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Influence of Time of Harvest and Variety on the Pasting Properties of Starch from Three Cassava Varieties- A Response Surface Analysis

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Authors' contributions

This work was carried out in collaboration between both authors. Author MOI designed the study, author ANA carried out the bench work, performed the statistical analysis, wrote the protocol and the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: Three cassava varieties TME 419, TMS 30572 and TMS 98/0505 were harvested at three months interval from maturity- 10, 13 and 16months. The aim was to optimize and determine the influence of experimental variables – time of harvest and cassava variety on their pasting properties.
Study Design: Starch was isolated from the cassava varieties at each harvesting regime and their pasting properties were determined using Rapid Visco Analyser.
Place and Duration of Study: Cassava tubers were obtained from National Research Institute, Umudike Abia State, starch was isolated at the Biochemistry Laboratory of National Research Institute, Umudike and the pasting work was done at Central Laboratory of the University of Ibadan, Oyo State.
Methodology: Sixteen experimental runs were generated. Center point was replicated seven times. Star and corner points were not replicated. Data obtained were subjected to response surface

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analysis. Optimization was done using optimization toolbox of Matlab r2012a software.
Results: Peak viscosity ranged between 5946RVU (TMS 98/0505-16 months) and 7327RVU (TME 419-13 months). Trough ranged between 2200RVU (TMS 30572-13 months) and 3463RVU (TMS 30572-10 months), Breakdown between 2878RVU(TMS 98/0505-16 months) and 4689RVU(TME 419-13 months). Final viscosity ranged from 3068RVU (TME 419-16 months) to 4154RVU (TMS 30572- 10 months). Setback ranged from 522RVU (TME 419-16months) and 1462RVU (TME 419-13months). Pasting temperature ranged between 75.05°C (TMS 30572- 16months) and 78.78℃ (TMS 98/0505-10 months). Peak time ranged from 3.80 min (TMS 30572-13months) to 4.47 min (TME 419-10months).Variety and time of harvesting significantly (*P*=0.05) affected the pasting properties of starch from the cassava varieties. Optimization gave the minimum and maximum values of pasting parameters obtainable.
Conclusion: Variety and time of harvesting significantly affected the pasting properties of starch from the cassava varieties.

Keywords: Cassava starch; response surface analysis; cassava varieties; pasting property; optimization; shredding.

ABBREVIATIONS

TME: Tropical Manihotelit; TMS: Tropical Manihot Select; ANOVA: Analysis of Variance; Y: The Response; CV: Cassava Varieties; TH: Time of Harvesting; b0: Intercept; b_{1x1}-b_{2x2}*: Linear (first order) Effect;* $b_{11}x_1^2$-$b_2x_2^2$*: Quadratic (second order) Effect;* $b_{12}x_1x_2$*: Cross Product (interactive) Effect;* R^2*: Coefficient of Determination; P: Probability Value; RSA: Response Surface Analysis; DF: Degree of Freedom; F: Variance Factor.*

1. INTRODUCTION

Cassava (*Manihot esculenta*) is a short- lived perennial plant of between 1 to 5metres tall [1]. Improved cassava varieties which include TMS 30572, TME 419, TMS 98/0505 and TMS 99/6012 amongst others have higher resistance to the effects of destructive pests and diseases, high yield, low cyanide and wide ecological adaptation [2]. The primary food products come from the underground storage organs that consist mostly of starch (up to 90% dry weight), but are otherwise of low nutritional value [3]. It can be continuously harvested and marketed throughout the year and this provides a consistent supply of product available for immediate processing at a fairly predictable price throughout the year making it preferable to other more seasonal crops such as grains, peas, beans and other food security crops [2]. Cassava root is highly perishable and cannot be stored in the fresh state after harvest for more than a few days [4]. It is therefore, converted into more stable forms such as starch, tapioca, chips, *garri* etc. so as to prolong its shelf-life [5]. The basic starch qualities that control the sensory attributes and stability of processed starch products are gelatinization, pasting properties, swelling power and solubility, enzymatic digestibility and retrogradation [6]. The behavior of starch during cooking, gelatinization and pasting has been linked to its quality and suitability for use [7,8]. Such information has been used to explain the functionality of starchy food ingredients in processes such as baking [9,10,11] and extrusion cooking [12]. Pasting property is therefore an important quality index in predicting the behaviour of a starch paste during and after cooking.

Response surface methodology (RSM) is a sequential form of experimentation used in predicting or optimizing response (dependent, outcome) variables. It is made up of a mathematical statistical model of several input (independent, predictor) factors [13]. RSM is a powerful and efficient mathematical approach widely applied in the optimization of processes [13,14]. The designs capable of generating a response surface include Central Composite and Box-Behnken designs [15]. Three main varieties of Central Composite designs are available [15]. Amongst the three, the face centered central composite design is simpler to carry out because it requires operating a process at only three level settings of each variable thereby eliminating unexpectedly large experimental error [16]. The chemical composition of the cassava roots differs considerably according to variety, age of the harvested crop, soil conditions, climate and other environmental factors during cultivation [17]. It has been reported that starch properties are significantly influenced by the cultivars and environmental factors [18]. The aim of this work was to optimize and investigate the influence of variety and time of harvest on the pasting properties of selected improved cassava varieties using response surface methodology.

2. MATERIALS AND METHODS

2.1 Materials

Cassava roots of TME 419, TMS 98/0505 and TMS 30572 were obtained from the National Research Institute, Umudike, Abia State, Nigeria. These roots were monitored from planting and harvested at 10, 13 and 16 months respectively.

2.2 Methods

2.2.1 Isolation of starch

Starch was isolated from the cassava roots at the Biochemistry Laboratory of the National Research Institute, Umudike, Umuahia, Abia State, Nigeria. The cassava starches were isolated following the method reported by Abera and Kumar [19] with modifications. Peeled fresh cassava roots of each of the cassava varieties were washed and shredded by a motorized shredding machine at a speed of 650 rpm, using 3 mm shredding aperture. The cassava shreds were blended (Model Master Chef 65, Moulinex France) with water in the ratio 90:10 for 5 min and sifted through a 200 mesh screen. The residue was rinsed twice to remove remnants of starch. The slurry was left for 3 h before decanting the liquor. The starch was suspended three times in water (the last suspension in distilled water) and non-starch materials removed by decanting the supernatant. It was then dried in a convection oven at 45ºC for 18 h, sifted with 200 mesh sieve, placed in a polythene bag and stored at room temperature (24ºC) until required.

2.2.2 Pasting properties determination

Pasting characteristics of the starch samples was determined at the Central Laboratory of the University of Ibadan, Oyo State, Nigeria using a Rapid Visco Analyzer (RVA) (Model RVA 3D Newport Scientific Pty, Ltd, Warriewood, Australia). First, 2.5 g of starch was weighed into a dry empty canister and 25 ml of distilled water was dispensed into the canister. The solution was thoroughly mixed and the canister was well fitted into the RVA as recommended. The slurry was heated from 50ºC to 95ºC with a holding time of 2 min followed by cooling to 50ºC with 2 min holding time. The rate of heating and cooling was at a constant rate of 11.25ºCmin^{-1}. Peak viscosity, trough, breakdown, final viscosity, setback, peak time and pasting temperature were read from the pasting profile with the aid of thermocline for windows software connected to a computer [20].

2.3 Experimental Design

A faced central composite design (k=2) was employed to study the linear, interactive and quadratic effects of the independent experimental variables. The statistical design with the model fitted to each set of data is shown below:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 + \epsilon \quad (1)$$

Key:

Y= dependent response variables peak, trough, breakdown, final, setback, pasting temperature and peak time of cassava starch, β_0 = intercept, $\beta_1 \ldots\ldots\ldots \beta_{12}$ = estimated regression coefficients, x_1, x_2 = independent variables in the model (cassava variety-cv, time of harvest-th), ϵ= random error.

The experimental variables were of three levels as shown in Table 1 while the experimental design with coded terms is as shown in Table 2. The center points were th = 13 months, cv = TMS 98/0505; corner points were th =16months, cv =TMS 30572 while the star points were th =10 months, and cv = TME 419. Runs 1-8 were performed once while run 9 was performed seven times [21]. A total of 16 experimental runs were generated.

2.4 Statistical and Data Analysis

Data on each run was statistically regressed and analyzed for variance using Minitab software. Statistical significance was accepted at 5% probability levels (*P*=0.05).The coefficients of determination (R^2) were computed. Plots of the fitted significant responses were made using Matlab software (version r2012a) to visualize these effects more clearly.

Statistical Package for Social Sciences (SPSS – version 20) was used to obtain mean and standard deviation. Means were separated using Duncan's Multiple Range Test (DMRT). Optimization was done using the optimization toolbox of Matlab r2012a software [22].

Table 1. Experimental variables applied in the faced-central composite design (k=2)

Independent variables	Variable levels		
	-1	**0**	**1**
Cassava varieties x_1	A	B	C
Time of harvest x_2 (months)	10	13	16

Where A= cassava shred from TME 419
B= cassava shred from TMS 98/0505
C= cassava shred from TMS 30572
-1= low factor setting
1=high factor setting
0=mid-point

Table 2. Experimental design for determination of pasting properties

Run	X_1	X_2
1	-1	-1
2	-1	1
3	1	-1
4	1	1
5	-1	0
6	1	0
7	0	-1
8	0	1
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0

X1= cassava variety (cv); X2= time of harvest (th)

3. RESULTS AND DISCUSSION

Results of the pasting properties of starch from the cassava varieties are shown in Tables 3 and 4. Variety and time of harvesting significantly affected (*P*=0.05) the pasting properties of cassava starch (Tables 3 and 4). Ikegwu et al. [23] observed that there were significant (*P*=0.05) differences in the pasting properties of starch samples from 13 improved cassava cultivars. Also, Sanni et al. [24] reported similar results for 43 cassava mosaic disease resistant clones in all the pasting properties except pasting temperature. Pasting properties are dependent on the rigidity of starch granules, which in turn affects the granule swelling potential [25].

3.1 Peak Viscosity (PV)

Peak viscosity ranged between 5946 and 7327RVU, the lowest for TMS 98/0505 (16 months) and the highest for TME 419 (13 months). Peak viscosity range of 74.25 to 178.25RVU from 13 improved cassava cultivars has been reported [23]. There was a significant (*P*= 0.05) difference in the peak viscosity of the starch samples. The same observation was made by Niba et al. [26] for 11 cassava genotypes assessed and they reported peak viscosity range of 414.7 to 502.1RVU. Peak viscosity is indicative of the strength of pastes, which are formed from gelatinization during processing in food applications. Genotype differences in peak viscosity, therefore, imply differences in paste strength and attendant differences in behaviour during processing [27]. Also, Ragaee and Abdel-Aal [28] reported that increase in peak viscosity may be attributed to an increased rate of water absorption and starch granule swelling during heating while Bahnassey and Breene [29] stated that the structural differences in the amylopectin molecules of the flour/starch sources may be a contributory factor in the increase in peak viscosity. On the other hand Adeyemi and Omolayo [30] reported that high peak viscosity and stability is associated with increased cassava starch concentration and Mepba et al. [31] added that there exists a linear logarithmic correlation between maximum viscosity and starch concentration.

Results of the regression of data on the peak viscosity of starch are shown in Table 5. Linear and quadratic effect of time of harvesting and interaction between cassava variety and time of harvesting were significant and they accounted for 92.6% variation in the peak viscosity of starch. The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Peak viscosity} = -5584+2024.9th-54.58cv.th-80.578th^2 \qquad (2)$$

Low swelling power values were recently attributed to the strong bonding forces between starch granules [32]. It has been reported that rainy season samples have larger average granule sizes, lower gelatinization temperatures and higher peak paste viscosities than the drought season samples Pathama et al. [33] and Lii [34] suggested that the rigidity of the starch granular structure might be directly proportional to its amylose content and inversely proportional to the degree of granular swelling. The amylose and amylopectin chains in the starches harvested in the dry season are more rigid, i.e. compact than the rainy season samples because of the lower environmental water availability [33]. The rainy season samples therefore have greater ability to swell much more freely than dry season samples because of the low rigidity of its starch granules.

From the response surface curve (Fig. 1), peak viscosity of 7297RVU was obtained from cassava variety TME 419 at the 13th month of harvest. However, optimization showed that the minimum peak viscosity obtainable was 5963RVU and from the cassava variety TMS 30572, at the 16th month of harvest while the maximum peak viscosity obtainable was 7298RVU, from the cassava variety TME 419 harvested at the 13th month.

3.2 Trough

Trough viscosity was found to be the lowest for TMS 30572-13 months (2200RVU) and the highest for TMS 30572-10months (3463RVU). Generally, high holding strength represents low cooking loss and superior eating quality [35]. It shows the ability of the flour samples to withstand heating and shear stress during processing [20].

Results of the regression of data on trough are shown in Table 6. Linear and quadratic effects of time of harvesting significantly (P=0.05) affected the trough viscosity of cassava starch. The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Trough viscosity} = 11998 - 1419.4th + 53.03th^2 \quad (3)$$

But from the optimization point of view, maximum possible trough was 3115RVU and it was obtained from cassava variety TMS 30572 at the 10th month of harvest while the minimum trough was 2472RVU obtained at the 13th month of harvest from the cassava variety TME 419. From the response surface curve (Fig. 2) trough viscosity of 3115RVU was obtained from cassava variety TMS 30572 at the 10thmonth of harvest. An R^2 of 63%, which indicates a goodness of fit, was established.

3.3 Breakdown

Breakdown viscosity was found to be the lowest for TMS 98/0505-16months (2878RVU) and the highest for TME 419-13months (4689RVU). Breakdown is a measure of susceptibility of cooked starch granules to disintegration [36] and has been reported by Beta et al. [37] to affect the stability of the flour/starch products. A low breakdown value indicated that the flour/starch products were more stable under hot condition [36].

Regression coefficients on the breakdown viscosity of starch are shown in Table 7. Linear and quadratic effect of time of harvesting significantly affected the breakdown viscosity of starch. The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Breakdown viscosity} = -17579 + 3444th - 133.59th^2 \quad (4)$$

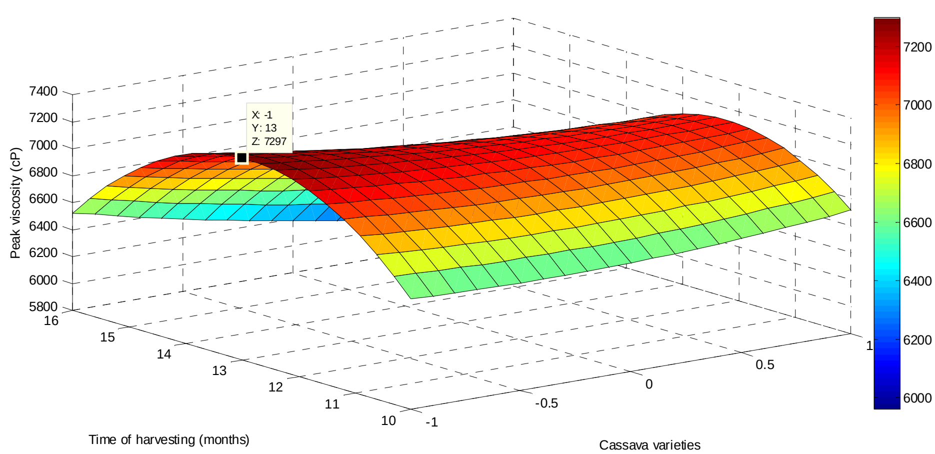

Fig. 1. Effect of time of harvesting and cassava varieties on the peak viscosity of starch

Table 3. Effect of time of harvest on the pasting properties of the different varieties of cassava starch

Variety/month	Peak viscosity	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temperature
TMS 98/0505							
10 Months	6614±5.66^{b}	2669.5±12.02^{b}	3944.5±17.7^{b}	3507±50.9^{a}	837.5±62.9^{b}	4.30±.05^{a}	78.78±.60^{a}
13 Months	7151±74.95^{a}	2535.5±21.92^{b}	4615.5±96.9^{a}	3912±172.5^{a}	1376.5±150.6^{a}	4.07±.00^{b}	76.78±.11^{b}
16 Months	5946±93.34^{c}	3068.5±82.73^{a}	2877.5±176.1^{c}	3837±128.7^{a}	768.5±45.96^{b}	4.37±.05^{a}	75.08±.04^{c}
Total	6570±542.61	2757.8±250.9	3812.5±789.1	3752±216.6	994.2±307.3	4.24±.14	76.88±1.68
TMS 30572							
10 Months	6783.5±6.4^{a}	3463±5.65^{a}	3320.5±12.02^{b}	4154±113.14^{a}	691±118.79^{b}	4.37±.05^{a}	77.55±0.778^{a}
13 Months	6805±114.55^{a}	2200±4.24^{c}	4605±118.79^{a}	3266.5±17.68^{b}	1066.5±21.9^{a}	3.80±.00^{b}	76.75±1.414^{a}
16 Months	6158.5±79.9^{b}	3026±226.27^{b}	3132.5±306.18^{b}	3771.5±251.0^{ab}	745.5±24.75^{b}	4.30±.05^{a}	75.05±0.071^{a}
Total	6582±334.3	2896±582.56	3686±731.7	3730.7±416.8	834.3±189.7	4.16±.28	76.45±1.14
TME 419							
10 Months	6545±38.18^{b}	3240.0±16.97^{a}	3305±21.21^{c}	3833±53.74^{b}	593±36.77^{b}	4.47±.00^{a}	77.5±.00^{a}
13 Months	7326.5±36.06^{a}	2638.0±7.07^{b}	4688.5±43.13^{a}	4100±62.23^{a}	1462±69.30^{a}	4.17±.05^{b}	75.85±.14^{b}
16 Months	6575±29.7^{b}	2545.5±20.51^{c}	4029.5±50.2^{b}	3067.5±13.44^{c}	522±33.94^{b}	4.17±.05^{b}	77.08±.53^{a}
Total	6815.5±396.9	2807.8±337.53	4007.7±619.7	3666.8±480.8	859±469.72	4.27±.16	76.81±.80

a, b, c- means in the same column bearing different superscripts are significantly different (P=0.05); values are mean± standard deviation.

Table 4.Varietal effect on the pasting properties of cassava starch at different times of harvest

Variety/month	Peak viscosity	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temperature
10 Months							
TMS 98/0505	6614±5.66^{b}	2669.5±12.02^{c}	3944.5±17.68^{a}	3507±50.91^{c}	837.5±62.93^{a}	4.30±.05^{b}	78.78±.60^{a}
TMS 30572	6783.5±6.36^{a}	3463±5.66^{a}	3320.5±12.02^{b}	4154±113.14^{a}	691±118.79^{a}	4.37±.05^{ab}	77.55±.00^{b}
TME 419	6545±38.18^{b}	3240±16.97^{b}	3305±21.21^{b}	3833±53.74^{b}	593±36.77^{a}	4.47±.00^{a}	77.50±.00^{b}
Total	6647.5±111.2	3124.2±366.16	3523.3±326.59	3831.3±295.60	707.17±126.5	4.38±.08	77.94±.70
13 Months							
TMS 98/0505	7151±74.95^{a}	2535.5±21.92^{b}	4615.5±96.87^{a}	3912±172.53^{a}	1376.5±150.61^{a}	4.07±.00^{b}	76.78±.11^{a}
TMS 30572	6805±114.55^{b}	2200±4.25^{c}	4605±118.79^{a}	3266.5±17.68^{b}	1066.5±21.92^{b}	3.80±.00^{c}	76.75±.00^{a}
TME 419	7326.5±36.06^{a}	2638±7.07^{a}	4688.5±43.13^{a}	4100±62.23^{a}	1462±69.30^{a}	4.17±.05^{a}	75.85±.14^{b}
Total	7094.2±245.64	2457.8±205.18	46.36.3±82.01	3759.5±399.61	1301.7±200.60	4.01±.17	76.46±.48
16 Months							
TMS 98/0505	5946±93.34^{b}	3068.5±82.73^{a}	2877.5±176.07^{b}	3837±128.69^{a}	768.5±45.96^{a}	4.37±.05^{a}	75.08±.04^{b}
TMS 30572	6158.5±79.90^{b}	3026±226.27^{a}	3132.5±306.18^{b}	3771.5±251.02^{a}	745.5±24.75^{a}	4.30±.05^{ab}	75.05±.00^{b}
TME 419	6575±29.70^{a}	2545.5±20.51^{b}	4029.5±50.21^{a}	3067.5±13.44^{b}	522±33.94^{b}	4.17±.05^{b}	77.08±.53^{a}
Total	6226.5±291.72	2880±281.4	3346.5±564.23	3558.7±401.94	678.7±124.93	4.28±.10	75.73±1.07

a, b, c- means in the same column bearing different superscripts are significantly different(P=0.05)

Breakdown indicates the stability of swollen starch granules to shearing and mixing. The rate of starch breakdown depends on the nature of the material, the temperature and the degree of mixing and shear applied to the mixture [20]. As peak viscosity increased, breakdown viscosity also increased [38].This trend indicates a rapid swelling of the rainy season samples but their inability to retain the swollen structure at cooking temperature and under stirring for a prolonged period. Furthermore Adebowale et al. [39] reported that the higher the breakdown in viscosity, the lower the ability of the sample to withstand heating and shear stress during cooling.

From the response surface curve (Fig. 3) breakdown viscosity of 4741RVU was obtained at the 13th month from cassava variety TME 419. Optimization showed that the minimum breakdown viscosity obtainable was 2864RVU and it was obtained from TMS 30572 at the 16th month while the maximum breakdown viscosity of 4744RVU was obtained at the 13th month from cassava variety TME 419. Analysis showed an R^2 of 90% which confers a goodness of fit.

Table 5. Response surface regression parameters for influence of harvesting time and cassava varieties on peak viscosity of cassava starch

Term	Coefficient	SE coefficient	T	P
Constant	-5584	1488	-3.75	0.004
CV	593.1	298.4	1.99	0.075
TH	2024.9	229.1	8.84	0.000*
CV^2	60.80	79.03	0.77	0.460
TH^2	-80.578	8.781	-9.18	0.000*
CV *TH	-54.58	22.56	-2.42	0.036*
S = 135.4	R^2 = 92.6%			R^2 (adj)= 88.9%

**significant at P=0.05*

Table 6. Response surface regression parameters for influence of cassava varieties and harvesting time on the Trough viscosity of starch

Term	Coefficient	SE coefficient	T	P
Constant	11998	2672	4.49	0.000
CV	-234.3	535.8	-0.44	0.671
TH	-1419.4	411.2	-3.45	0.006*
CV^2	26.7	141.9	0.19	0.854
TH^2	53.03	15.77	3.36	0.007*
CV*TH	21.42	40.50	0.53	0.609
S= 243.0	R^2= 63.3%			R^2(adj)= 45.0%

**significant at P=0.05*

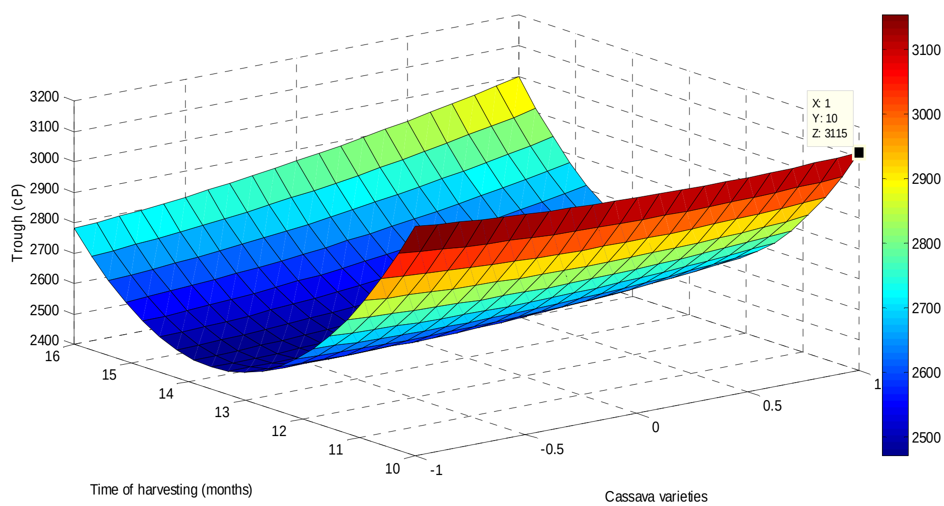

Fig. 2. Effect of time of harvesting and cassava varieties on the Trough viscosity of starch

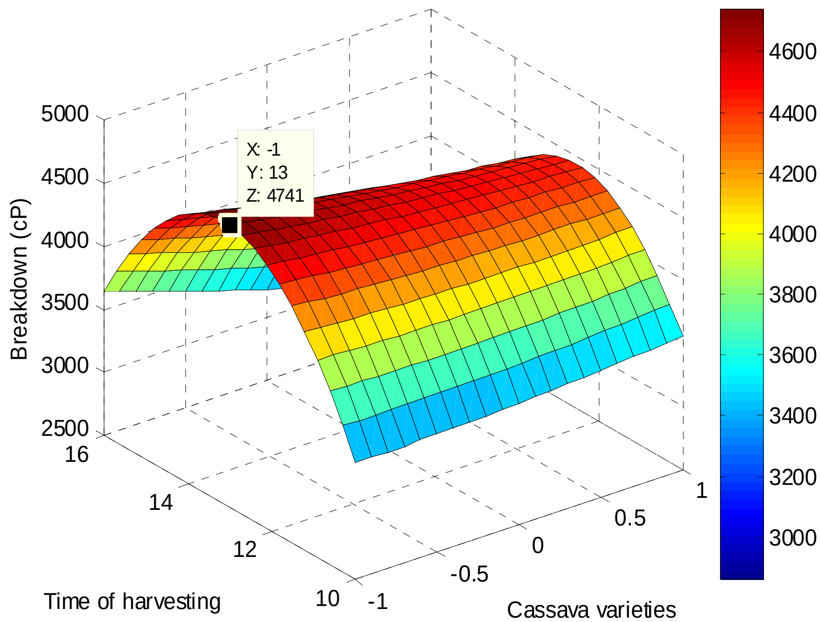

Fig. 3. Effect of time of harvesting and cassava varieties on the breakdown viscosity of starch

Table 7. Response surface regression parameters for influence of cassava varieties and harvesting time on the breakdown viscosity of starch

Term	Coefficient	SE coefficient	T	P
Constant	-17579	2775	-6.34	0.000
CV	828.3	556.4	1.49	0.167
TH	3444.0	427.1	8.06	0.000*
CV^2	33.2	147.4	0.23	0.826
TH^2	-133.59	16.37	-8.16	0.000*
CV*TH	-76.08	42.06	-1.81	0.101
S= 252.4	R^2= 89.9%			R^2(adj)= 84.9%

**significant at P= 0.05*

Table 8. Response surface regression parameters for influence of harvesting time and cassava varieties on the final viscosity of starch

Term	Coefficient	SE coefficient	T	P
Constant	2218	3346	0.66	0.522
CV	-382.9	670.9	-0.57	0.581
TH	302.3	514.9	0.59	0.570
CV^2	-108.8	177.7	-0.61	0.554
TH^2	-13.37	19.74	-0.68	0.514
CV*TH	31.92	50.72	0.63	0.543
S= 304.3	R^2= 24.4%			R^2(adj)= 0.0%

3.4 Final Viscosity

Final viscosity indicates the ability of the starch to form a viscous paste. It ranged from 3068RVU to 4154RVU, the lowest was shown in TME 419 (16 months) and the highest in TMS 30572 (10 months). This viscosity indicates the stability of cooked starch paste in actual use and the ability of a starch to form a paste or gel after cooling [40]. Increase in final viscosity might be due to the aggregation of the amylose molecules on cooling [41]. On the other hand, differences amongst varieties in final viscosity could be associated with differences in amylose contents [40]. This is because the linear chains can orient parallel to each other, moving close enough together to bond [40].

Regression coefficients for final viscosity of starch are shown in Table 8. The experimental variables had no significant effect (*P*=0.05) on the final viscosity of starch. Final viscosity has been reported as the most commonly used parameter to characterize the ability of starch-based material to form a viscous paste or gel after cooking and cooling as well as the resistance of the paste to shear force during stirring [39,42]. However, optimization showed that the minimum final viscosity obtainable was 3383RVU from cassava variety TMS 30572 at the 16th month of harvest while the maximum final viscosity obtainable was 3921RVU at the 10th month from cassava variety TMS 98/0505. Analysis showed an R^2 of 24% implying that there is no goodness of fit.

3.5 Setback

Setback viscosity for the various starch samples differed significantly. Cassava variety TME 419 (16months) exhibited the lowest setback of 522RVU, whereas it was found to be the highest for cassava variety TME 419 (13 months) (1462RVU). Oduro-Yeboah et al. [43] observed highly significant (*P*=0.05) differences in the setback viscosity of starch from five cassava varieties analysed. Setback viscosity is an index of the retrogradation of linear starch molecules during cooling. Sanni et al. [44] reported that lower setback during the cooling of paste from starch or a starch-based food indicates greater resistance to retrogradation. High retrogradation tendency could be due to the crystallization involving amylose molecules and the long-branch chain of amylopectin [31]. The difference in setback among different starches may be due to the amount and the molecular weight of amylose leached from the granules and the remnant of the gelatinized starch [45]. Regression coefficients for the setback viscosity of starch samples are shown in Table 9.

Linear and quadratic effects of time of harvesting and quadratic effect of cassava variety significantly (*P*=0.05) affected the setback viscosity of starch and they accounted for 94% of the variation in the setback viscosity of starch. The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Setback viscosity} = -9778 + 1721.7th - 136.59cv^2 - 66.399th^2 \quad (5)$$

Response surface curve (Fig. 4) shows that setback viscosity of 1386RVU was obtained from cassava variety TMS 98/0505 at the 13th month. Optimization showed that the maximum setback viscosity obtainable was 1387RVU from cassava variety TMS 98/0505 at the 13th month of harvesting while the minimum setback viscosity obtainable was 657.6RVU, from cassava variety TMS 30572 at the 16th month of harvest.

3.6 Peak Time

Peak time of the cassava starches ranged from 3.80min (TMS 30572; 13months) to 4.47min (TME 419; 10months). Variety and time of harvesting significantly affected the peak time of the cassava starches. Ikegwu et al. [23] observed that there was significant difference in the peak time of improved cassava of 13 cultivars studied. For technical and economic reasons, starches with low pasting time and temperature may be preferred when all other properties are equal [23]. Regression coefficients for peak time of starch are shown in Table 10.

Linear and quadratic effect of time of harvest significantly ($p \leq 0.05$) affected the peak time of starch. The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Peak time} = 9.9172 - 0.8840th + 0.033359th^2 \quad (7)$$

From the response surface curve (Fig. 6), peak time of 4.48 min was obtained from cassava variety TME 419 at the 10th month of harvest. However, optimization shows that minimum peak time obtainable was 3.97 min from the cassava variety TMS 30572 at the 13th month of harvest while the maximum peak time obtainable was 4.48min from the cassava variety TME 419 at the 10th month of harvest. Analysis showed an R^2 of 82% which confers a goodness of fit.

3.7 Pasting Temperature

Pasting temperature for various cassava starches ranged between 75.05℃ and 78.78℃, the lowest shown by the cassava variety TMS 30572 (16 months) and the highest by TMS 98/0505 (10 months). Pasting temperature is the temperature at which starch granules swell on heating in water resulting in an initial slight increase in viscosity of the aqueous starch or flour suspension [46]. Attainment of the pasting temperature is essential in ensuring swelling, gelatinization, and subsequent gel formation during processing [27]. The high pasting temperature of starch from TMS 98/0505 (10 months) indicates that it has a higher resistance towards swelling. Variety and time of harvesting significantly affected the pasting temperature of the cassava starches. Ikegwu et al. [23] observed that there were significant differences (P=0.05) in the pasting temperature of the starch isolated from 13 improved cassava cultivars and they noted that the pasting temperatures of the starch samples ranged from 63℃ for sample NR01/0161 to 65℃ for sample TMS00/0214. The difference in the pasting temperatures is an indication of different gelatinization temperatures of the flours [47]. Regression coefficients on the pasting temperature of starch are shown in Table 11.

Cassava variety and interaction between cassava variety and time of harvesting significantly affected (P=0.05) the pasting temperature of starch. The resulting polynomial after removing non-significant terms for the analysis becomes:

Pasting temperature =

$$81.237 + 3.019cv – 0.24583cv.th \qquad (6)$$

Response surface curve (Fig. 5) shows that pasting temperature of 78.1ºC was obtained from cassava variety TMS 30572 at the 10th month. However from optimization, the minimum pasting temperature obtainable was 74.7ºC from cassava variety TMS 30572 at the 16th month of harvest while the maximum pasting temperature obtainable was 78.1ºC from TMS 30572 at the 10th month of harvest. Analysis showed an R^2 of 76% which confers a goodness of fit.

Table 9. Response surface regression parameters for influence of harvesting time and cassava varieties on the setback viscosity of starch

Term	Coefficient	SE coefficient	T	P
Constant	-9778	1134	-8.62	0.000
CV	-148.7	227.3	-0.65	0.528
TH	1721.7	174.5	9.87	0.000*
CV^2	-136.59	60.21	-2.27	0.047*
TH^2	-66.399	6.690	-9.93	0.000*
CV*TH	10.50	17.19	0.61	0.555
S= 103.1	R^2= 94.1%			R^2(adj)= 91.2%

**significant at P=0.05*

Table 10. Response surface regression parameters for influence of harvesting time and cassava varieties on the peak time of starch

Term	Coefficient	SE Coefficient	T	P
Constant	9.9172	0.9551	10.38	0.000
CV	-0.3058	0.1915	-1.60	0.141
TH	-0.8840	0.1470	-6.01	0.000*
CV^2	-0.04977	0.05072	-0.98	0.350
TH^2	0.033359	0.005632	5.92	0.000*
CV*TH	0.01917	0.01448	1.32	0.215
S= 0.08686	$R^{2=}$ 81.9%			R^2 (adj)=72.9%

**significant at P=0.05*

Table 11. Response surface regression parameters for influence of harvesting time and cassava varieties on the pasting temperature of starch

Term	Coefficient	SE coefficient	T	P
Constant	81.237	5.576	14.57	0.000
CV	3.019	1.118	2.70	0.022*
TH	-0.3621	0.8581	-0.42	0.682
CV^2	-0.1902	0.2961	-0.64	0.535
TH^2	-0.00164	0.03290	0.05	0.961
CV*TH	-0.24583	0.08452	-2.91	0.016*
S= 0.5071	R^2=75.7%			R^2(adj)= 63.5%

**significant at P= 0.05*

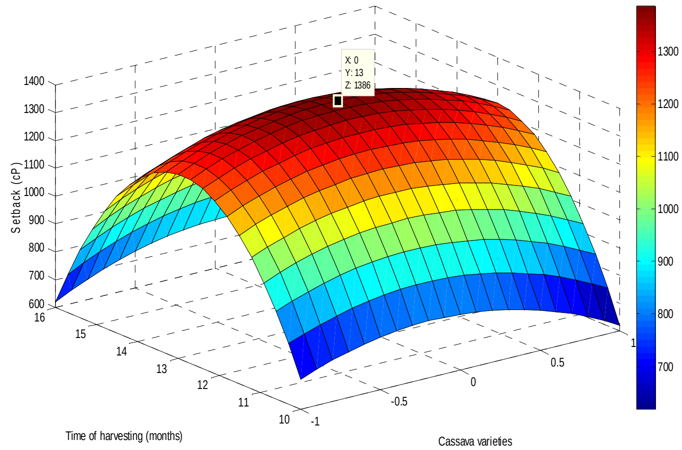

Fig. 4. Effect of time of harvesting and cassava varieties on the setback of starch

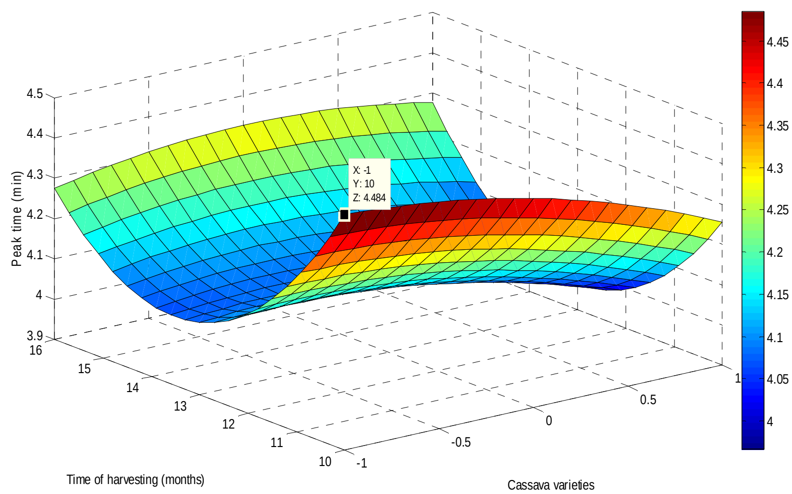

Fig. 5. Effect of time of harvesting and cassava varieties on the peak time of starch

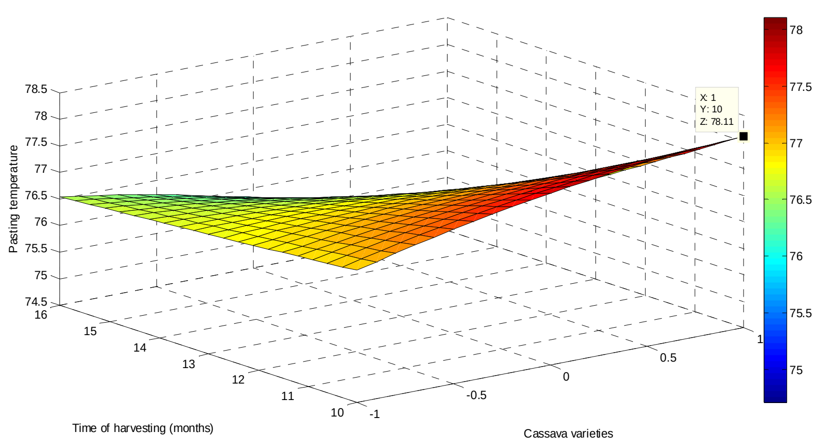

Fig. 6. Effect of time of harvesting and cassava varieties on the pasting temperature of starch

4. CONCLUSION

Variety and time of harvesting significantly (*P*=0.05) affected the pasting properties of starch from the cassava varieties. The high peak viscosity of starch from TME 419 (13 months) indicates that it has higher water absorption capacity and would require more moisture during reconstitution. High final viscosity (4154RVU) of starch from the cassava variety TMS 30572 (10 months), its low setback (691RVU) and high trough (3463RVU) indicate that it has the ability to withstand heating and shear stress during processing. Its gel does not break and has higher resistance to retrogradation. Starch samples from TMS 98/0505 (16 months) are more stable under hot conditions because of their low breakdown (2878RVU). Low peak time (3.8min) of starch from TMS 30572 (13 months) suggests that they have low resistance to swelling and the low pasting temperature (75.05ºC) of starch from TMS 30572 (16 months) suggests that they easily formed pastes hence, more suitable in most food and non-food industrial processes because of reduced energy costs during production processes. This wide variation in the pasting properties of the different cassava varieties indicates their suitability in different applications.

COMPETITING INTERESTS

Authors have declared that no competing interests exist.

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