

Original Research Article

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

ABSTRACT

Aims: Three cassava varieties TME 419, TMS 30572 and TMS 98/0505 were harvested at three months interval from maturity- 10, 13 and 16 months. 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 ViscoAnalyser. A faced central composite design ($k=2$) was employed to study the linear, interactive and quadratic effects of the independent variables.

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 analysis and Analysis of variance. 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 419-16 months) and 1462RVU (TME 419-13 months). Pasting temperature ranged between 75.05°C (TMS 30572- 16 months) and 78.78°C (TMS 98/0505-10 months). Peak time ranged from 3.80min (TMS 30572-13 months) to 4.47min (TME 419-10 months). 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: The variation in the pasting properties of the cassava varieties indicates their suitability in different applications.

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

ABBREVIATIONS

TME: tropical *manihot* elite, TMS: tropical *manihot* select, ANOVA: Analysis of variance, Y: the response, CV: cassava varieties, TH: time of harvesting, b_0 : intercept, b_{1x_1} - b_{2x_2} : linear (first order) effect; $b_{11x_1^2}$ - $b_{22x_2^2}$: quadratic (second order) effect; $b_{12x_1x_2}$: 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 5 metres 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 of 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 [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 650rpm, using 3mm shredding aperture. The cassava shreds were blended (Model Master Chef 65, Moulinex France) with water 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 hours 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. The starch was then dried in a convection oven at 45°C for 18h, sifted with 200 mesh sieve, placed in a polythene bag and stored at room temperature 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, 2.5g of starch was weighed into a dry empty canister

and 25ml 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 50°C to 95°C with a holding time of 2 min followed by cooling to 50°C with 2 min holding time. The rate of heating and cooling was at a constant rate of 11.25°Cmin⁻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:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_{11}X_1^2 + \beta_{22}X_2^2 + \beta_{12}X_1X_2 + \epsilon \quad (1)$$

Key:

Y= dependent response variables peak, trough, breakdown, final, setback, pasting temperature and peak time of cassava starch, β_0 = intercept, $\beta_1, \dots, \beta_{12}$ = 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 = 13months, cv = TMS 98/0505; corner points were th =16months, cv =TMS 30572 while the star points were th =10months, 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.

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

144

145 **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

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

147

148 2.4 Statistical and Data Analysis

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

153 Statistical Package for Social Sciences (SPSS – version 20) was used to obtain mean,
 154 standard deviation and analysis of variance (ANOVA) was done and judged for significance at $p \leq 0.05$.
 155 Means were separated using Duncan's Multiple Range Test (DMRT). Optimization was done using
 156 the Optimization toolbox of Matlab r2012a software [22].

157 3. RESULTS AND DISCUSSION

158 Results of the pasting properties of starch from the cassava varieties are shown in Tables 3 and 4.
 159 Variety and time of harvesting significantly affected ($p \leq 0.05$) the pasting properties of cassava starch
 160 (Tables 3 and 4). It was observed that there were significant ($p \leq 0.05$) differences in the pasting
 161 properties of the starch samples from 13 improved cassava cultivars [23]. Also, [24] reported similar
 162 results for 43 cassava mosaic disease resistant clones in all the pasting properties except pasting
 163 temperature. Pasting properties are dependent on the rigidity of starch granules, which in turn affects
 164 the granule swelling potential [25].

165

166

167 **Table 3. Effect of time of harvest on the pasting properties of the different varieties of**
 168 **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±	3068.5±	2877.5±	3837±	768.5±	4.37±	75.08±

	93.34 ^c	82.73 ^a	176.1 ^c	128.7 ^a	45.96 ^b	.05 ^a	.04 ^c
Total	6570±	2757.8±	3812.5±	3752±	994.2±	4.24±	76.88±
	542.61	250.9	789.1	216.6	307.3	.14	1.68
TMS 30572							
10 Months	6783.5±	3463±	3320.5±	4154±	691±	4.37±	77.55±
	6.4 ^a	5.65 ^a	12.02 ^b	113.14 ^a	118.79 ^b	.05 ^a	0.778 ^a
13 Months	6805±	2200±	4605±	3266.5±	1066.5±	3.80±	76.75±
	114.55 ^a	4.24 ^c	118.79 ^a	17.68 ^b	21.9 ^a	.00 ^b	1.414 ^a
16 Months	6158.5±	3026±	3132.5±	3771.5±	745.5±	4.30±	75.05±
	79.9 ^b	226.27 ^b	306.18 ^b	251.0 ^{ab}	24.75 ^b	.05 ^a	0.071 ^a
Total	6582±	2896±	3686±	3730.7±	834.3±	4.16±	76.45±
	334.3	582.56	731.7	416.8	189.7	.28	1.14
TME 419							
10 Months	6545±	3240.0±	3305±	3833±	593±	4.47±	77.5±
	38.18 ^b	16.97 ^a	21.21 ^c	53.74 ^b	36.77 ^b	.00 ^a	.00 ^a
13 Months	7326.5±	2638.0±	4688.5±	4100±	1462±	4.17±	75.85±
	36.06 ^a	7.07 ^b	43.13 ^a	62.23 ^a	69.30 ^a	.05 ^b	.14 ^b
16 Months	6575±	2545.5±	4029.5±	3067.5±	522±	4.17±	77.08±
	29.7 ^b	20.51 ^c	50.2 ^b	13.44 ^c	33.94 ^b	.05 ^b	.53 ^a
Total	6815.5±	2807.8±	4007.7±	3666.8±	859±	4.27±	76.81±
	396.9	337.53	619.7	480.8	469.72	.16	.80

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

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

Total	6226.5±	2880±	3346.5±	3558.7±	678.7±	4.28±	75.73±
	291.72	281.4	564.23	401.94	124.93	.10	1.07

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

3.1 Peak viscosity (PV)

Peak viscosity ranged between 5946 and 7327RVU, the lowest for TMS 98/0505 (16months) 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 [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, [28] reported that increase in peak viscosity may be attributed to an increased rate of water absorption and starch granule swelling during heating while [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 [30], reported that high peak viscosity and stability is associated with increased cassava starch concentration and [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 Tables 5(a) and (b). 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:

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

Analysis of variance also showed that the experimental variables significantly affected the peak viscosity of starch.

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 [33] and [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 shows that the minimum peak viscosity obtainable was 5963RVU and from the cassava variety TMS 30572, at the 16th month while the maximum peak viscosity obtainable was 7298RVU, from the cassava variety TME 419 harvested at 13months.

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

(a) Regression coefficients

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%

(b) Analysis of variance (ANOVA)

Source	DF	SS	MS	F	P
Regression	5	2286306	457261	24.96	0.000*
Error	10	183220	18322		
Total	15	2469525			

*significant at $P=0.05$

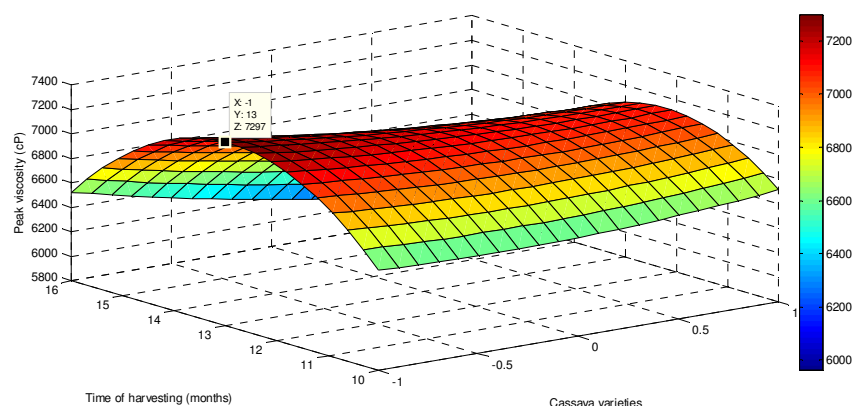


Fig.1.Effect of time of harvesting and cassava varieties on the peak viscosity of starch

3.2Trough

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 showed 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 Tables 6 (a) and (b). Linear and quadratic effects of time of harvesting significantly ($p \leq 0.05$) affected the trough viscosity of cassava starch. The resulting polynomial after removing non-significant terms for the analysis becomes:

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

Analysis of variance showed that the variables had significant ($p \leq 0.05$) effect on the trough viscosity of the starch.

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

(a) Regression coefficients

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%	

(b) Analysis of variance (ANOVA)

Source	DF	SS	MS	F	P
Regression	5	1019015	203803	3.45	0.045*
Error	10	590594	59059		
Total	15	1609609			

*significant at $P=0.05$

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 13months 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 10months of harvest. An R² of 63%, which indicates a goodness of fit, was established.

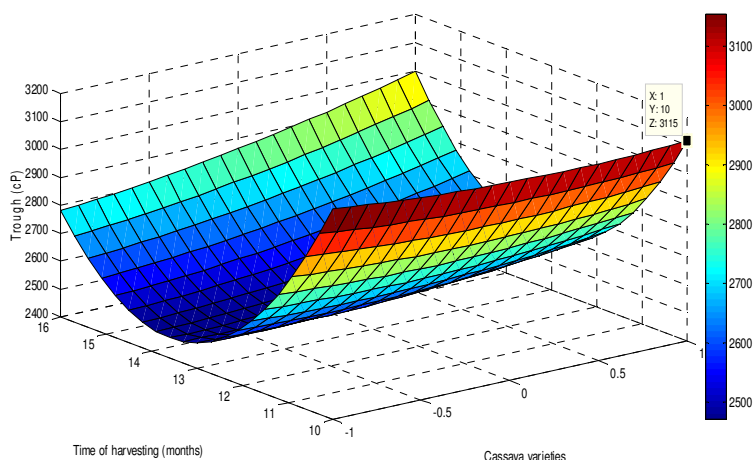


Fig.2.Effect of time of harvesting and cassava varieties on the Trough viscosity of starch

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 Tables 7 (a) and (b).

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:

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

Analysis of variance shows that the variables affected the breakdown viscosity of starch. 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, [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 13months from cassava variety TME 419. Optimization shows 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 13th month from cassava variety TME 419. Analysis showed an R^2 of 90% which confers a goodness of fit.

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

(a) Regression coefficients

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	$R^2 = 89.9\%$		$R^2(\text{adj}) = 84.9\%$	

(b) Analysis of variance (ANOVA)

Source	DF	SS	MS	F	P
Regression	5	5696085	1139217	17.89	0.000*
Error	10	636901	63690		
Total	15	6332986			

*significant at $P = 0.05$

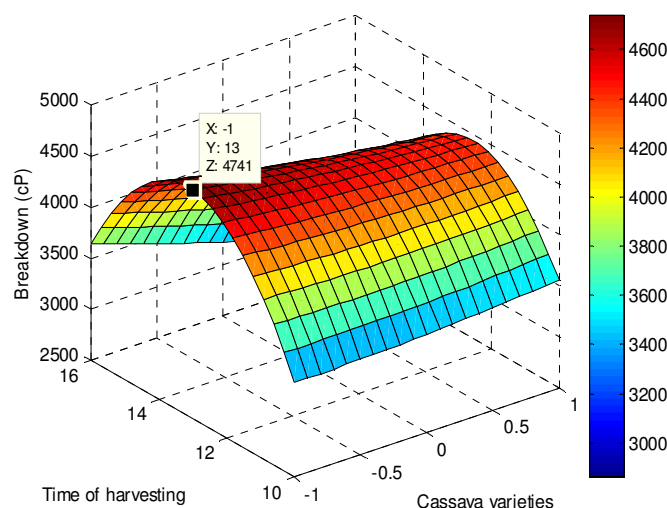


Fig. 3. Effect of time of harvesting and cassava varieties on the breakdown viscosity of starch

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 (16months) and the highest in TMS 30572 (10months). 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 Tables 8 (a) and (b). The experimental variables had no significant effect ($p \geq 0.05$) on the final viscosity of starch. Analysis of variance showed that the variables had no significant effect ($p \geq 0.05$) 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.

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

(a) Regression coefficients

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	$R^2 = 24.4\%$			$R^2(\text{adj}) = 0.0\%$

(b) Analysis of variance (ANOVA)

Source	DF	SS	MS	F	P
Regression	5	298639	59728	0.65	0.672
Error	10	925961	92596		
Total	15	1224600			

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 (13months) (1462RVU). [43]Observed highly significant ($p \leq 0.05$) 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. [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 Tables 9 (a) and (b).

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

(a) Regression coefficients

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%

(b) Analysis of variance (ANOVA)

Source	DF	SS	MS	F	P
Regression	5	1700895	340179	31.99	0.000
Error	10	106329	10633		
Total	15	1807224			

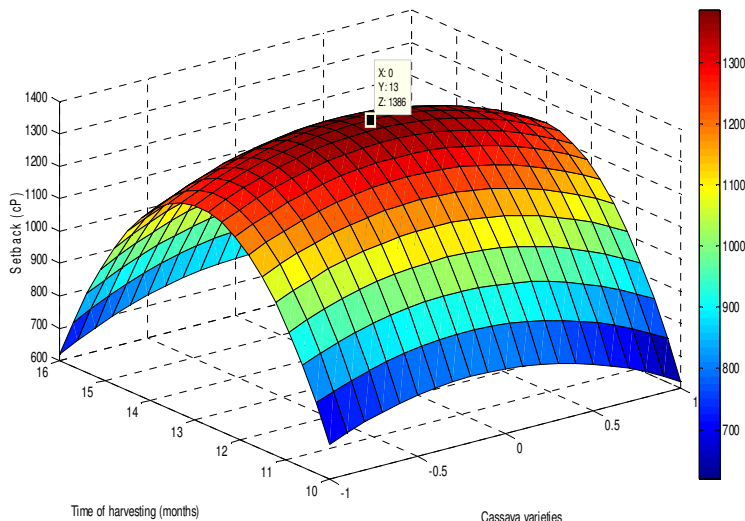
*significant at $P=0.05$

Linear and quadratic effects of time of harvesting and quadratic effect of cassava variety significantly ($p \leq 0.05$) 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:

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

Analysis of variance shows that the variables significantly ($p \leq 0.05$) affected the setback viscosity of starch. 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 13th month of harvesting while the minimum setback viscosity obtainable was 657.6RVU, from cassava variety TMS 30572 at the 16th month.

353



354

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

356 **3.6 Peak time**

357 Peak time of the cassava starches ranged from 3.80min (TMS 30572; 13months) to 4.47min (TME
358 419; 10months). Variety and time of harvesting significantly affected the peak time of the cassava
359 starches.[23]observed that there was significant difference in the peak time of improved cassava of 13
360 cultivars studied. For technical and economic reasons, starches with low pasting time and
361 temperature may be preferred when all other properties are equal [23].

362 Regression coefficients for peak time of starch are shown in Tables 10 (a) and (b).

363

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

366

367

(a) : Regression coefficients

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%	

368

369

(b) Analysis of variance (ANOVA)

Source	DF	SS	MS	F	P
Regression	5	0.342492	0.068498	9.08	0.002*
Error	10	0.075452	0.007545		
Total	15	0.417944			

370

371

*significant at $P=0.05$

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:

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

Analysis of variance shows that the variables had significant ($p \leq 0.05$) effect on the peak time of starch. From the response surface curve (Fig. 6), peak time of 4.48min was obtained from cassava variety TME 419 at 10months of harvest. However, optimization shows that minimum peak time obtainable was 3.97min 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.

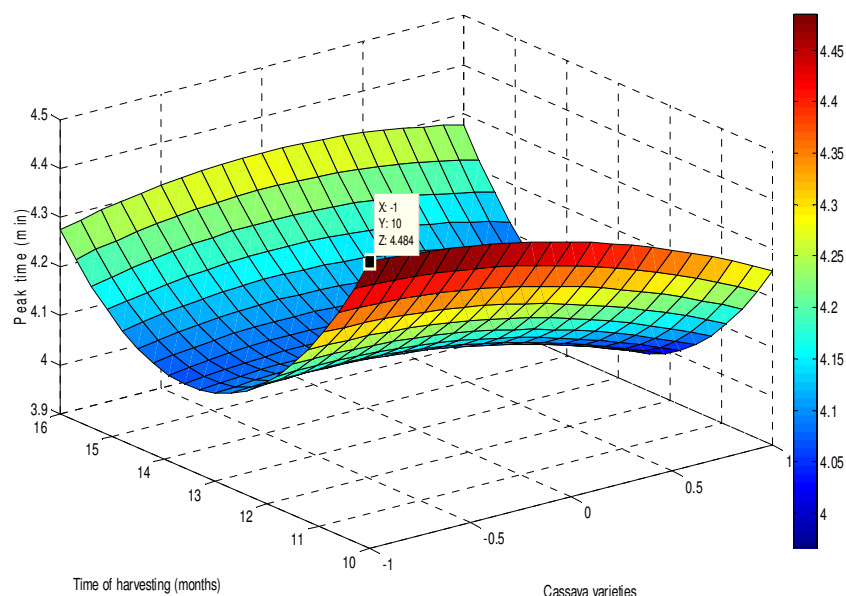


Fig. 5. Effect of time of harvesting and cassava varieties on the peak time of starch

3.7 Pasting temperature

Pasting temperature for various cassava starches ranged between 75.05°C and 78.78°C, the lowest shown by the cassava variety TMS 30572 (16months) and the highest by TMS 98/0505 (10months). 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 (10months) 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 ($p \leq 0.05$) 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°C for sample NR01/0161 to 65°C 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 Tables 10 (a) and (b).

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

(a) Regression coefficients

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%

(b) Analysis of variance(ANOVA)

Source	DF	SS	MS	F	P
Regression	5	8.0000	1.6000	6.22	0.007*
Error	10	2.5716	0.2572		
Total	15	10.5716			

*significant at $P= 0.05$

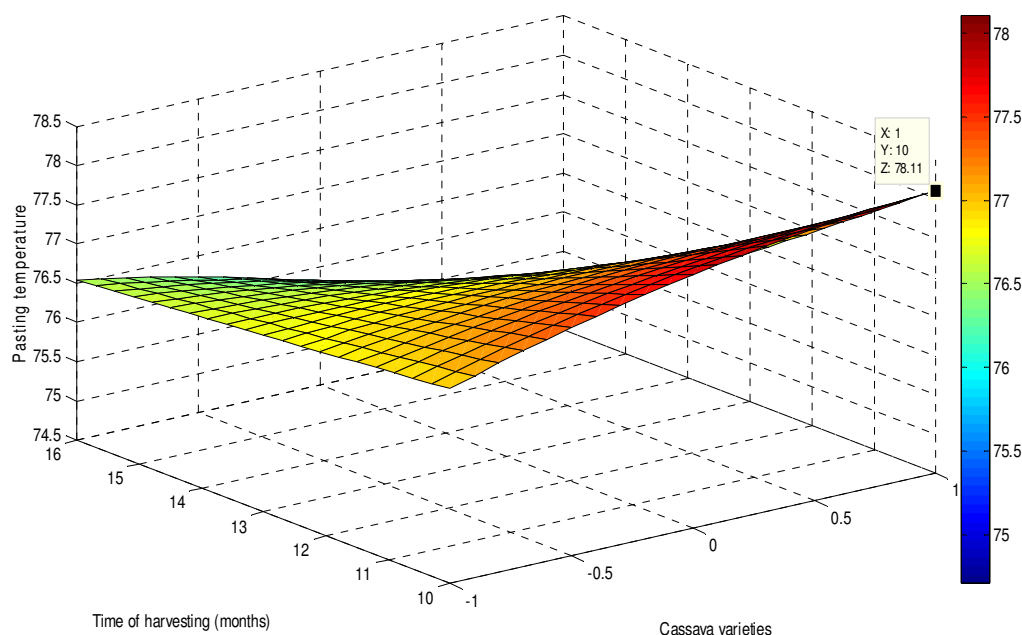
Cassava variety and interaction between cassava variety and time of harvesting significantly affected ($p \leq 0.05$) the pasting temperature of starch. The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Pasting temperature} = 81.237 + 3.019cv - 0.24583cv.th \quad (6)$$

Analysis of variance shows that the variables had significant effect ($p \leq 0.05$) on the pasting temperature of starch.

Response surface curve (Fig. 5) shows that pasting temperature of 78.1°C was obtained from cassava variety TMS 30572 at the 10th month. However from optimization, the minimum pasting temperature obtainable was 74.7°C from cassava variety TMS 30572 at the 16th month of harvest while the maximum pasting temperature obtainable was 78.1°C from TMS 30572 at the 10th month of harvest. Analysis showed an R² of 76% which confers a goodness of fit.

421



422

423 **Fig. 6.Effect of time of harvesting and cassava varieties on the Pasting temperature of starch**

424

425 **4. CONCLUSION**

426 Variety and time of harvesting significantly ($P=0.05$) affected the pasting properties of starch from the
 427 cassava varieties. The high peak viscosity of starch from TME 419 (13months) indicates that it has
 428 higher water absorption capacity and would require more moisture during reconstitution. High final
 429 viscosity (4154RVU) of starch from the cassava variety TMS 30572 (10months), its low setback
 430 (691RVU) and high trough (3463RVU) indicate that it has the ability to withstand heating and shear
 431 stress during processing. Its gel does not break and has higher resistance to retrogradation. Starch
 432 samples from TMS 98/0505 (16months) are more stable under hot conditions because of their low
 433 breakdown (2878RVU). Low peak time (3.8min) of starch from TMS 30572 (13months) suggests that
 434 they have low resistance to swelling and the low pasting temperature (75.05°C) of starch from TMS
 435 30572 (16months) suggests that they easily formed pastes hence, more suitable in most food and
 436 non-food industrial processes because of reduced energy costs during production processes. This
 437 wide variation in the pasting properties of the different cassava varieties indicates their suitability in
 438 different applications.

439 **COMPETING INTERESTS**

440 Authors have declared that no competing interests exist.

441

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