# Interative Study of Some Mechanical Parameters of an Automated Grain Drinks Processing Machine with Respect to its Blending Efficiency

**Experiment Findings** · October 2015

DOI: 10.13140/RG.2.2.23323.87846

# Interative Study of Some Mechanical Parameters of an Automated Grain Drinks Processing Machine with Respect to its Blending Efficiency

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*Abstract -* **The optimal values of the functional parameters of an automated grain drinks production machine that yielded the best blending efficiency using response surface methodology (RSM) was investigated. The machine blended soaked soyabean grains, mixed the slurry, extracted the aqueous liquid and expelled the paste from the machine in single unit. The machine mechanical parameters, such as blade type, basket orientation and speed were explored by empirical experiment. Blending efficiency was considered as performance characteristics. The experiment was based on central composite rotatable design (CCRD). The experimental result showed that the developed regressional model could describe the performance indicators within the experimental range of the factors been investigated. Blade type and speed of rotation were found to be significant, while basket orientation was insignificant. Numerical optimization carried out produced optimum values of 3-blade assembly, basket orientation at 40º and speed of 1400 revolutions per minute and the blending efficiency was 84.77 %.**

***Keywords—Automated; Functional; Grain; Drinks;Blending Efficiency***

## I. INTRODUCTION

Soya milk is considered as very important component of diets of Nigerians and other people of the developing countries. It is usually taking as refreshing drinks by some and for its health benefit by others [1]. A lot of research work has reported on health benefits of soya milk. Soya milk and other grain beverages are easily adulterated or contaminated during production process [2].

The available equipment and machine for production of grains beverages are made from mild steel which can easily rust due to its frequent contact with water during the production process and result to contamination of the drink [3]. Another aspect of possible contamination of the drink is batch nature of the production process. The production process involve different stages using different equipment, for instance after the milling using the available plate mill, the grounded slurry are then sieved using manual means. During this process the milk is also predisposed to contamination [4].

Considering the possibility of contamination of the drink during the production process, an automated grain drink processing machine was developed using stainless steel materials. The machine was designed to blend, mix, sieve, extract the milk and expel the paste out of the machine in a single unit. The basic operation of blending, mixing, sieving and paste expelling were automated. This paper therefore, is presentation of an interactive study of the mechanical parameters of the grain drinks production machine as they affect its blending efficiency.

## 2.0 MATERIALS AND METHODS

### *2.1 Materials*

The soya beans used in this study was obtained from Kure Modern Market, Minna Niger State Nigeria. It was prepared by cleaning and sorting before soaking for 12 hour at room temperature as recommended by [3] and [5], in order to soften the grains kernel and also to facilitate the yield of the milk. The grains were then processed using the developed machine as recommended by [6] as shown in Plate I to III.

### *2.2 Grain Drinks Production*

The raw soya milk production process was conducted in four stages involving blending of the soaked grains, mixing of the slurry with water, extraction of the aqueous liquid and expelling of the paste out of the basket, all these operation were carried in single unit. The soya beans were fed into the machine through the hopper as shown in Plate I.

Plate I: Feeding of Soya Beans into the Machine

The blending operation was carried out by putting on the machine to activate the blending blades. Water was then allowed to flow into the system in order to aid the washing of the milk from the paste. The centrifugal force generated by the high rotational speed of the central shaft and the basket forces the aqueous liquid and the paste to move towards the wall of the basket. The aqueous liquid was filtered out through perforation in the basket while the paste migrates up along the wall of the basket and is expelled out. The expelled paste are scrapped out by the scrappers attached to the basket and are collected at the paste collector as shown in Plate II, while the liquid are collected at the bottom of the basket and flow out through the liquid outlet as shown in Plate III.

Plate II: Paste being expelled out of machine

(A) (B)

Plate III: Soya milk flow from bending chamber to;

*2.3 Experimental Design*

Response surface methodology (RSM) was used in the study. RSM was reported by [7], as a combination of mathematical and statistical techniques that are useful for modeling and analysis of problems where the observed response is influenced by several variables and aim to optimize the response. Central composite rotatable design (CCRD) of response surface methodology was tested at five levels with three independent variables including blade type, basket orientation and combine speed of blending and rotation of basket was used to evaluate the machine blending efficiency. The experiment consists of 20 experimental runs and the design matrix is shown in Table 1 as reported by [8].

*2.4 Optimization Analysis*

Optimization is the process of finding the best solution for a system or operation. The main purpose of optimization is to achieve optimum conditions for the operation of a system or machine. In this study the optimization analysis were carried out as reported by [8].

*2.5 Optimization Technique*

Design expert ® 7.0.0. Software was employed using numerical technique for the optimization of independent variables and the dependent variables in this study. By applying the desirability functions method in RSM, number of solutions was obtained for the optimum covering criteria with desirability close to 1 and the first solution with desirability closest to 1 was selected.

Table 1: Matrix Transformation of Five Level- Three Factors Central Composite Rotatable Design of the Experiment

| Run order | Coded | Values | | Real | Values | | Response |
|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | Blade Configuration | Basket Orientation | Combine Speed of Blade and Basket | Blending Efficiency (%) |
| 1 | - | - | - | 3 | 30 | 1000 | 53.71 |
| 2 | + | - | - | 5 | 30 | 1000 | 47.88 |
| 3 | - | + | - | 3 | 50 | 1000 | 58.9 |
| 4 | + | + | - | 5 | 50 | 1000 | 55.75 |
| 5 | - | - | + | 3 | 30 | 1400 | 60.06 |
| 6 | + | - | + | 5 | 30 | 1400 | 56.39 |
| 7 | - | + | + | 3 | 50 | 1400 | 81.14 |
| 8 | + | + | + | 5 | 50 | 1400 | 35.3 |
| 9 | -1.682 | 0 | 0 | 2 | 40 | 1200 | 59.7 |
| 10 | +1.682 | 0 | 0 | 6 | 40 | 1200 | 77.85 |
| 11 | 0 | -1.682 | 0 | 4 | 23 | 1200 | 84.15 |
| 12 | 0 | +1.682 | 0 | 4 | 57 | 1200 | 74.64 |
| 13 | 0 | 0 | -1.682 | 4 | 40 | 864 | 61.56 |
| 14 | 0 | 0 | +1.682 | 4 | 40 | 1536 | 63.17 |
| 15 | 0 | 0 | 0 | 4 | 40 | 1200 | 60 |
| 16 | 0 | 0 | 0 | 4 | 40 | 1200 | 30.61 |
| 17 | 0 | 0 | 0 | 4 | 40 | 1200 | 74.64 |
| 18 | 0 | 0 | 0 | 4 | 40 | 1200 | 29.03 |
| 19 | 0 | 0 | 0 | 4 | 40 | 1200 | 45.36 |
| 20 | 0 | 0 | 0 | 4 | 40 | 1200 | 24.24 |

The experiment was conducted as per the design matrix and the blending efficiency was computed as follows;

The Blending Efficiency

This is the measure of the degree by which the grains are reduced in size and was determined as reported by [9] and [10]

$$E_B = \frac{\text{A}}{\text{MT}} \text{x } 100 \quad (1)$$

$$E_B = \frac{\text{A}-\text{W}}{\text{MT}-\text{W}} \text{x } 100 \quad (2)$$

where, $E_B$ = the blending efficiency (%)

A = the amount of the material passing through the sieve (kg)

MT = the total weight of the material feed into the machine (kg)

W = the amount of water used (kg)

## 3.0 RESULTS AND DISCUSSION

*Blending Efficiency*

The blending efficiency is the degree by which the materials were reduced in size. It was observed that the blending efficiency ranged between 24.24 % and 84.15 %. The highest blending efficiency of 84.15 was obtained from interaction between 3 blades assembly, basket with half angle of 30° (angle of 60° from the horizontal) and speed of 1400 r.p.m, while the least blending efficiency of 24.24 % was obtained from interaction between 4 blades assembly, basket with half angle of 40° (angle of 50° from the horizontal) and speed of 864 r.p.m. This result is similar to crushing efficiency of 82.3 % reported by [9]

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 10, October-2016

*Statistical Analysis*

A statistical analysis of variance (ANOVA) of the experimental was carried out with the aid of software (Design Expert 7.0.0). The Table 2 below shows the results of statistical analysis of variance of data obtained from the results of processing soya beans to soya milk in order to determine the effect, contribution, model coefficient, test for Lack-of-fit and the significance of the variables and their respective interaction on the blending efficiency and quadratic model was statistically significant for the response. The significant model terms were identified at 95% significance level. From Table 2 below it was observed that the variables C and AB with positive co-efficient are directly proportioned to the blending efficiency while A, B, AC, BC, $A^2$, $B^2$ and $C^2$ all have negative coefficient and exhibit an inverse proportionality behaviour with respect to the blending efficiency. The Quadratic regression model equation developed to predict the blending efficiency with respect to functional machine parameters (independent variables) was given as shown in equation 3 and 4.

*Calibration of the Model*

The results in Table 2 showed that the model was significant (P≤ 0.001). There was only 0.01% chance that a Model F value this large could occurred due to noise. The results also showed that blade type and speed were significant model terms (P≤ 0.05). It can be clearly observed that C (speed) has the highest significant effects on the blending efficiency with coefficient of estimate of 15.53. The "Lack of Fit F-value" of 0.04 implies that the Lack of Fit is not significant relative to the pure error. There is a 68.27% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good because if it is significant them the model will not be able to predict the response [11]. The coefficient of determination R value of 0.9840 indicated that the model was able to predict 98.40 % of the variance and only 1.60 % of the total variance was not explained by the model. The coefficient of correlation R-Squared value of 0.9683 was high very close to 1 as recommended by [12]. It was also observed that the Predicted R – Squared of 0.946747 was in reasonable agreement with the Adjusted R – Squared of 0.939736 which indicated that the experimental data fitted better.

Adequate Precision measures the ratio of signal to noise and minimum value of 4 was reported by [13] as desirable value. The value of adequate precision of 20.165 obtained indicated an adequate signal which showed that the model can be used to navigate the design space.

**Table 2: Regression Analysis of Response of Blending Efficiency**

| Source | Coefficient of Estimate | Standard Error | F - value | P- value Prob >F | R-Squared | |
|---|---|---|---|---|---|---|
| **Model** | 63.02059 | 1.736828 | 33.91995 | < 0.0001 | 0.968282 | Significant |
| **A-Blade Confg. (No.)** | -11.3929 | 1.152346 | 97.74755 | < 0.0001 | | |
| **B-Basket Orient. (Degree)** | -0.5918 | 1.152346 | 0.263748 | 0.6187 | | |
| **C-Speed (r.p.m.)** | 15.5256 | 1.152346 | 181.5228 | < 0.0001 | | |
| **AB** | 1.14375 | 1.505613 | 0.57708 | 0.4650 | | |
| **AC** | -2.77875 | 1.505613 | 3.406218 | 0.0947 | | |
| **BC** | -0.00375 | 1.505613 | 6.2E-06 | 0.9981 | | |
| **A^2** | -3.00452 | 1.121778 | 7.173579 | 0.0232 | | |
| **B^2** | -1.8537 | 1.121778 | 2.730649 | 0.1294 | | |
| **C^2** | -4.39221 | 1.121778 | 15.3304 | 0.0029 | | |
| **Lack of Fit** | | | 0.040493 | 0.9984 | | not significant |

Regressed Model Equation in Terms of coded Factors

$$Y_B = 63.02 - 11.39A - 0.59B + 15.53C + 1.14AB - 2.78AC - 3.75 \times 10^{-3}BC - 3.00^2 - 1.85B^2 - 4.39C^2 \quad (1)$$

Where, $Y_B$ = Blending Efficiency (%)

A = is the blade type (Number)

B = is the basket orientation (Degree)

C = is the speed of blending (r.p.m)

The regressed model equations contain both significant and insignificant terms. Values greater than 0.1000 implies that the model terms are not significant (that is B, AB, AC, BC, were not significant) and since these terms are insignificant the model was reduced to equations 6 in order to improve it [11].

*Fitted Model Equation*

$$\text{Blending Efficiency (\%)} = 63.02 - 11.39A + 15.53C - 3.00A^2 \quad (2)$$

It is important to add that the variable C in the model has positive co-efficient implying a direct proportionality while A has negative co-efficient implying an indirect proportionality. That is independent increase in A decreased the blending efficiency while increase in C increased the blending efficiency.

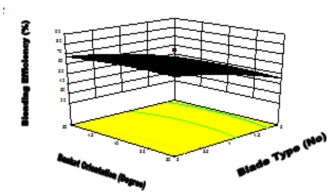
*Simulation and Validation of the Model*

The model equation obtained was simulated and the blending efficiency was observed to be within the experimental range. From Table 3 the actual value of blending efficiency was observed to be in close agreement with the predicted value validating the need for the model equation to be used to determine the optimum blending efficiency at various operating condition.

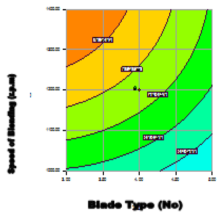
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 10, October-2016

Table 3: Relationship Between Actual and Predicted Values of Blending Efficiency

| Standard Order | Actual Value | Predicted Value |
|---|---|---|
| 1 | 47.88 | 48.59055 |
| 2 | 29.03 | 29.07467 |
| 3 | 45.36 | 45.12694 |
| 4 | 30.61 | 30.18606 |
| 5 | 84.15 | 85.20676 |
| 6 | 53.71 | 54.57588 |
| 7 | 81.14 | 81.72815 |
| 8 | 55.75 | 55.67227 |
| 9 | 74.64 | 73.6831 |
| 10 | 35.3 | 35.36197 |
| 11 | 60.06 | 58.77282 |
| 12 | 56.39 | 56.78224 |
| 13 | 24.24 | 24.48668 |
| 14 | 77.85 | 76.70838 |
| 15 | 59.7 | 63.02059 |
| 16 | 63.17 | 63.02059 |
| 17 | 74.64 | 63.02059 |
| 18 | 58.9 | 63.02059 |




(a) Response Surface for Blending Efficiency




(b) Contour Plot for Response Surface of Blending Efficiency

Figure 1: Response Surface and Contour Plot for Response Surface of Blending Efficiency

*Response surface and contour plot for blending efficiency*

The response surface and contour plot for blending efficiency is presented in Figure 1. The blending efficiency increased from 42 % to 84.7 % as the speed of blending increased from 1000 r.p.m to 1400 r.p.m. This could be due to increase in impact force, cutting and shearing actions of the blade with increased in rotational speed. [14] had reported that rotational speed was found to be a key factor to size reduction of solid materials. Where higher speed of blending resulted to higher blending efficiency, while lower speed of blending resulted to low blending efficiency. It was obvious that the blending efficiency decrease from 42 % to 30 % with increased in blade configuration from 3 blades to 5 blades assembly. This could be as result of decreased in contact between the blade and the grains with increased in configuration.

All the blades were designed to have equal area of cutting edges. This agreed with the result of earlier findings by [15] where blade design was found to affect blending of materials. It was clearly observed that there was significant ($P \leq 0.05$) difference in blending efficiency between speed of 1000 r.p.m and 1400 r.p.m. Also significant ($P \leq 0.05$) difference was observed between blending efficiency of 3 and 5 blades assembly. The optimum blending efficiency of 84 % was obtained from combination of speed of 1400 r.p.m and 3 blades assembly. This value was observed to decrease to 77.85 % when the speed was increased to 1536 r.p.m and 74.64 % when the blade decreases to 2 blades assembly. This could be as result of more impact of the blade with increased in speed which produced finer particles in the slurry. These fine particles clumped together and formed larger particles that clogged the sieve holes. As result of this some aqueous liquid were discharged out together with the paste. This agreed with the result of an earlier study by [16] where high speed of blending was found to produce finer particles in slurry. This particles clogged together and blocked the sieve holes, thus prevent materials from passing through the holes.

*Effect of Basket Orientation on Blending Efficiency*

From the analysis of variance (ANOVA) conducted basket orientation was observed to have no no any significant ($P \leq 0.05$) effect on the blending efficiency. Also from Figure 2 there was no any significant ($P \leq 0.05$) difference between basket orientation with half angle of 30° and that with 50°.

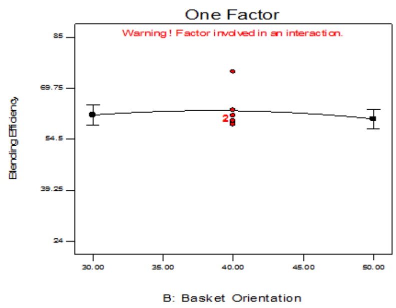



Figure 2; Effect of Basket Orientation on Blending Efficiency

*Optimization of the machine functional parameters*

The ramp for the optimization is shown in Figure 3; it gave the optimum values of 3-blades assembly, basket of half angle of 40° and speed of 1400 r.p.m., while for the responses; blending efficiency was 84.77 %,

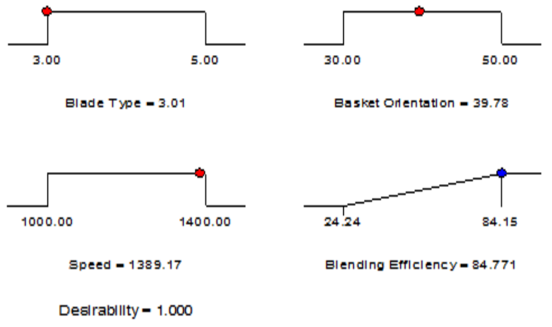



**Figure 3: Ramp for Optimization of Machine Performance Parameters**

## CONCLUSIONS

The interaction effects between the machine parameters showed that blending efficiency increase with increased in speed of blending from 1000 r.p.m to 1400 r.p.m and also with decrease in blade type (number) from 5 blades assembly to 3 blades assembly. The basket orientation was found to have no any significant effects on blending efficiency.

The developed mathematical models and individual coefficient were found to be significant while the Lack of fit was significant. The experimental values were found to fit better with close agreement between predicted r-squared and adjusted r-squared values. The model equations can be used to navigate within the experimental ranges with high adequate precision values of 20.16.

Optimization of the functional machine parameters was carried out using numerical optimization technique by applying desirability function method in rsm. The best optimal machine functional parameters of 3-blades assembly, basket of half angle of 40$^o$ and speed of 1400 r.p.m., while for the responses; blending efficiency was 84.77 %.

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