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Optimization of Yam Milling-A Response Surface Approach

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Abstract: This study was performed to optimise the process of milling dry yam using central composite rotatable design of response surface methodology. The independent variables were; feed moisture content (8, 12, 16, 20, 24% w.b, respectively), worm shaft speed (288, 346, 432, 576, 864 r.p.m, respectively) and feed opening (1300, 2600, 3900, 5200, 6500 mm^2, respectively). Data were analysed by regression and ANOVA. Maximum, minimum and mean percentages of flour obtained were 56.3, 42.2 and 49.1±4.3%, respectively. Maximum, minimum and mean percentages of grit were 35.9, 21.1 and 26.7±3.4%, respectively. Maximum, minimum and mean percentages of meal obtained from yam milling were 33.7, 12.8 and 24.3±4.6%, respectively. Coefficients of determination R^2 for flour, meal and grit models were 0.73, 0.72 and 0.73, respectively. The best desirability (0.78) was achieved at moisture content of 12% w.b., worm shaft speed of 576 rpm and feed opening of 5200 mm^2. These process parameters gave 19.13% grit, 23.59% meal and 54.20% flour.

Keywords: Milling efficiency, models, optimisation, process variables, yam flour

INTRODUCTION

Yam (*Dioscorea specie*) is an important source of carbohydrate for many people of the sub-Saharan region, especially in the yam zone of West Africa (Akissoe *et al*., 2003). Yam tuber belongs to the genus *Dioscorea* of the family *dioscoreaceae*: which has about 600 species of which *D.alata*, *D.cayennensis* Lam and *D.rotundata* Poir, has the greatest economic importance. Yams are wide spread and are one of the major stable foods in many tropical countries (Omonigbo and Ikenebomeh, 2000). Nigeria is the world's largest producer of edible yams, with *D. rotundata* and *D. alata* as the two most cultivated yam species in the country (Federal Office of Statistics, 2007). Yams like other root and tuber crops are subject to physiological deterioration after harvest leading to fresh weight losses up to 60% after 9 months storage (Mozie, 1988), up to 70% rotted tubers after 5 months and up to 60-70% losses of consumable dry matter after 10 months (Giradin *et al*., 1998).

The global production of yam has risen significantly over the years leading to large amount of losses usually during storage in developing countries like Nigeria. Yam flour production enhances the utilisation and storability of yam. In addition, demand for yam flour has increased significantly due to attendant advantages of been an easy substitute to fresh yam, easily reconstituted and offers longer shelf life. Like many agricultural products, the processing of the raw material into the consumable stages usually entails size reduction. Quality of the product depends on milling efficiency which is influenced by the design of the milling machine. Available literature on yam flour milling does not cover the effect of processing parameters (such as moisture content of dry yam, feed opening, machine speed) during milling on quality characteristics of the yam flour derived.

In order to have an efficient process, it is necessary to have a clear insight into the mechanisms of yam flour milling and an understanding of the important process variables. Prediction of flour texture and quality can then be obtained in terms of process parameters. Studies to generate models and data that can serve as useful tool in adequate selection of processes and equipment for efficient milling of yam at different processing parameters are necessary. This is with a view to optimise yam flour production. Thus, the objective of this study is to determine effect of machine speed, moisture content, feeding opening on fractions of dry milled yam.

MATERIALS AND METHODS

The experimental studies were carried out in the laboratory of the Department of Agricultural and

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Experimental design: Central composite rotatable experimental design was employed (Mullen and Ennis, 1979). In using rotatable designs, the levels of a variable in range are spanned without going to the extremes. Using the plan provided for the three variable case, 15 different formulations are prepared. Twenty-one formulations with six repetitions of the 0, 0, 0 formulations and a numerical sense response was obtained for each formulation. By replicating the center points, a very good power of prediction at the middle of the experimental region is obtained. Five levels of moisture contents (8.0, 12.0, 16.0, 20.0, 24.0 % w.b, respectively), speed of worm shafts (288, 346, 432, 576, 864 r.p.m, respectively) and feeding rate openings (1300, 2600, 3900, 5200, 6500 mm^2, respectively) were investigated (Table 1).

Material preparations: Fresh white yam (*Dioscorea rotundata*) was purchased from a local market (Bodija) in Ibadan, Nigeria. The moisture content was determined using the (Horwitz, 2005) The tubers were washed, manually peeled (using very sharp stainless steel knives and cut into rectangular slices of thickness having 50x10x30 mm. The slices were blanched at 63°C for 5 min and the blanched slices were immediately cooled in cold water (25°C) for 5 min to remove excess heat. Samples were weighed into sample containers. Yam samples were then transferred into the dryer (Hotpack Supermatec, Phila, P.A. U.S.A). The dryer was allowed to run for about an hour prior to loading of samples to allow the heated air to stabilise at the desired temperature of 105°C and at constant air velocity (1.5 ms^{-1}). The samples were removed at regular intervals until constant weight was achieved. The samples were cooled in desiccators and weighed to determine moisture loss by using a digital compact balance model (AND 6100i Digital Weighing Balance, A&D Co. Ltd. Japan) that weighs within ±1 mg in 2 decimal places. The moisture contents was calculated using Eq. (1):

$$M = \frac{M_2 - M_3}{M_2 - M_1} \times 100 = \frac{Loss\ in\ weight}{initial\ weight\ of\ sample} \times 100 \qquad (1)$$

where,
M_1: Mass of container (g)
M_2: Mass of sample + container (g)
M_3: Mass of dried sample + container (g)

Speed variation: Five pulley diameters 10, 15, 20, 25 and 30 cm, respectively where used to vary the speed of the worm shaft by pulley arrangement (via transmission v-belts) with a 1440 r.p.m., 2hp ARNO electric motor. Hence five varying shaft speed were derived which are 288, 346, 432, 576 and 864 r.p.m, respectively. The pulleys were mounted on a 3 cm diameter shaft that is mounted on ball bearings and extended to drive the mill; the shaft was fastened to the frame carrying the mill. Speed was varied using Eq. (2):

$$V = \pi n_2 \mathrm{Dp}_2 = \pi n_3 \mathrm{Dp}_3 \qquad (2)$$

where,
n_2, n_3 : Angular speeds of rotation of sheaves 2 and 3, respectively in rev/s
Dp_2, Dp_3 : Pitch diameters of sheaves 2 and 3, respectively (m)

Feed opening variation: The rate of entry of the dried yam samples was varied by using a sliding gate arrangement as described by (Sanjay and Agrawal, 2005) The discharge end of the hopper measuring (6.5x10 cm i.e., 6500 mm^2) was divided into five entry levels 1300, 2600, 3900, 5200 and 6500 mm^2, respectively. This corresponds to opening lengths of 2, 4, 6, 8, 10 cm, respectively.

Milling: The yam samples (5 mm on the average) were adjusted to various moisture contents considered in the study. Prepared samples (1 kg) were fed into the hopper at pre-determined openings (feeding openings) and milled with the plate mill at determined worm shaft speed. The milled samples were then collected in separate buckets. The milled product consisted of a mixture of grits, meal and flour. A total of 21 treatment combinations were carried out for the entire experiment (Table 2).

Particle size distribution: Particle size was determined by shaking the mixture for 20 min using a laboratory sieve shaker (WQS Vibrator) (Plate 3.4). This comprised of the sieves with standard sieve apertures BSS6 to BSS90, a lid and solid base (pan). The sieves were made of brass frame and steel mesh. A milled sample was fed unto the largest sieve size and covered with a lid. The sieve arrangement was then clamped onto the rotap shaking machine and operated for 20 min during which each sieve retained a fraction of the sample. The retained fraction on each sieve and the sieve was weighed using a sensitive balance (AND EK-6100i Digital Compact Balance, A&D Co. Ltd. Japan)

Table 1: Process variable used in the rotatable design

	Variable level cod					
	Code	-1.682	-1	0	1	1.682
Moisture content (w.b)	X_1	8	12	16	20	24
Shaft speed (rpm)	X_2	288	346	432	576	864
Feeding opening (mm²)	X_3	1300	2600	3900	5200	6500

Table 2: Fractions obtain after milling of different treatment combinations

Variables				Fractions		
Tratment	X_1	X_2	X_3	Grits (g)	Meal (g)	Flour (g)
1	12	346	2600	200.8	257.6	541.6
2	12	346	5200	204.0	230.4	565.6
3	12	576	2600	202.2	233.6	564.2
4	12	576	5200	203.6	242.4	554.0
5	20	346	2600	221.8	284.6	493.6
6	20	346	5200	234.9	270.7	494.4
7	20	576	2600	228.7	278.9	492.4
8	20	576	5200	226.4	282.6	491.0
9	24	432	3900	276.9	300.1	423.0
10	8	432	3900	306.8	210.6	482.6
11	16	864	3900	219.0	308.0	473.0
12	16	288	3900	127.8	358.6	513.6
13	16	432	6500	271.6	218.8	509.6
14	16	432	1300	269.4	264.2	466.4
15	16	432	3900	245.4	257.5	497.6
16	16	432	3900	286.4	274.6	439.0
17	16	432	3900	337.2	240.6	422.2
18	16	432	3900	276.5	275.5	448.0
19	16	432	3900	265.2	260.8	474.0
20	16	432	3900	255.9	280.1	464.0
21	16	432	3900	288.0	264.2	447.8

(Plate 3.3) for improved accuracy. The weights of the empty sieves were taken before the experiment. The weights of the retained fractions were then taken as the difference of the two readings (i.e., sieve and fraction less the sieve). The retained fractions were classified into grits (g) (those that passed through 2.81 mm sieve), meal (g) (those that passed through 1.00 mm sieve) and flour (g) (those that passed through 0.211 mm sieve) (Matz, 1970). The milling efficiency was determined using Eq. (3):

$$Milling\ Efficiency = \frac{W_1}{W_2} \times 100 \tag{3}$$

where,

W_1: Weight of fraction (g)
W_2: Total weight of milled products (g)

Statistical data analysis: Data were analysed using multiple regression technique. A commercial statistical package, design expert 8.0 trial versions (Stat Ease Inc. Minneapolis, U.S.A) was used for response surface analysis and optimisation. Models were generated for these responses (grit, meal and flour). The three variable model for a rotatable response surface design is:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 \tag{4}$$

where,

Y: Response (dependent variable)
β_o: Constant term
β: Coefficients which indicate the importance of their associated X value
X_i: Independent variables in coded values

RESULTS AND DISCUSSION

Effect of process variables on flour: Milling efficiencies were generally high for flour when compared with grits and meal (Table 2). Similar observations were reported for partially deflated hazelnut flour (Sibel and Fahretin, 2009). Maximum, minimum and mean percentages of flour obtained were 56.3, 42.2 and 49.1±4.3%, respectively (Table 3). Peak

Table 3: Values of milling responses (efficiencies) for different treatment combinations

Efficiencies				Responses		
Treatment	Grits (g)	Meal (g)	Flour (g)	Grit (%)	Meal (%)	Flour (%)
1	200.8	257.6	541.6	20.08	25.76	54.16
2	204.0	230.4	565.6	20.40	23.04	56.56
3	202.2	233.6	564.2	20.22	23.36	56.42
4	203.6	242.4	554.0	20.36	24.24	55.40
5	221.8	284.6	493.6	22.18	28.46	49.36
6	234.9	270.7	494.4	23.49	27.07	49.44
7	228.7	278.9	492.4	22.87	27.89	49.24
8	226.4	282.6	491.0	22.64	28.26	49.10
9	276.9	300.1	423.0	27.69	30.01	42.30
10	306.8	210.6	482.6	30.68	21.06	48.26
11	219.0	308.0	473.0	21.90	30.80	47.30
12	127.8	358.6	513.6	12.78	35.86	51.36
13	271.6	218.8	509.6	12.78	35.86	51.36
14	269.4	264.2	466.4	26.94	26.42	46.64
15	245.4	257.5	497.6	24.54	25.75	49.76
16	286.4	274.6	439.0	28.64	27.46	43.90
17	337.2	240.6	422.2	33.72	24.06	42.22
18	276.5	275.5	448.0	27.65	27.55	44.80
19	265.2	260.8	474.0	26.52	26.08	47.40
20	255.9	280.1	464.0	25.59	28.01	46.40
21	288.0	264.2	447.8	28.80	26.42	44.78

efficiency of 56.6% was attained at moisture content of 12%, worm shaft speed of 346 r.p.m and feeding opening of 5200 mm^2 conducted at one pass of feed. Similar results were reported by (Sanjay and Agrawal, 2005) in the milling of green gram using roller mill at 10% d.b moisture content, 140 mm^2 outlet opening, 13 m/s roller speed, 32 cm roller length and 5^o roller inclination. A maximum hulling efficiency of 73.72% was reported. Variation in the efficiency may be traced to design mechanism of the milling machines. Roller mills achieve greater efficiency than plate mills (McCabe *et al*., 2005).

Using coded values, mathematical relationship between the independent and dependent variables is expressed as Eq. (5):

$$F = 45.89 + 0.65 * A - 1.26 * B + 1.50 * C + 0.56A * \mathrm{B} - 0.24A * C + 2.47 * B * C + 2.62 * A^2 + 0.50 * B^2 + 1.50 * C^2 \quad (5)$$

$R^2 = 0.73$ $\quad\quad$ $F - value = 3.29$

where,

F: Flour
A: Moisture content (%)
B: Worm shaft speed (r.p.m)
C: Feeding opening (mm^2)
R^2: Coefficient of determination

From the model summary statistics, the quadratic model comes out best. Analysis of Variance (ANOVA) of the data confirms the adequacy of the quadratic model at $p<0.10$. The quadratic response surface model shows a non-significant lack of fit. The multiple regression models developed in predicting the flour fraction could explain 73% of the observed variations. Coefficient of determination R^2 (0.73) is high, an indication that the model has a good fit. The feed moisture level was found to be the most significant process variable influencing the flour fraction. The combined effect of the process variables is significant at $p<0.10$.

Effect of process variables on meal: Maximum, minimum and mean percentages were 35.9, 21.1 and 26.7±3.4%, respectively (Table 3). In coded values, Functional relationship between process variables and meal fraction is as expressed in Eq. (6):

$$M = 26.38+3.72*A+ 1.69 * B - 1.50* C - 0.20 * A * B- 0.19 * A* C - 0.36 * B * C+ 0.86 * A^2 - 0.87 * B^2 + 0.39 * C^2 - 0.77 * A * B * C - 1.69 * A^2 * B + 1.30 * A^2 * C - 5.17 * A* B^2 \quad (6)$$

($R^2 = 0.72$) $\quad\quad$ F – value = 4.68
where,

M: Meal

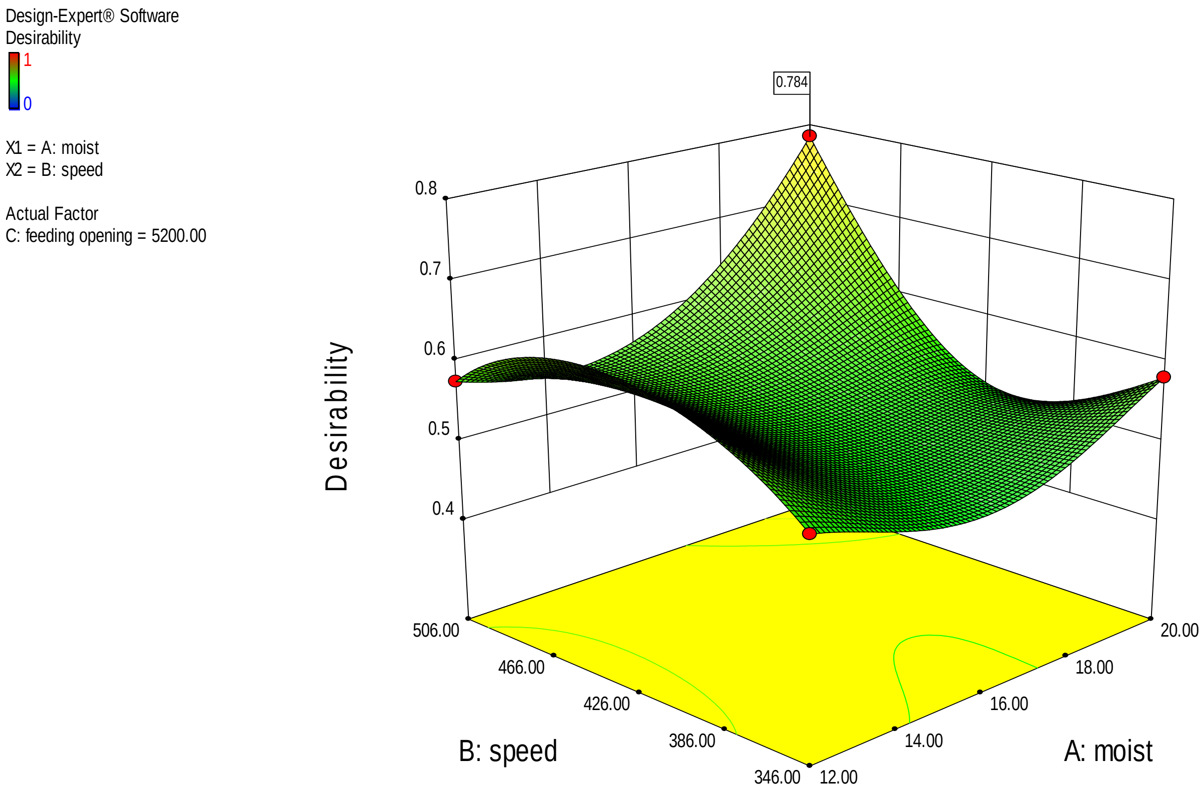

Fig. 1: Response surface plots of the compromise optima

The multiple regression models developed in predicting meal fraction could explain 72% of its variations and a non-significant lack of fit. Coefficient of determination R^2 (0.72) is high, an indication that the model has a good fit. ANOVA confirms the adequacy of the model at $p<0.05$. Moisture content and shaft speed showed significant influence on the model at $p<0.05$. From the model summary statistics, the cubic model comes out best.

Effect of process variables on grit: Maximum, minimum and mean percentages of meal obtained from yam milling were 33.7, 12.8 and 24.3±4.6%, respectively (Table 3). Functional relationship between process variables and grit fraction is as expressed in Eq. (7):

$$Gt = 27.72 - 1.34 * A + 0.57 * B - 0.76 * C - 0.36 * A * B + 0.43 * A * C - 2.11 * B * C - 3.48 * A^2 + 0.37 * B^2 - 1.90 * C^2 \quad (7)$$

$$(R^2 = 0.73) \qquad F - value = 6.44$$

where,
Gt: Grit

From the model summary statistic, the Quadratic model comes out best. The ANOVA confirms the adequacy of the quadratic model (the model Prob>f is less than 0.05). Coefficient of determination R^2 is high, an indication that the model has a good fit. The quadratic model does not show significant lack of fit. The variables which showed significant influence on the model was its feed moisture content at $p<0.05$ and a quadratic response model was found to be appropriate.

Optimisation of processing conditions: Optimization of the process produced twenty-six possible solutions with desirability range from 0.52 to 0.784. The desirability lies between 0 and 1; and it represents the closeness of a response to its ideal value. If a response falls within the unaceptable intervals the desirability is 0 and if it falls within the ideal intervals or the response reach as to ideal value, the desirability is 1. The best desirability (0.78) was achieved at moisture content of 12% w.b., worm shaft speed of 576 rpm and feed opening of 5200 mm^2. These process parameters gave 19.13% grit, 23.59% meal and 54.20% flour. Visual illustration of the interaction is shown as Fig. 1.

CONCLUSION

This study has clearly demonstrated the significance of process variables as important factors in the dry milling of yam. The process variables dictate largely the product fractions obtained. To achieve optimum product these variables must be correctly selected during milling. Flour fraction increased with decreasing levels of moisture content (%), shaft speed (r.p.m) and increasing levels of feeding opening (mm^2). Meal fraction increased with increasing levels of moisture content, feeding opening and decreasing levels of speed. Grit fraction increased with increasing levels of moisture content. Feeding opening and shaft speed had minimal effect on grit fraction.

REFERENCES

Akissoe, N., D.J. Hounhouigan, C. Mestres and M. Nago, 2003. How blanching and drying affect the colour and functional characteristics of yam (Dioscorea Cayenensis-Rotundata) flour. Food Chem., 82: 257-264.

Federal Office of Statistics, 2007. Nigeria Trade Summary. Federal office of Statistics, Lagos, Nigeria.

Giradin, O., C. Nindjin, Z. Farah, F. Escher, P. Stamp and D. Otokore, 1998. Use of gibberellic acid to prolong dormancy and reduce losses during traditional storage of yams. J. Sci. Food Agric., 77: 172-178.

Matz, A.S., 1970. Cereal Technology. 1st Edn., AVI Publishing Co., Westport, pp: 388, ISBN: 0870550713.

Horwitz, W., 2005. Official Methods of Analysis of Aoac International. 18th Edn., AOAC International, Gaithersburg, ISBN: 0935584757.

McCabe, W., J.C. Smith and P. Harriott, 2005. Unit Operations of Chemical Engineering. 7th Edn., McGraw Hill, New York, pp: 967-1000.

Mozie, O. 1988. Effect of storage temperature on storage weight losses in white yam (*Dioscorea Rotundata Poir*) tubers. Trop. Sci., 28: 273-276.

Mullen, K. and D.M. Ennis, 1979. Rotatable designs in product development. Food Technol., 33(7): 5-5.

Omonigbo, S.E. and M.J. Ikenebomeh, 2000. Effect of temperature on the treatment on the chemical composition of pounded white yam during storage. Food Chem., 71: 215-220.

Sanjay, K.S. and U.S. Agrawal, 2005. Optimisation of grain and machine conditions for milling of green gram (Phaseolus Aureus). J. Food Sci. Technol., 42(1): 11-16.

Sibel, Y. and G. Fahretin, 2009. Development of extruded snack from food by-products: A response surface analysis. J. Food Proc. Eng., 32(4): 565-586.