have lost income when cassava was harvested at 9 MAP (Fig. 7 A&B). According to our results, it is riskier for farmers to sell cassava roots when harvesting between March and April, and also at a crop age of 9 MAP (Fig. 8). However, the risk of negative net revenues was much lower when harvesting later in the year and at higher crop ages. The perpetual variation in the price of fresh storage roots can be linked to supply and availability of cassava roots (Fig. 6).

Generally, farmers boost production when prices are attractive to leverage higher margins, however, they forget that it takes about one year before the cassava will be ready for the market, at which time it causes an oversupply of roots causing prices declines. When root prices are low, fewer farmers cultivate cassava, resulting in lower production in consecutive seasons and sooner or later insufficient supply, which causes higher prices (Koyama et al., 2015). Over the years FAO has reported annual fluctuations in cassava root prices has been reported by Food and Agric in Nigeria, however for farmers and processors to plan production and processing schedules they need to understand seasonal fluctuations of prices and yields within the year. From our study, rainfall conditions allow for a year-round production in Nigeria, hence farmers should aim at phases or periods within the year where buyers e.g., processors offer high prices to generate more income. According to (Hoback et al., 2015) processors change prices more frequently and rapidly as a response to the availability of cassava roots in the market, exposing farmers to a higher risk of low net revenue, while traders' price offers are usually more stable. If factories want to realize a year-round consistent supply in sufficient quantity, then good price incentives need to be offered to farmers to harvest outside conventional windows (March and April). Hence there are some factors that need to be considered if profitability is expected to increase: (i) consider the month in which you intend to plant and the age of the crop when you intend to harvest; (ii) farmers should only sell when roots are harvested at the end of rainy season or before the start of the rains and avoid harvesting between March and April (beginning of rainy season) in Nigeria, (iii) prices are based on demand, so it may be beneficial to delay harvesting if you expect higher prices later in the year.

5. Conclusion

Our results show that variations in cassava starch content and fresh storage root yield and root prices exist across the year. The currently common practice in Nigeria of planting early (March and April) does not always produce higher yields and starch contents. The higher yields attained when harvesting outside conventional phases combined with price fluctuations, shows that there is ample opportunity to increase gross and net revenues. In Nigeria, there is a possibility for the commercialization of cassava that would benefit farmer if planting and harvesting schedules are properly planned. Farmers that are willing to harvest in dry phases will benefit from high root prices and this will benefit farmers that are financially constrained. Research should further focus on providing technical solutions associated with harvesting in dry phases when yields and starch contents are high. However, famers should avoid harvesting at 9 MAP because it produced lower yields, gross revenues and net revenues. Finally, the decision on the best time to harvest cassava should consider market price, labour availability and environmental conditions at the time of harvest.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fcr.2022.108639.

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