ACTA TECHNICA CORVINIENSIS – BULLETIN OF ENGINEERING
TOME XVI [2023] | FASCICULE 4 [OCTOBER – DECEMBER]

[1.] U.J. ETOAMAIHE, [2.] C. DIRIOHA, [3.] T. PAUL, [4.] K.O. UMA

EFFECT OF SPEED AND BAFFLE SIZE ON THE DEGREE OF MIXING OF TUMBLE DRUM FEED MIXER USING RESPONSE SURFACE METHODOLOGY

[1,2,3]Department of Agricultural Engineering, Michael Okpara University of Agriculture, Umudike, Umuahia, Abia State, NIGERIA
[4]Department of Animal Production, Michael Okpara University of Agriculture, Umudike, Umuahia, Abia State, NIGERIA

Abstract: The effects of speed, number of baffles and baffle lengths of a developed tumble drum mixer as they relate to the degree of mixing of feed in the mixer were investigated. Results showed that the degree of mixing of the tumble drum mixer was influenced by the linear effects of the number of baffles, also the interactions of the number of baffles and baffle lengths of the mixer at 5% probability. These factors accounted for about 94.37% of the variations in the degree of mixing of the mixer. The highest degree of mixing of 79.21% was obtained when the number of baffles were 9 and baffle length was 20cm.
Keywords: drum, mixer, baffles, response, surface, methodology, degree, mixing

INTRODUCTION

Feed production for livestock and aquatic animals involve processing operations like grinding, mixing pelleting and drying (Okafor, 2015). Mixing operation is very important because through it different ingredients of the feed are mixed in such a way to get the desired balanced feed formulation (Balami *et al.,* 2013). Mixing is known to be the process by which feed or food ingredients are stirred together to give a uniform mixture (Adeleke *et al*., 2020). Mixers are generally designed to mix varieties of free flowing materials for feed and food formulation. Hence, to have a well–balanced diet with all the required nutrients, mixing is necessary, providing a uniform mixture by the stirring of two or more ingredients together (Pastukhov and Dogan, 2014). The main purpose of mixing is to blend ingredients (formulation) into a compound such that each unit of the sample (given mass) has the same ingredient composition as the designed formula (Okwabi, 2016).

Feed mixing operations can either be mechanical or manual. According to Adebukola and Patrick (2019), manual method of mixing food/feed involves using hand or shovel to mix up the feed's constituents into one another on open space for proper blending. However, the manual mixing of feed ingredients is usually characterized by low output, low efficiency and drudgeries can be hazardous and unsafe to the health of intending consumers. The mechanical method of mixing on the other hand involves the use of mechanized mixers for mixing/blending while eliminating the drudgeries in manual mixing. Tumble barrel mixers are generally mechanized mixers that engage the principle of rotating barrel and internal baffles/stirrers to properly mix feed/food homogeneously inside a barrel. The total mixing of constituents and elimination of unmixed spots in the mixing barrel due to the tumbling actions of the mixer is an advantage (Chikelu, 2015).

MATERIALS AND METHODS

The tumble drum feed mixer was developed in Agricultural and Bioresources Engineering Department, Michael Okpara University Umudike, Abia State. The tumble barrel mixer which consists of a cylindrical stainless steel drum of length 0.99m and diameter of 0.5m mounted on a rigid steel frame work, powered by a 3Hp variable speed gear motor (Etoamaihe *et al*., 2022). The frame is 0.6m in height, 1.8m length and 0.54m width. The driving shaft length was 1.9m and the cylindrical drum was slanted 30° to the horizontal to aid mixing. The mixer had a feed opening at the topmost part of the drum and a discharge point at the bottom. Stirrers are fixed on the driving shaft inside the drum. There are also baffles by the sides of the drum located below and above the stirrers on the driving shaft. The mixer was designed to operate in batches. The isometric and orthographic drawings of the machine are shown in Figs 1 and 2, while the developed machine is shown Fig.3.

The response surface methodology (RSM) is important in formulating, designing, developing, and analyzing new scientific studies and products. It is also efficient in the improvement of existing studies and products (Khurmi and Gupta, 2005; Oni *et al.*, 2009). The most common applications are in food science, physical and engineering science, industrial, biological and clinical science and social science.

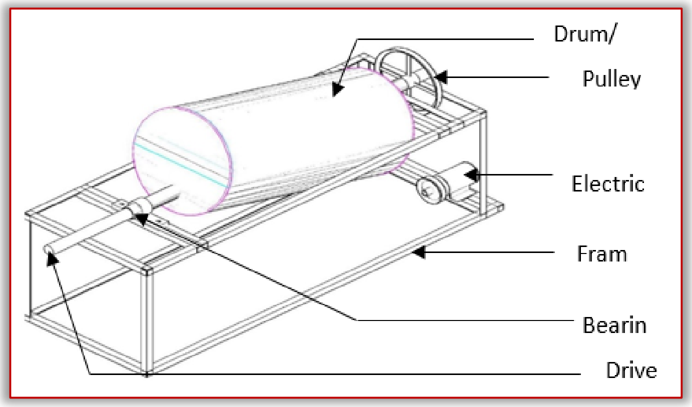

Figure 1: Isometric View of the Tumble Drum Mixer

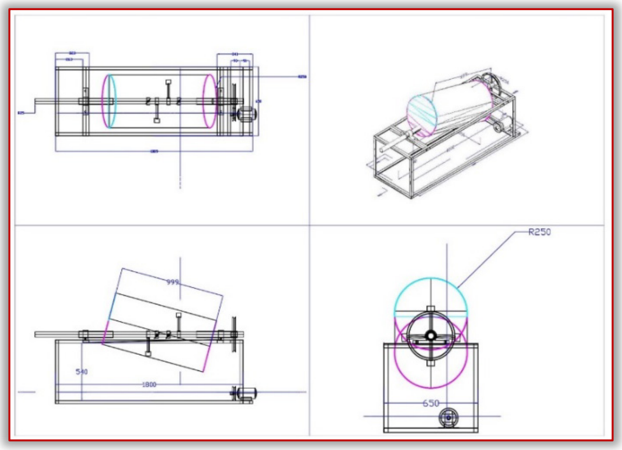

Figure 2: Orthographic view of the tumble drum mixer

Figure 3: The developed tumble drum mixer

According to Myers and Montgomery (2002), response surface methodology is an experimental design that employs the use of first–degree polynomial model to approximate the response variable. However, the model is simply an approximation, but it is easy to estimate and apply, even when little is known about the process. Response surface methods are designs and models for working with continuous treatments when finding the optima or describing the response (Agriga and Iwe 2008). Firstly, the goal of response surface method is to evaluate the optimum response. When there is more than a response then it is important to find the optimum that does not optimize only one response (Jau *et al.*, 2009; Rosell and Collar, 2009). When there are constraints on the design data, then the experimental design has to meet requirements of the constraints. Further goal is to understand how the response changes in a given direction by adjusting the design variables. In general, the response surface can be visualized graphically. The graph is helpful to see the shape of a response surface; hills, valleys, and ridge lines (Yeng and Yu, 2011; Paul *et al*, 2021). According to Deniz and Ismail (2007), response surface is the most popular optimization method used in recent years because of the ease of application and least number of experimental runs needed to evaluate the process (Okwabi, 2016).

The performance tests for the tumble drum mixer was carried out according to the standard test procedure for farm batch mixers which was developed by ASAE (2006). In the tests, 100kg of ground corn and 2.8kg of shelled corn were put into the mixer before operation. Three speeds of the machine which are 100, 150 and 200 rpm were tested for the three different number of baffles 3, 6 and 9 and three baffle lengths of 10, 15 and 20cm of the machine to determine their various percentage degrees of mixing (DM). Each of the tests were carried out for a period of 5 minutes mixing duration in all cases. At the end of each test run, ten samples of 500g each were drawn from the mixed components and analysed.The coefficient of variation among the blended samples and level of mixing were computed using the expressions developed by Ibrahim and Fasasi (2004).

$$CV = \frac{SD}{Y} \times 100 \quad (1)$$

$$Y = \frac{\sum yi}{n} \quad (2)$$

$$SD \equiv \sqrt{\frac{(Y - yi)^2}{n-1}} \quad (3)$$

$$DM = 100 - \%CV \quad (4)$$

where, CV = percent coefficient of variation, *DM* = degree of mixing (percent), *SD* = standard deviation

Y = mean, *yi* = individual sample analysis results, *n* = total number of samples

A faced centred response surface methodology (RSM) using central composite design (CCD) was used to design the experiments (NIST/SEMATECH, 2012). This method is useful because it uses very few experimental runs to describe how the test variables affect the response. (Agriga, 2008; Etoamaihe, 2015). RSM helps to determine the inter–relationships among test variables on the response and also helps to describe the combined effects of all the test variables on the response (Agriga and Iwe 2008). A 3 factor, 3 level central composite design of RSM was used in this study and the design is suitable for exploring quadratic response surfaces and evaluation of second order polynomial model thereby optimizing the process using a small number of experimental runs (Myers and Montgomery, 2002; Arocha *et al*., 2021). A total of 20 experimental runs were used. The nonlinear model of response surface methodology is given as:

$$Y = bo + \sum_{i} biXi + \sum_{i} biiXi^2 + \sum \sum_{ik(k\angle j)} bjkXjXk \quad (5)$$

where Y= response variable

bo = intercept

Xk, Xj, Xi = independent variables.

bii, bjk, bi= regression coefficients of the model.

In the tests, the three factors considered are speed, number of baffles and baffle lengths of the tumble drum mixer, these were investigated as they affect the degree of mixing of the machine. The regression analysis was carried out with Minitab 16 software, while the response surface graphs were plotted with Matlab R2015a software. In the design the linear, interactive and quadratic effects of the factors (independent variables) were studied as they affect the response percent degree of mixing (DM) of the mixer. Three levels of each of the factors were studied. They are listed as follows: Three different speeds of the machine, namely; 100rpm, 150rpm and 200rpm. Different number of baffles in the machine, namely; 3, 6 and 9. Three different baffle lengths of the machine namely; 10cm, 15cm and 20cm.

RESULTS AND DISCUSSIONS

The experimental variables and coding are shown in Table 1, while the experimental results with the independent variables are shown in Table 2.

Table 1: Experimental Variables and Coding Used in the Design

Independent Variables	Variable Levels		
Speed of mixer, X1	100rpm	150rpm	200rpm
Number of Baffles, X2	3	6	9
Baffle Lengths, X3	10cm	15cm	20cm
Code Designation	–1	0	1
Dependent Variable (Response)			
Degree of Mixing (%) Y			

Table 2: Experimental Results of Independent Variables and Response in Coded Terms

Runs	X1	X2	X3	Y
1	1	1	1	73
2	–1	–1	–1	74
3	0	–1	0	75
4	–1	–1	1	54
5	0	0	1	74
6	0	0	0	64
7	0	0	0	63
8	0	0	0	63
9	0	0	0	64
10	0	1	0	62
11	1	0	0	68
12	1	–1	1	64
13	1	1	–1	36
14	0	0	–1	59
15	1	–1	–1	85
16	0	0	0	64
17	0	0	0	65
18	–1	1	–1	56
19	–1	1	1	81
20	–1	0	0	62

The estimated regression coefficients for the degree of mixing versus speed, number of baffles and baffle lengths of the mixer are shown in Table 3, while the analysis of variance associated with the regression are shown in Table 4. From Table 3, the linear effects of number of baffles, the interactions of speed and number of baffles and also the interactions of the number of baffles and baffle lengths were significant to the degree of mixing of the tumble drum mixer at 5% probability ($P \leq 0.05$). These factors accounted for about 94.37% of the variations in the degree of mixing of the machine. The analysis of variance Table 4 also fully confirms the stated results. From the response surface curve in Fig. 4, the highest Degree of Mixing of 66.49% was obtained when the number of baffles were 9 and the speed was 60rpm while in Fig. 5 the highest degree of mixing of 68.51% was obtained when the baffle length was 20cm and the speed was 200rpm. In Fig 6, the overall highest degree of mixing of 79.21% was obtained when the baffle length was 20cm and the number of baffles were 9.

Table 3: Response Surface Regression: Y versus X1, X2, X3

Term	Coef	SE Coef	T	P
Constant	64.8455	1.182	54.874	0.000
X1	–0.1000	1.087	–0.092	0.929
X2	–4.4000	1.087	–4.048	0.002
X3	3.6000	1.087	3.312	0.008
X1*X1	–1.3636	2.073	–0.658	0.525
X2*X2	2.1364	2.073	1.031	0.327
X3*X3	0.1364	2.073	0.066	0.949
X1*X2	–6.1250	1.215	–5.040	0.001
X1*X3	1.3750	1.215	1.131	0.284
X2*X3	12.8750	1.215	10.594	0.000

S = 3.43746 PRESS = 1152.97

R–Sq = 94.37%;R–Sq (pred) = 45.05% ;R–Sq (adj) = 89.30%

The regression equation:

$$Y=64.85-0.1X_1-4.4X_2+3.6X_3-1.36X_1^2+2.14X_2^2+0.136X_3^2-6.13X_1X_2+1.38X_1X_3+12.88X_2X_3$$

Table 4: Analysis of Variance for Y

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	1980.04	1980.04	220.00	18.62	0.000
Linear	3	323.30	323.30	107.77	9.12	0.003
X1	1	0.10	0.10	0.10	0.01	0.929
X2	1	193.60	193.60	193.60	16.38	0.002
X3	1	129.60	129.60	129.60	10.97	0.008
Square	3	15.36	15.36	5.12	0.43	0.734
X1*X1	1	0.00	5.11	5.11	0.43	0.525
X2*X2	1	15.31	12.55	12.55	1.06	0.327
X3*X3	1	0.05	0.05	0.05	0.00	0.949
Interaction	3	1641.38	1641.38	547.13	46.30	0.000
X1*X2	1	300.13	300.12	300.12	25.40	0.001
X1*X3	1	15.13	15.13	15.13	1.28	0.284
X2*X3	1	1326.13	1326.13	1326.13	112.23	0.000
Residual Error	10	118.16	118.16	11.82		
Lack–of–Fit	5	115.33	115.33	23.07	40.70	0.000
Pure Error	5	2.83	2.83	0.57		
Total	19	2098.20				

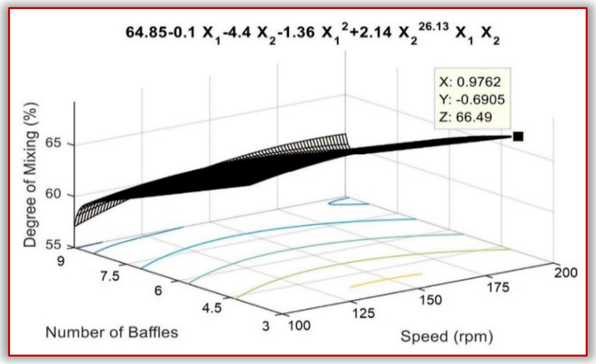

Figure 4: Response Surface Curve of the Effects of Number of Baffles and Speed on the Degree of Mixing of the Mixer

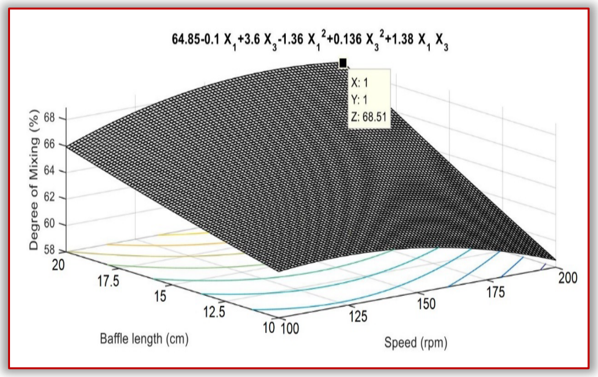

Figure 5: Response Surface Curve of the Effects of Baffle Lengths and Speed on the Degree of Mixing of the Mixer

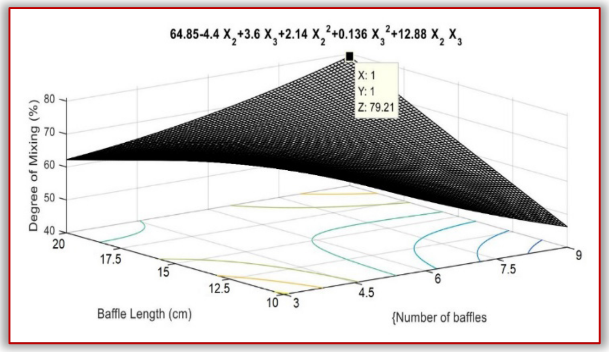

Figure 6: Response Surface Curve of the Effects of Baffle Lengths and Number of Baffles on the Degree of Mixing of the Mixer

CONCLUSIONS

From experimental results and analysis, the following conclusions can be drawn from this study. The degree of mixing of the tumble barrel mixer was influenced by the linear effects of the number of baffles, also the interactions of the number of baffles and baffle lengths of the mixer at 5% probability. These factors accounted for about 94.37% of the variations in the degree of mixing of the mixer. The overall highest degree of mixing of 79.21% was obtained when the number of baffles were 9 and baffle length was 20cm.

References

[1] Okafor B. E (2015). Design of Power Driven Dough Mixing Machine. Int'l Journal of Engineering and Technology 5(2): 71–74.

[2] Balami, A. A., Adgidzi, D, and Muazu, .A (2013). Development and Testing of an Animal Feed Mixing Machine, International Journal of Basic and Applied Sciences 1(3): 491–503.

[3] Adeleke A.E, Oni O.K, Ogundana T.O, Satimehin A.A and Oyelami S. (2020). Development and performance evaluation of a dough mixing machine. Journal of Engineering and Environmental Sciences. 2 (2): 30–41.

[4] Pastukhov A. and Dogan H. (2014). Studying of Mixing speed and Temperature impacts on rheological properties of wheat flour dough using Mixolab. Agronomy Research 12(3): 779–786.

[5] Okwabi R. (2016). Design and construction of a hand operated mixer machine for food fortification. International Research Journal of Engineering and Technology. 3(9): 6 –15.

[6] ASAE Standards (2006). ASAE S380 R2006. Test Procedure to Measure Mixing Ability of Portable Farm Batch Mixers, pp 261–262.

[7] Adebukola A.A and Patrick O.A (2019). Development and Evaluation of a Fish Feed Mixer. Agric Eng. Int: CIGR Journal Open Access. 21(3): 43–56.

[8] Chikelu C.C, Ude M.U, Onyekwere D.C, Eze N.N and Ukwuani S.T (2015). Design and development of a cross ribbon dough mixer. International Journal of Adavnced Engineering Research and Scieence. 7 (2): 24–27.

[9] Etoamaihe U.J., Dirioha, N.R., Uma K.O and Oluwaseun Babalola, (2022). Development and Performance Evaluation of a Motorized Tumble Barrel Feed/Food Mixer. Scientific Journal of Agricultural Engineering, Faculty of Agriculture, University of Belgrade.No.4 pp 15– 27.

[10] Oni, O. K. Alakali J. S and Akpapumam M. A (2009). Design, Fabrication and Performance

[11] Gupta J. K (2005). A Textbook of Machine Design. Eurasia publishing house Ltd, New Delhi.

[12] Myers, R.H., and Montgomery, D.C. Response Surface Methodology. Process and Product Optimization Using Designed Experiments. 2nd Edition, John Wiley and Sons New York.

[13] Agriga A.N. and Iwe M.O (2008). Physical Properties of Cookies Produced from Cassava, Groundnut–Corn Starch Blend. A Response Surface Analysis. Nigerian Food Journal 26(2) 83–96.

[14] Jau, K.W., Hua, S. C, and Ching, S.H (2009). Optimization of the Medium Components by Statistical Experimental Methods to Enhance Nattokinase Activity. Fooyin Journal of Health Sciences 1(1)21–27.

[15] Rosell C.M and Collar C. (2009). Effect of Temperature and Consistency on Wheat Dough Performance. International Journal of Food Science and Technology. 6(2): 52–64.

[16] Yeng Y.T and Yu C.H (2011). Flow Characteristics in Mixers Agitated by Helical Ribbon Blade Impeller. Engineering Applications of Computational Fluid Mechanics 5(3): 416–429.

[17] Paul .T, Adejumo B.A, Nwakuba N.R and Ehiem J.C (2021). Proximate composition of packaged freeze dried cheeses in storage. Agricultural Engineering international. 23 (2): 264–272.

[18] Deniz, B. and Ismail, H.B (2007). Modelling and Optimization: Usability of Response Surface Methodology. Journal of Food Engineering. 78(3):836–845.

[19] Fasasi M.B (2004). Design and Development of a Portable Feed Mixer for Small Scale Poultry Farmers. Proceedings of NIAE 26 Ilorin.

[20] NIST/SEMATECH (2012). Handbook of Statistical Methods http://www.itl.nist.gov/div 898, Accessed 17th January 2023.

[21] Etoamaihe, U.J, (2015). Effects of Additives and Briquetting on the Calorific Values of Cassava Peels Using Response Surface Methodology. ASABE Annual International Meeting 152186792. (doi:10.13031/aim.20152186792).

[22] Agriga, A.N (2008). Development and Evaluation of Cassava–Groundnut Bars Using Corn–Starch as Binder. A Response Surface Analysis. Unpublished M.Sc. Thesis. Dept of Food Science and Technology. Michael Okpara University of Agriculture Umudike pp 38–43.

[23] Arocha C.G, Simonyan K.J and Paul .T (2021). Performance evaluation of a motorized ginger rhizomes peeling machine. Agricultural Engineering. 46 (4): 84–96.

ISSN: 2067-3809