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Effect of Different Harvesting Regimes on the Pasting Properties of Selected Varieties of Banana – A Response Surface Study

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Abstract

Banana fruits from three banana varieties – *M. Cavendish AAA, M. paradisiaca AAB,* and *M. acuminata AAA* were harvested at 11, 13 and 15 weeks of maturity to determine the effect of different harvesting regimes on the pasting properties of the banana varieties. Flour was prepared from the banana fruits at the different harvesting regimes and the pasting properties of the flour samples were determined. A response surface, central composite for faced central composite design (K=2), was used to study the effect of the experimental variables - banana variety and time of harvesting on the pasting properties of banana flour. Regression models developed showed that the experimental variables had significant ($p \leq 0.05$) effect on the peak, trough, breakdown, final and setback viscosities of flour processed from banana varieties. They also had significant ($p \leq 0.05$) effect on the peak time and pasting temperature of the flour samples. The large range of values obtained in the pasting profile of the cassava roots studied is indicative of the wide genetic variations existing in the cassava clones analyzed and hence, the flour from the various clones will find wide applications for household and industrial uses.

Keywords: Drying; Flour; Banana; Response surface methodology; Pasting properties; Optimization

Introduction

Banana is a general term embracing a number of species or hybrids of the genus *Musa* of the family *Musaceae* which is cultivated in more than 100 countries throughout the tropics and subtropics. *Musa* is one of the cheapest food crops to produce and the cost of production is less than most other staples. The banana cultivars originated from the intra- and inter-specific hybridization of two wild diploid species, *Musa acuminata Colla* and *Musa balbisiana Colla*, contributing the A and B genomes respectively [1]. In terms of gross value of production, bananas are the developing world's fourth most important crop after rice, wheat, and maize. The bulk of the banana is eaten as raw [2] and only a very small proportion are processed in order to obtain a storable product [3]. They are harvested unripe and green, because they can ripen and spoil very rapidly.

Unfortunately, losses during banana production are very high, reaching 40% of the total, due to their highly perishable nature and inadequate post-harvest handling. These losses can be reduced by the processing of surplus fruits. Since unripe bananas contain large amounts of starch (over 70% of dry weight), their processing into flour and starch is of interest as a possible resource for food and/or other industrial purposes [4]. Unripe banana flour can be an alternative to minimize post-harvest loss and to increase the aggregate value of banana fruit. Subjecting *Musa spp.*, to processing methods will help enhance and improve the value of the fruit and make it available all year round for better utilization. Also, Banana is cheaper relatively when compared with wheat and other cereals for the production of flours.

Although, banana flour has recorded success when used in addition to the conventional wheat flour in baking and confectioneries, there is need to investigate the application of *Musa* flour from the point of view of their pasting properties. Pasting properties of starch/flour are used in assessing the suitability of their application in food and other industrial products [5]. During food processing, flour undergoes changes such as gelatinization and pasting which influence the texture and stability of the food products. Pasting properties of flour, starch and their products are important for their use in the food industry [6]. Harvesting at the correct maturity is the key to satisfying quality expectations. It is an important factor affecting quality perception and the rate of change of quality during post-harvest handling. By knowing the best stage to harvest Musa, it would be possible to schedule harvesting, handling and marketing operations efficiently. This will also help to determine their processing quality or suitability for processing.

Response surface methodology is made up of a mathematical statistical model of several input (independent, predictor) factors [7]. The response surface procedures are a collection involving experimental strategy, mathematical methods and statistical inference which when combined enable the experimenter to make an efficient empirical exploration of the system in which he is interested [8]. A computer takes the experimental results and calculates models using Taylor second-order equations which define relationship between variables and responses. The models can then be used to calculate any and all combinations of variables and their effects within the test range [9]. The most common response surface models are the central composite design (CCD) [10] and Box-Behnken (BB) designs [9]. The Box-Behnken design is one of the most efficient designs capable of generating a response surface.

Central Composite designs are very efficient providing much information on experimental variable effects and over-all experimental error in a minimum number of required runs [11]. Three main varieties of central composite designs are available [12]. 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 [11]. This work examines the effect of time of harvesting (using the Response surface methodology) on the pasting properties of selected varieties of banana so as to determine their suitability for use in food industries.

Materials and Methods

Materials

Banana fruits from Red banana (*Musa acuminata Colla AAA, cv.* 'Red'), Cooking banana (*Musa paradisiaca L AAB*) and Dessert banana (*Musa Cavendishii AAA*) respectively were obtained from banana trees located at Ado in Ekiti State, Nigeria. The time when the first bunch first became visible (shooting) on each tree was recorded. Bunches were tagged with different colored ribbons at the time of shooting and the colour of the ribbons was changed weekly to coincide with the time of shooting and subsequently the age of the bunch. These bunches of matured unripe banana fruits were harvested at three different maturity stages namely; stage 1 (11 weeks), stage 2 (13 weeks) and stage 3 (15 weeks).

Methods

Production of unripe banana flours: Unripe banana flour was produced according to the procedure of Saifullah et al. [13] with modifications. Fresh unripe bananas were washed and peeled. They were then cut into 0.5 cm slices using sharp knife and immediately dipped in sodium metabisulfite solution (1% w/v) for 15 min to inhibit oxidation/ browning. The slices were dried in the oven at 50°C for 48 h, milled and sieved to obtain fine "flour". Flour was stored in airtight plastic packs in cold storage (15 ± 2°C) for further analyses.

Pasting properties determination: Pasting characteristics of the flour samples was determined using a Rapid Visco Analyzer (RVA) (Model RVA 3D Network Scientific, Australia (CHEC). 2.5 g of flour 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 50°C to 95°C with a holding time of 2 minutes followed by cooling to 50°C with 2 minutes holding time. The rate of heating and cooling was at a constant rate of 11.25°C/min. 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 [14].

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

$$Y=\beta 0 + \beta 1x1 + \beta 2x2 + \beta 11x12 + \beta 22x22 + \beta 12x1x2 + \epsilon \quad (1)$$

Key: Y=dependent response variables such as peak viscosity, trough, pasting temperature etc., β_0, β_1......β_{12}=estimated regression coefficients, x_1, x_2,=independent variables in the model (bv, 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 weeks, bv=dessert banana; corner points were th=15 weeks, bv=cooking banana while the star points are th=11 weeks, and bv=red banana. Runs 1-8 were performed once while run 9 was performed seven times [15]. A total of 16 experimental runs were generated. The analytical determinations were conducted in duplicate.

Independent variables	Variable levels		
	-1	0	1
Banana varieties X_1	A	B	C
Time of harvesting X_2 (weeks)	11	13	15

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

Where A=flour from red banana; B=flour from dessert banana; C=flour from cooking banana; -1=low factor setting; 1=high factor setting; 0=mid-point

Run	X_1 (Banana variety)	X_2 (Time of harvesting)
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

Table 2: Experimental design for response surface methodology

Data on each run were statistically regressed and analyzed for variance using Minitab software (Minitab Inc., State College, PA). Statistical significance was accepted at 5% probability levels ($p \leq 0.05$). Plots of the fitted significant responses were made using Matlab software (version r2012a, Mathworks Inc., Natick, MA) to visualize these effects more clearly. Statistical Package for the Social Sciences (version 20, IBM Corporation, Armonk, NY) was used to obtain the mean; standard deviation and analysis of variance (ANOVA) was performed and judged for significance at p ≤ 0.05. Means were separated using Duncan's multiple range tests. Optimization was carried out using the Optimization Toolbox of Matlab r2012a software [16].

Results and Discussion

Results of the pasting properties of selected varieties of banana flour are shown in Tables 3 and 4. Variety and time of harvesting (Tables 3 and 4) had significant effect on the pasting properties of banana flour.

Variety/ Month	**Peak Viscosity (RVU)**	**Trough (RVU)**	**Breakdown (RVU)**	**Final Viscosity (RVU)**	**Setback (RVU)**	**Peak Time (min)**	**Pasting Temperature (°C)**
M. acuminata							
11 Weeks	489.10^{b} ± 12.87	343.08^{b} ± 0.11	200.89^{b} ± 0.34	390.00^{b} ± 3.04	89.47^{c} ± 0.21	4.67^{a} ± 0.03	64.85^{a} ± 0
13 Weeks	651.00^{a} ± 8.49	579.66^{a} ± 0.93	405.29^{a} ± 0	407.56^{a} ± 0.03	239.95^{a} ± 0.57	3.99^{c} ± 0	64.6^{b} ± 0.09
15 Weeks	310.96^{c} ± 14.79	214.88^{c} ± 19.64	70.75^{c} ± 0.33	285.63^{c} ± 0.18	96.08^{b} ± 0.11	4.28^{b} ± 0.01	64.72^{ab} ± 0.04
Total	483.67 ± 152.43	379.21 ± 165.75	225.64 ± 150.83	361.06 ± 58.97	141.83 ± 76.06	4.31 ± 0.31	64.73 ± 0.12
M. cavendishii							
11 Weeks	550.01^{a} ± 0.27	495.95^{a} ± 8.42	314.67^{a} ± 2.6	156.24^{c} ± 2.32	127.00^{a} ± 0	4.89^{a} ± 0	64.85^{b} ± 0
13 Weeks	515.87^{b} ± 7.02	501.21^{a} ± 1.57	257.67^{b} ± 1.12	429.20^{a} ± 0.14	120.00^{a} ± 12.94	4.39^{c} ± 0.01	64.81^{b} ± 0.04
15 Weeks	459.07^{c} ± 1.51	380.91^{b} ± 0.31	119.10^{c} ± 0.21	336.00^{b} ± 0.07	70.09^{b} ± 0.06	4.55^{b} ± 0.08	64.98^{a} ± 0
Total	508.32 ± 41.21	459.36 ± 60.93	230.48 ± 89.97	307.15 ± 124.11	105.70 ± 28.36	4.61 ± 0.23	64.88 ± 0.08
M. Paradisiaca							
11 Weeks	556.69^{b} ± 0	522.02^{b} ± 0.06	359.99^{b} ± 1.26	190.00^{c} ± 0	100.76^{b} ± 0.26	4.55^{b} ± 0	64.70^{c} ± 0.056
13 Weeks	671.00^{a} ± 15.7	610.25^{a} ± 13.79	406.43^{a} ± 0.95	433.82^{a} ± 0.21	258.12^{a} ± 0.17	4.01^{c} ± 0.03	64.81^{b} ± 0.01
15 Weeks	451.68^{c} ± 2.69	401.93^{c} ± 1.85	115.39^{c} ± 1.98	359.00^{b} ± 14.31	96.97^{c} ± 0.42	5.03^{a} ± 0.042	65.10^{a} ± 0.07
Total	559.79 ± 98.37	511.40 ± 93.73	293.94 ± 139.86	327.61 ± 111.9	151.95 ± 82.26	4.53 ± 0.46	64.87 ± 0.189

Table 3: Effect of time of harvesting on the pasting properties of flour from varieties of banana; ^{abc}Means in the same column bearing different superscripts are significantly different (P ≤0.05)

Variety/Month	**Peak viscosity (RVU)**	**Trough (RVU)**	**Break down (RVU)**	**Final Viscosity (RVU)**	**Setback (RVU)**	**Peak Time (RVU)**	**Pasting Temperature (°C)**
11 Weeks							
M. acuminata	481.10^{b} ± 12.87	343.08^{c} ± 0.11	200.89^{c} ± 0.34	390.00^{a} ± 3.04	89.47^{c} ± 0.21	4.67^{b} ± 0.03	64.85a ± 0
M. cavendishii	550.01^{a} ± 0.27	495.95^{b} ± 8.42	314.67^{b} ± 2.6	156.24^{c} ± 2.32	127.00^{a} ± 0.00	4.89^{a} ± 0	64.85^{a} ± 0
M. paradisiaca	556.69^{a} ± 0.00	522.02^{a} ± 0.06	359.99^{a} ± 1.26	190.00^{b} ± 0.00	100.76^{b} ± 0.26	4.55^{c} ± 0	64.70^{b} ± 0.06
Total	531.93 ± 33.81	453.68 ± 86.54	291.85 ± 73.33	245.41 ± 13.02	105.74 ± 17.22	4.70 ± 0.16	64.80 ± 0.08
13 Weeks							
M. acuminata	651.00^{a} ± 8.49	579.66^{b} ± 0.93	405.29^{a} ± 0	407.56^{c} ± 0.03	239.95^{a} ± 0.57	3.99^{b} ± 0	64.61^{b} ± 0.09
M. cavendishii	515.87^{b} ± 7.03	501.21^{c} ± 1.57	257.67^{b} ± 1.12	429.20^{b} ± 0.14	120.00^{b} ± 12.94	4.39^{a} ± 0.01	64.81^{a} ± 0.04

M. paradisiaca	671.00^a ± 15.70	610.25^a ± 3.79	406.43^a ± 0.95	433.82^a ± 0.21	258.12^a ± 0.17	4.01^b ± 0.03	64.81^a ± 0.01
Total	612.62 ± 76	563.71 ± 50.69	356.46 ± 76.53	423.53 ± 12.54	206.02 ± 67.38	4.13 ± 0.2	64.74 ± 0.11
15 Weeks							
M. acuminata	310.96^b ± 14.79	214.88^b ± 9.64	70.75^c ± 0.33	285.63^b ± 0.18	96.08^b ± 0.11	4.28^c ± 0.01	64.72^b ± 0.04
M. cavendishii	459.07^a ± 1.51	380.91^a ± 0.31	119.10^a ± 0.21	336.00^a ± 0.01	70.09^c ± 0.06	4.55^b ± 0.09	64.98^a ± 0
M. paradisiaca	451.68^a ± 2.69	401.93^a ± 1.85	115.39^b ± 1.98	359.00^a ± 14.31	96.97^a ± 0.42	5.03^a ± 0.04	65.10^a ± 0.07
Total	407.24 ± 74.95	332.57 ± 2.07	101.75 ± 24.08	326.88 ± 4.17	87.71 ± 13.66	4.62 ± 0.34	64.93 ± 0.18

Table 4: Varietal effect on the pasting properties of banana flour; ^{abc}Means in the same column bearing different superscripts are significantly different (P ≤ 0.05)

Peak viscosity

Peak viscosity (PV) ranged between 310RVU and 671RVU, the lowest for *M. acuminata* (15 weeks) and the highest for *M. paradisiaca* (13weeks) (Table 3). 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 [17]. Ragaee and Abdel-Aal [18] 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 [19] stated that the structural differences in the amylopectin molecules of the flour sources may be a contributory factor in the increase in peak viscosity. On the other hand, Mepba et al. [20] reported that there exists a linear logarithmic correlation between maximum viscosity and starch concentration.

Results of the regression of data on the peak viscosity of banana flour are shown in Tables 5a and 5b.

Predictor	Coefficients	StDev	P
Regression on constant	-3331	1389	0.037
Bv	-80.8	184.2	0.670
Th	625.8	213.7	0.015
bv*th	9.14	14.06	0.530
bv*bv	55.29	32.83	0.123
th*th	-25.270	8.208	0.012

Table 5a: Estimated regression coefficients for peak viscosity of banana flour using the variables; Th=Time of harvesting; Bv=Banana varieties

Standard Error: 56.23, R-Square: 66.8%, Adjusted R-Square: 50.2%

The linear and quadratic effect of time of harvesting had significant effect (p ≤ 0.05) on the peak viscosity of banana flour.

The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Peak viscosity} = -3331 + 625.8th - 25.270th^2 \quad (2)$$

Analysis of variance showed that the variables had significant effect (p ≤ 0.05) on the peak viscosity of banana flour.

Response surface plot (Figure 1) shows that peak viscosity of 623.9RVU was obtained from *M. paradisiaca* at the 13th month of harvest. Optimization showed that the maximum peak viscosity obtainable was 628.99RVU from *M. paradisiaca* at the 13th week of harvest while the minimum peak viscosity obtainable was 352.57RVU, from *M. acuminata* and at the 15th week of harvest. However, the regression indicated an R^2 of 66.8%, which confers good fitness of fit.

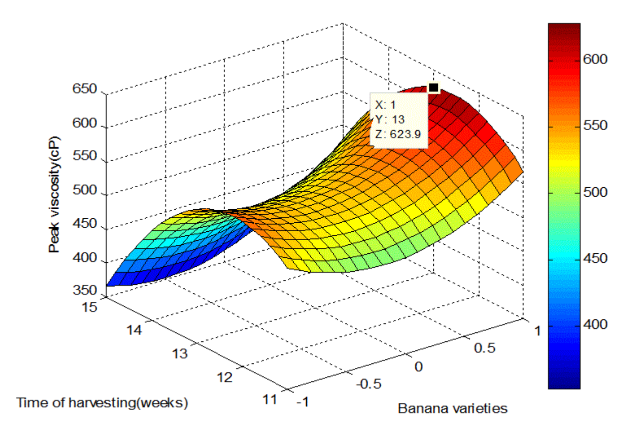


Figure 1: Response surface curves of effects of time of harvesting and banana varieties on the peak viscosity of banana flour

Trough viscosity

Trough or hot paste viscosity, which is the viscosity at the end of holding time at 95°C [21] ranged from 214.88RVU for *M. acuminata* (15 weeks) to 610RVU for *M. paradisiaca* (13 weeks). Higher holding strength of flour from cooking banana (13 weeks) might be due to strong associative forces within its starch granules [22]. Regression coefficients for trough viscosity of banana flour are shown in Tables 6a and 6b.

Source	DF	SS	MS	F	P
Regression	5	63589	12718	4.02	0.029
Error	10	31622	3162	-	-
Total	15	95211	-	-	-

Table 5b: Estimated analysis of variance (ANOVA) for peak viscosity of banana flour using the variables; Th=time of harvesting; Bv=banana varieties

Predictor	Coef	St. Dev	P
Regression on constant	-4848	1278	0.004
Bv	52.9	169.5	0.761
Th	855.5	196.7	0.001
bv*th	1.01	12.94	0.939
bv*bv	20.25	30.22	0.518
th*th	-34.070	7.555	0.000

Table 6a: Estimated regression coefficients for trough viscosity of banana flour using the variables; Th=time of harvesting; Bv=banana varieties

Standard Error: 51.75; R-Square: 80.4%; Adjusted R-Square: 70.6%

Source	DF	SS	MS	F	P
Regression	5	109755	21951	8.20	0.003
Error	10	26785	2679	-	-
Total	15	136541	-	-	-

Table 6b: Estimated analysis of variance (ANOVA) for trough viscosity of banana flour using the variables; Th=time of harvesting; Bv=banana varieties

The linear and quadratic effects of time of harvesting had significant effect on the trough viscosity of banana flour. The resulting polynomial after removing non-significant terms for the analysis becomes:

Trough viscosity=-4848+855.5th –34.070th^2 (3)

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

Response surface plot (Figure 2) shows that trough viscosity of 603.3RVU was obtained from *M. paradisiaca* at the 13t^{h} week of harvest. Optimization showed that the maximum trough viscosity obtainable was 609.72RVU at the 13^{t}h week of harvest, from *M. paradisiaca* while the minimum trough viscosity obtainable was 271.70RVU from *M. acuminata* at the 15th week of harvest. Regression showed an R^2 of 80.4% which indicates goodness of fit.

Breakdown viscosity

The breakdown viscosity which is regarded as a measure of the degree of disintegration of granules or paste stability [6] ranged from 70.75RVU (*M. acuminata*-15 weeks) to 406.43RVU (*M. paradisiaca* - 13 weeks). Oduro et al. [23] reported that starches/flours with low paste stability or breakdown have very weak crosslinking within the granules. A low breakdown value suggests that they are more stable under hot condition [24]. It therefore means that there is stronger cross-linking within the granules of flour sample from *M. paradisiaca* (13 weeks).

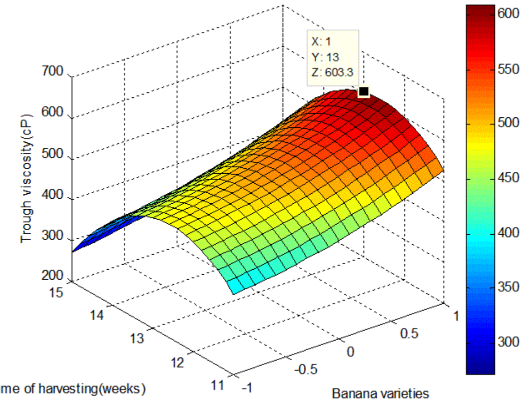


Figure 2: Response surface curve of effects of time of harvesting and banana varieties on the trough viscosity of banana flour

Regression coefficients on the breakdown of banana flour are shown in Tables 7a and 7b.

Predictor	Coef	St. Dev	P
Regression on constant	-4256	1272	0.007
Bv	220.1	168.7	0.221
Th	744.4	195.8	0.003
bv*th	-14.31	12.88	0.293
bv*bv	67.14	30.07	0.050
th*th	-30.460	7.519	0.002

Table 7a: Estimated regression coefficients for breakdown viscosity of banana flour using the variables; Th=time of harvesting; Bv=banana varieties.

Standard Error: 51.51; R-Square: 80.3%; Adjusted R-Square: 70.5%

Source	DF	SS	MS	F	P
Regression	5	108421	21684	8.17	0.003
Error	10	26530	2653	-	-

Total	15	134952	-	-	-

Table 7b: Estimated Analysis of variance for breakdown viscosity of banana flour using the variables; Th=time of harvesting; Bv=banana varieties

Linear effect of time of harvesting and quadratic effect of banana variety and time of harvesting had significant effect ($p \leq 0.05$) on the breakdown viscosity of banana flour. The resulting polynomial after removing non-significant terms for the analysis becomes:

Breakdown viscosity=-4256+744.4th +67.14bv.bv −30.460th.th (4)

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

In the response surface curve (Figure 3), breakdown value of 362.7RVU was obtained from *M. paradisiaca* at the 13th week of harvest. Optimization showed that the minimum breakdown viscosity obtainable was 41.39RVU and it was obtained from *M. cavendishii* at the 15th week of harvest while the maximum breakdown value obtainable was 395.54RVU, from *M. paradisiaca* at the 13th week of harvest. Regression showed an R^2 of 80.3% which confers goodness of fit to the analysis.

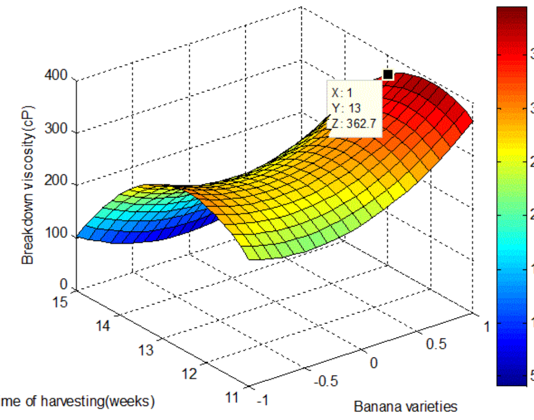


Figure 3: Response surface curves of effects of time of harvesting and banana varieties on the breakdown viscosity of banana flour

Final viscosity

Final viscosity indicates the stability of cooked starch paste in actual use and ability of a starch to form a paste or gel after cooling [25]. The high final viscosity (433.8RVU) exhibited by flour sample from *M. paradisiaca* - 13 weeks makes them more suitable in many food products such as sauces, soups, dressings and in the textile and the wet stage of paper making where high viscosity is desired and indicates that the gel does not break. The low final viscosity (156.2RVU) of flour sample from *M. cavendishii* (11 weeks) makes them more suitable in the dry stage of paper production where lower viscosity and good film forming capacity are preferred [26].

Regression coefficients on the final viscosity of banana flour are shown in Tables 8a and 8b.

Predictor	**Coef**	**StDev**	**P**
Regression on constant	-6307.2	903.9	0.000
Bv	-460.1	119.9	0.003
Th	1015.1	139.1	0.000
bv*th	34.171	9.150	0.004
bv*bv	24.04	21.37	0.287
th*th	-38.258	5.343	0.000

Table 8a: Estimated regression coefficients for final viscosity of banana flour using the variables; Th=Time of harvesting; Bv=Cassava varieties

Standard Error: 36.36; R-Square: 88.9%; Adjusted R-Square: 83.3%

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	5	107264	21453	16.01	0.000
Error	10	13396	1340	-	-
Total	15	120660	-	-	-

Table 8b: Estimated analysis of variance (ANOVA) for final viscosity of banana flour using the variables; Th=Time of harvesting; Bv=Cassava varieties

Linear effect of banana variety and time of harvesting, interaction between banana variety and time of harvesting and quadratic effect of time of harvesting had significant effect ($p \leq 0.05$) on the final viscosity of banana flours.

The resulting polynomial after removing non-significant terms for the analysis becomes:

Final viscosity=-6307.2–460.1bv +1015.1th +34.171bv.th –38.258th.th (4)

Analysis of variance shows that the variables had significant effect ($p \leq 0.05$) on the final viscosity of banana flour. From the response surface curve (Figure 4), final viscosity of 454.7RVU was obtained from *M. acuminata* at the 13th week of harvest. Final viscosities are important in determining ability of the sample material to form a gel during processing. The exhibition of final viscosity by individual flour samples is a reflection of their ability to form a viscous paste or gel after cooking and cooling [27].

On the other hand, optimization indicated that the maximum possible value for final viscosity was 456.17RVU and it was obtained from *M. acuminata* at the 13th week of harvest while the minimum possible value for final viscosity was 163.90RVU obtained from *M. paradisiaca* at the 11th week of harvest. Regression showed an R^2 of 88.9% which confers goodness of fit to the analysis.

Setback viscosity

Results of the setback viscosity of the flour samples ranged from 70.09RVU – *M. cavendishii* (15 weeks) to 258.12RVU – *M. paradisiaca* (13 weeks). Setback is the cooling phase of the mixture during pasting in which a re-association between the starch molecules occurs to a greater or lesser degree [28]. Sanni et al. [28] reported that lower setback viscosity indicates higher resistance to retrogradation and Etudaiye et al. [29] reported that it indicates high stability.

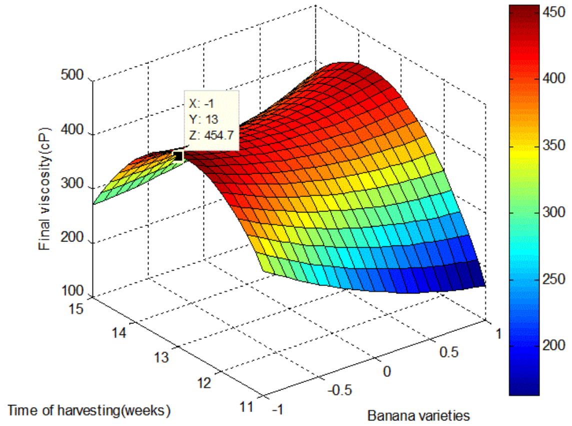


Figure 4: Response surface curves of effects of time of harvesting and banana varieties on the final viscosity of banana flour

The high set back viscosity of flour from *M. paradisiaca* (13 weeks) would limit its application in the food and textile industries [26]. High setback value is associated with a cohesive paste and has been reported to be significant in domestic products like pounded yam which requires high setback, high viscosity and high paste stability [30].

Regression coefficients for setback viscosity of banana flours are shown in Tables 9a and 9b.

Predictor	Coef	StDev	P
Regression on constant	-3246.3	917.7	0.005
Bv	22.0	121.7	0.860
Th	524.2	141.2	0.004
bv*th	-1.300	9.290	0.891
bv*bv	69.14	21.70	0.010
th*th	-20.336	5.424	0.004

Table 9a: Estimated regression coefficients for setback viscosity of banana flour using the variables; Th=time of harvesting; Bv=Banana varieties

Standard Error: 37.16; R-Square: 63.2%; Adjusted R-Square: 44.8%

Source	DF	SS	MS	F	P
Regression	5	23725	4745	3.44	0.046
Error	10	13808	1381	-	-
Total	15	37533	-	-	-

Table 9b: Estimated analysis of variance (ANOVA) for setback viscosity of banana flour using the variables; Th=time of harvesting; Bv=banana varieties

Linear effect of time of harvesting and quadratic effect of banana variety and time of harvesting had significant effect ($p \leq 0.05$) on the setback viscosity of banana flour. The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Setback viscosity}=-3246.3+524.2th+69.14bv.bv-20.336th.th \quad (6)$$

Analysis of variance showed that the variables had significant effect ($p \leq 0.05$) on the setback viscosity of banana flour. In the response surface curve (Figure 5), setback viscosity of 209.5RVU was obtained from cooking banana at the 13th week of harvesting.

Optimization showed that the maximum setback viscosity of banana flours obtainable was 209.8RVU, from *M. paradisiaca* at the 13th week of harvest while the minimum setback viscosity of banana flour obtainable was 46.48RVU and it was obtained from *M. cavendishii* which was 15 weeks old. An R2 of 63.2%, which indicates a goodness of fit, was established.

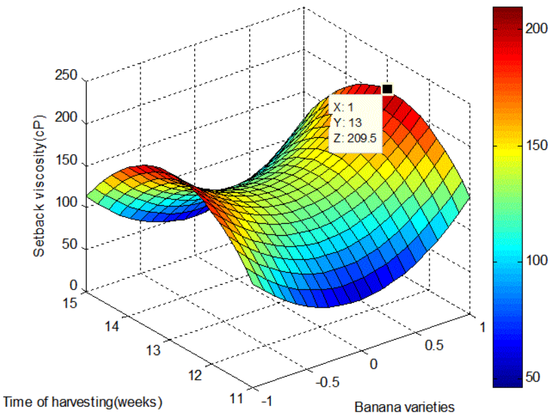


Figure 5: Response surface curves of effects of time of harvesting and banana variety on the setback viscosity of banana flour

Pasting temperature (°C)

The pasting temperature which is a measure of the minimum temperature required to cook a given foodstuff [14], ranged from 64.61°C for *M. acuminata* (13 weeks) to 65.10°C for *M. paradisiaca* (15 weeks). The low pasting temperature of the banana flours 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. It is clear from the result that the flour samples will cook faster and less energy consumed thereby saving cost and time. High pasting temperature indicates higher resistance towards swelling [31].

Regression coefficients for pasting temperature of banana flour are shown in Tables 10a and 10b. Experimental variables had significant effect on the pasting temperature of banana flours. The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Pasting temperature}=69.3385-0.78958bv-0.73042th+0.066250bv.th-0.08750bv.bv+0.029375th.th \quad (7)$$

Analysis of variance showed that the variables had significant effect ($p \leq 0.05$) on the pasting temperature of banana flour. In the response surface curve (Figure 6), pasting temperature of 65.08°C was obtained from *M. paradisiaca* at the 15th week of harvesting.

Optimization showed that the maximum pasting temperature of banana flours obtainable was 65.08°C, from *M. paradisiaca* at the 15th week of harvest while the minimum pasting temperature of banana flour obtainable was 64.61°C and it was obtained from *M. acuminata* which was 13 weeks old. An R^2 of 98.3%, which indicates a goodness of fit, was established.

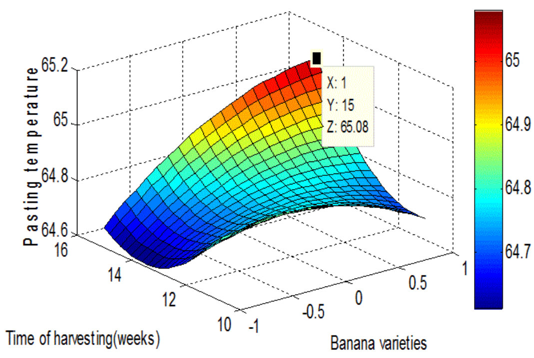
Predictor	Coef	StDev	P
Regression on constant	69.3385	0.4254	0.000
Bv	-0.78958	0.05642	0.000
Th	-0.73042	0.06546	0.000
bv*th	0.066250	0.004306	0.000
bv*bv	-0.08750	0.01006	0.000
th*th	0.029375	0.002514	0.000

Table 10a: Estimated regression coefficients for pasting temperature of banana flour using the variables; Th=Time of harvesting; Bv=banana varieties

Standard Error: 0.01722; R-Square: 98.3%; Adjusted R-Square: 97.5%

Source	DF	SS	MS	F	P
Regression	5	0.172208	0.034442	116.10	0.000
Error	10	0.002967	0.000297	-	-
Total	15	0.175175	-	-	-

Table 10b: Estimated analysis of variance (ANOVA) for pasting temperature of banana flour using the variables; Th=Time of harvesting; Bv=Banana varieties



Peak time

Peak time which is the time at which viscosity peaks [29] and gives a measure of the cooking time [32] ranged from 3.99 minutes (*M. acuminate* - 13 weeks old) to 5.03 minutes (*M. paradisiaca* – 15 weeks old). Flours with short peak paste time have low resistance to swelling and would be expected to swell rapidly and become susceptible to concurrent shear induced disintegration [6]. A long paste peak time may be associated with granules which swell more gradually and thus are not as susceptible to mechanical damage [33].

Regression coefficients for the peak time of banana flour are shown in Tables 11a and 11b.

Predictor	Coef	Se	P
Regression on constant	23.957	2.482	0.000
Bv	-1.4500	0.3292	0.001
Th	-2.9858	0.3820	0.000
bv*th	0.12000	0.02513	0.000
bv*bv	-0.21500	0.05869	0.004
th*th	0.11375	0.01467	0.000

Table 11a: Estimated regression coefficients for peak time of banana flour using the variables; Th=Time of harvesting; Bv=Banana varieties

Standard Error: 0.1005; R-Square: 90.2%; Adjusted R-Square: 85.3%

Source	DF	SS	MS	F	P
Regression	5	0.92957	0.18591	18.40	0.000
Error	10	0.10103	0.01010	-	-
Total	15	1.03060	-	-	-

Table 11a: Estimated analysis of variance (ANOVA) for peak time of banana flour using the variables; Th=Time of harvesting; Bv=Banana varieties

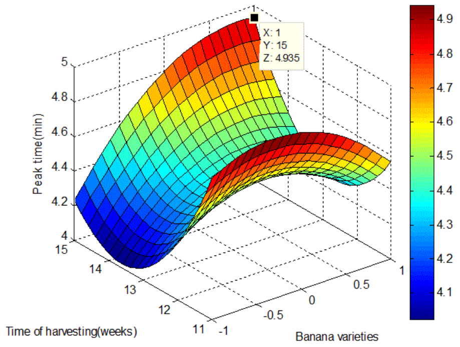


Figure 7: Response surface curves of effects of time of harvesting and banana varieties on the peak time of banana flour

Experimental variables had significant effect on the peak time of banana flours. The resulting polynomial after removing non-significant terms for the analysis becomes:

Peak time=23.957−1.4500bv −2.9858th+0.12000bv.th −0.21500bv.bv +0.11375th.th (8)

Analysis of variance showed that the variables had significant effect ($p \leq 0.05$) on the peak time of banana flour. In the response surface curve (Figure 7), peak time of 4.935 min was obtained from cooking banana at the 15th week of harvesting.

Optimization showed that the maximum peak time of banana flours obtainable was 4.94 min from *M. paradisiaca* at the 15th week of harvest while the minimum peak time of banana flour obtainable was 4.02 min and it was obtained from *M. acuminata* which was 13 weeks old. An R^2 of 90.2%, which indicates a goodness of fit, was established.

Conclusion

Variety and time of harvesting significantly ($p \leq 0.05$) affected the pasting properties of flour from the banana varieties. The high peak viscosity (671RVU) of *M. paradisiaca* (13 weeks) flours would make them very useful in food applications where high thickening power is desired such as in the production of jellies or binders. The low peak viscosity (310RVU) of *M. acuminata* (15 weeks) flours shows that the flours will be more stable under hot conditions than the other flour samples and they are desirable for preparing weaning foods and lighter gruels. Flour from *M. acuminata* (15 weeks) had the lowest breakdown value (70.75RVU) and this shows that it is more stable than the other flour samples. High final viscosity (433.8RVU) and high trough (610RVU) of flour from the banana variety *M. paradisiaca* (13 weeks) indicate that it has the ability to withstand heating and shear stress during processing. Low peak time (3.99 min) and pasting temperature (64.61°C) of flour from *M. acuminata* (13 weeks) suggests that they have low resistance to swelling and they easily formed pastes, hence more suitable in most food and non-food industrial processes because of reduced energy costs during production processes. Based on the results obtained, banana flour has a good potential to be used in the food industry.

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