DEVELOPMENT, TESTING AND OPTIMIZATION INDICES OF DRY STATE DEHULLER FOR BREADFRUIT SEEDS

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Abstract. Dehulling is a process that combines cracking and expression to free hulls from seed kernels. In dehulling of breadfruit seeds cracking and expression take place as independent drudgery and low productive operations, especially in wet dehulling. This study was aimed at the development and testing of a dehuller envisaged to satisfy the processing need for dry breadfruit seed dehulling to meet market demands. The design concept involved the use of rotating vanned horizontal output shaft to generate centrifugal force, impact and frictions to crack, express and classify kernels and hulls in one single operation. The developed machine has 1 kg holding capacity-hopper, 5 kg holding capacity-cylindrical dehulling chamber housing the rotating vanned horizontal output shaft driven by a rubber pulling system connected to -3.5 kw electric motor. The kernel and hulls are discharged efficiency and separately at outlet ports. The dehulling capacity, dehulling efficiency and separation efficiency were 20 kg/hr, 54 % 49 % respectively. The post optimization values for dehulling and separation efficiencies were 48.70 % and 44.66 % respectively with the prospect for components scale up ratio of 1:1. The machine is a novel development as a dry seed dehuller which instead of blower uses internal material flow and air current to classify hulls and kernels. This dehuller valued at $750 is equally holds good promise for quick return of investiment and global trade on breadfruit seeds.

Keywords: *African breadfruit, dehuller, development and testing, optimization*

Introduction

Dehulling involves the application of shear on grain surface in order to remove hulls from kernels of seeds. Four main types of dehuller in operation are; (a) cone; and (b) disc abrasive hullers; (c) engelberg dehuller; and (d) rubber rolls hullers (Brian and Alexandra, 2006). All classes of huller but engelberg hullers use abrasive friction to achieve hull-kernel separation (Brian and Alexandra, 2006). The requirements of commercial processors of roasted seeds are not met by present class of dehullers (Nwigbo et al., 2008; Omobuwajo et al., 1999).Also most dehullers in operation are intended for wet dehulling of grains. In effect the productivity of commercial processors of roasted snack seeds of breadfruits (*Treculia africana*) and seeds with similar configurations are constrained by the absence of product specific dehullers.

The continued reliance of roasted seed processors on traditional methods of dehulling, and where contingent their use of process limiting adaption of cereal attrition mills for dehulling processes account for their low productivity. Traditional methods of dehulling involving the spreading of roasted seeds on cement floors and the use of bottles to express kernels from seed hulls. The use of traditional methods of hulling and the adaption of attrition mills are tiresome, less productive(less than 4.5kg/day) and unable to meet the commercialization indices needed for profit. It is the roasted seeds that is driving the global trade in breadfruit. Roasted seeds as article of trade have better shelf life, convenience and overall acceptability than parboiled wet seeds. For example in a micro market study posting a net income of about N40 million naira($450,000=) from sale of breadfruit seeds, the reported yield per season was about 20% of investment (Moujekwu et al., 2017). This estimated return on investment represents less than 10 % of the total national market of breadfruit seeds.

Large scale dehulling for commercial purposes is hinged on efficiency of equipment and processes. The most efficient method of dehulling of seeds combines impact and centrifugal actions (Gupta and Das, 1999). The combined forced of impact friction, shear and centrifugal forces between particles, walls of dehulling chamber cause the hulls to crack and break away from kernels (Sharma et al., 2013; Doehlert et al., 2009). Information in literature underscore the absence of dehullers that combine impact and centrifugal force for dehulling of roasted breadfruit seeds or similar seeds. Centrifugal methods of dehulling of grains and seeds has been shown to be efficient with higher output of products (Sharma et al., 2013; Gupta and Das, 1999).The absence of such dehuller account for the under exploitation of the huge market opportunities for roasted snack seeds. Other probable reasons for the absence of appropriate dehuller for roasted breadfruit seeds include the early unrecognized potentials of some lesson known legumes and cereals. More especially breadfruits seeds diet was often seen as food of depravity. The changing perception about breadfruit seeds as nutritious and healthy legume (Osabor et al., 2009), the nutritional and industrial potentials of breadfruits (FAO, 2015) have become important motivators for a sustainable mechanization of roasted seed processing for food and industrial needs. There is a technological demand for a dehuller of roasted seeds to fill the market demand gap created by the absence of appropriate dehulling machine.The development of the dehuller is envisaged to enhance the output of roasted seeds for full commercialization of the global demand of breadfruits seeds for food and pharmaceutical industries.

Design concepts

The dehuller was conceptualized to be cylindrical shaped designed to facilitate the tumbling rotation of roasted seeds against the internally mounted beaters on a horizontal output shaft.The designed dehuller handles roasted breadfruits or seeds with similar shapes and sizes. The design considerations were based on seed size and shape, physical forces and 0perationality. The design combines impact and frictional forces for dehulling of seeds. Tumbling action of the seeds reduces the physical impact on the endosperm resulting in dehulled whole kernels. To achieve the needed result, a rotating steel horizontal output shaft with equidistantly placed beaters driven by a 3.5 kw electric motor generates the rotary movement of seeds , the shear force, frictions and centrifugal force ($F = Mv^2/r$) within the dehulling chamber. The use of an electric motor of 3.5 kwh rating was based on the power required to drive the horizontal shaft and loads. To ensure good manufacturing practice and elimination of food contamination risks only stainless steels were used for all internal materials of the dehuller. Costs efficiency and safety of machine for operators were other important considerations in the design of the machine.

Machine design specification

Determination of engineering data and machine design parameters employed regular equations and their adaptations. These include;

Dehulling chamber

The volume of the dehulliing chamber was calculated using the equation as described by Ozigbo and Murphy (2016);

$$v = \pi r^2 h \qquad \text{(Eq. 1)}$$

Where; v is volume, π is the constant with 3.14, r is the radius of cylinder, and h is the height of cylinder. Determination of volume of hopper (Adgidzi, 2007) using;

$$V = \frac{h}{3}\left[A_1 + A_2 + \sqrt{(A_1 + A_2)}\right] \qquad \text{(Eq. 2)}$$

Where; v is the volume of hopper (M^3), A_1 and A_2 is the area of top (M^2), and h is the height of the hopper (m). The determination of horizontal output shaft diameter (Hall et al., 1961) using;

$$d = \left(\frac{16}{\pi s}\left(\sqrt{(K_b M_b)^2} + (K_t M_t)^2\right)^{1/3} \qquad \text{(Eq. 3)}$$

Where; K_b is the fatigue and shock factors (bending moment), K_t is the fatigue and shock factor (torsional moment), M_b is the maximum bending moment on shaft, M_t is the maximum torsional moments on shaft, S is the maximum permissible shear stress, and π is the constant with 3.14. The determination of machine speed determined (Khurmi and Gupta, 2005a) using;

$$MS = \frac{D_2}{D_1} = \frac{N_1}{N_2} \qquad \text{(Eq. 4)}$$

Where; Ms is the machine speed, D_2 is the diameter of larger wheel, D_1 is the diameter of small wheel, N_1 is the rotation of small wheel, and N_2 is the rotation of large wheel. The determination of angular velocity using;

$$w = \frac{\pi n}{30} = \frac{3.14n}{30} = 58.29 \text{ rad sec}^{-1} \qquad \text{(Eq. 5)}$$

Where; w is the angular velocity, n is the revolution per min; 3.14 is the dimensional factor, and π is the constant with 3.14. The determination of dehulling force (Khurmi and Gupta, 2005b) using;

$$F = \mu (w + 2mw^2) \qquad \text{(Eq. 6)}$$

Where; F is the dehulling force, µ is the (0.38) coefficient of friction between walls of dehulling chamber and breadfruits, m is the mean mass of breadfruit seed, w is the angular velocity, and w is the mean weight of breadfruit seed. Determination of Power required by the horizontal shaft used;

$$P = Tw \qquad \text{(Eq. 7)}$$

Where; w is the angular velocity, and T is the torque developed. The total force (power) can be express as;

$$TP = F + P \qquad \text{(Eq. 8)}$$

The determination of Dehulling Efficiency, D_E is expressed as;

$$D_E = [(M_f – M_d)/M_f] \text{ X } 100 \qquad \text{(Eq. 9)}$$

Where; D_E is the dehulling efficiency, M_f is the mass of feed sample and M_d is the mass of dehulled sample. In determination of Dehulling Capacity, DC is stated as mass dehulled divided by time. In determination of Separation (Hull-Kernel) Efficiency, S_E is expressed as;

$$S_E = [(M_c – M_e) / M_f] \text{ X } 100 \qquad \text{(Eq. 10)}$$

Where; S_E is the separation efficiency, M_c is the mass of feed sample cracked, M_e is the mass of endosperm without hulls, and M_f is the mass of feed sample.

Materials and Methods

Sourcing of materials for fabrication of prototype dehuller

The materials for fabrication of the centrifugal impact prototype dehuller were procured locally from Aba, Jos and Umuahia, Nigeria. All materials used were of best qualities and purchased according to material specifications.

Machine fabrication

The machine was fabricated at the Agricultural Engineering Workshop of Michael Okpara University of Agriculture, Umudike, Nigeria in collaboration with the Mechanical workshop of National Root Crops Research Institute, Umudike, Nigeria.

Optimization of machine process

After fabrication of the machine its operations (under load and without load), noise levels, vibration and condition the rotating parts were evaluated.The conditions of the dehulled seeds was examined to assess rate of fragmentation and kernel-hull separation. It's Dehulling and separation efficiencies were optimized (*Table 1*) using Response surface methodology (Khuri and Cornell, 1996), to assess the relationship between empirical and regression conditions considered useful for parametric scale up of the dehuller. Optimization has been employed to successfully attain best quality product among similar products class or design.

***Table 1**. Dataset used in the experiment.*

Category	Codes	-1.682	-1	0	1	1.682
Roasting temperature RT (◦C)	X_1	123.36	140	160	180	193.64
Roasting time RM (min)	X_2	31.59	35	40	45	48.4

Feed quantity FQ (g)	X_3	331.80	400	500	600	668.2

Optimization of the machine performance was performed using Central Composite Rotable Design and Minitab Statistical Software version 15 (Minitab Inc.). The experimental level is shown on *Tables 1*. The experimental layout comprised of 8 factorial 6 axial and 6 replications at the centre with a minimum of 15 experimental runs.Description of statistical relationship between response and inputs is described by equation 12. All statistical analyses were conducted at 95% confidence level.

Results and Discussion

Description of machine

The developed dehuller is shown on *Figure 1*, while *Figure 2* shows the isometric view and dimensions of the machine. The dehuller comprises of hopper (1 kg holding capacity), dehulling chamber (5 kg holding capacity), vanned horizontal output shaft, variable rubber pulley system, motorized power source, discharge ports, machine stand and accessories. The cylindrical dehulling chamber houses the horizontal mounted steel output shaft driven by an electric motor using a rubber belt pulley system. Dehulling in the chamber is achieved by the combined actions of shear, inter particulate friction, impact on walls of dehulling chamber and angular velocity generated by the horizontal output shaft. The dehulling capacity was 20kg/h .Which is superior to the maximum of 4.5kg/day obtainable through traditional dehulling methodate.The machine be used for batch or automated processing. The speed of the machine is controlled by a rubber belt pulley system linked to a 3 kW electric motor energized through mains power supply.

Figure 1. *The developed of Dehuller.*

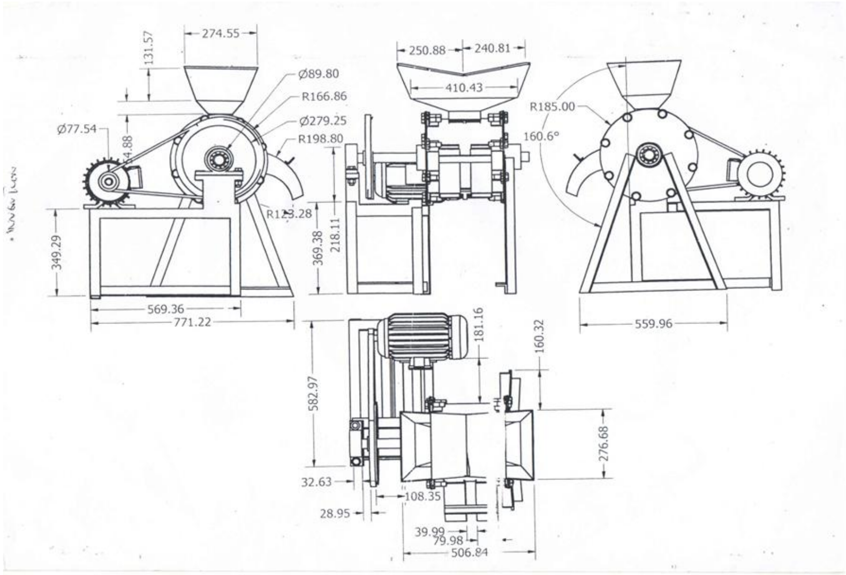

Figure 2. Cross sectional view and dimensions of the developed dehuller.

Operation of the machine

Materials for the dehullling are fed into chamber through the hopper and after dehulling exit through the semi-circular shaped discharge ports situated at the upper half of the dehulling chamber. The separated hulls from kernels are collected below the perforated bottom of the dehulling chamber. The hulls though lighter than the kernels are blown into the bottom exit ports by the action of the beater blades on vanes of the horizontal output shaft. During the running operations the machine showed no load stress. It was smooth running without vibration or whipping of the horizontal output shaft. The dehulled materials discharged efficiently through the discharge ends. The separated kernels showed only 11% fragmentation.

Pre-optimization efficiencies for Dehulling and separation efficiency were 54% and 49% respectively. The result of optimization experiments is described by Equation 11 and *Figure 3*. The dehulling efficiency and separation efficiency of the dehuller are indicative of the scale-up potentials of the machine. Roasting temperature, time and mass were seen as the significant ($p<0.05$) terms of models.

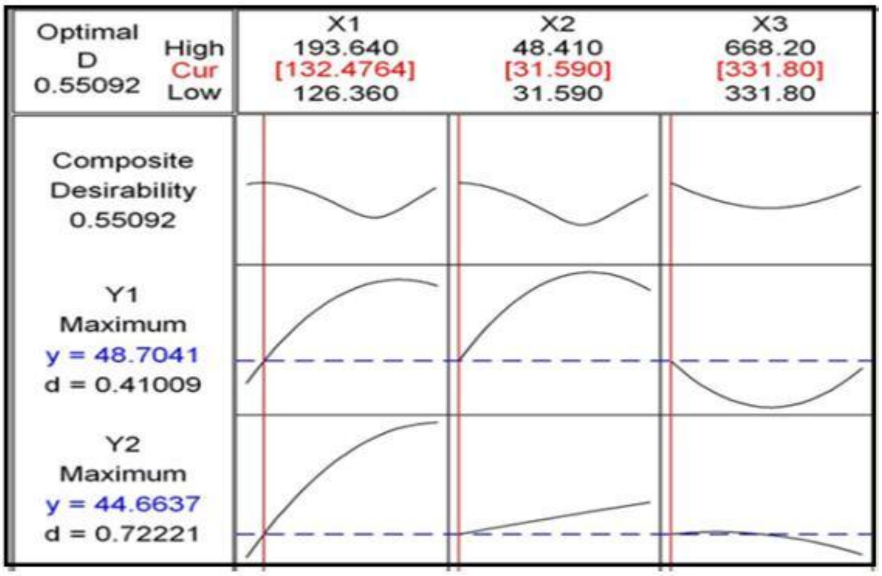

Figure 3. *Optimization plot for machine performance.*
Notes: X_1 *is roasting temperature (RT),* X_2 *is roasting time (RT),*
X_3 *is feed quantity (FQ),* Y_1 *is the dehulling efficiency,* Y_2 *is separation yield.*

The Regression Coefficients of model were 0.94, 0.88 and 1.69 for co-efficient of determinant R^2, adjusted R^2 and S respectively. The models significance (P=0.000) and non-significant ($p<0.05$) lack of fit, between predicted and empirical models underscored the adequacy of the models to explain variations in response characteristics. The relationship between roasting temperature, time and feed quantity as input variables, and the Dehulling Efficiency (DE) of the dehuller described as the response characteristic of independent variables is summarized as;

$$DE = 290.295 + 2.333\ RT + 1.348RM - 0.231FQ - 0.103RM^2 - R^2\ (0.94) \qquad \text{(Eq. 11)}$$

Where; RT is the roasting temperature, RM is the roasting time, and FQ is the feed quantity. The effect of Roasting temperature on dehulling efficiency showed an inverse inverse relationship with feed quantity. Heat transfer rates are influenced by shape and size of product. The regression model for Separation Efficiency was not significant ($p<0.05$). However the non significant lack of fit between the predicted and empirical models ($p=0.949$), co-efficient of determination R^2 (0.69) adjusted R^2 (0.41) placed against S (1.60) are indicative of the moderate usefulness of the empirical model to describe response data. Roasting temperature and time are the two standout terms that influence dehulling and separation of kernels from hulls of roasted breadfruit seeds.At optimum process variable cconditions of 193.64^0C, 48.41min and 668.20g (as in *Figure 3*) dehulling and separation ratio was approximately 1:1, which supports simultaneous upgrading of machine design and capacity.

Dehulling capacity, efficiency and separation efficiency

Dehulling efficiency and separation efficiency showed comparable responses to Roasting temperature and time variations. The optimization profile points to the positive correlation between temperature and time for dehulling efficiency; and the positive correlation between temperatures are only for separation yield. This could be attributed to the drying effect of high temperatures on seed moisture content and the strain and stress on hulls. The effect of high temperature is reduced by high mass volume. The capacity for efficient hull separation by the machine was observed to be impeded by higher seed mass.

Conclusion

This machine is envisaged to aid processors and to address the limitations of drudgery and low productivity associated with traditional method of dehulling. This design achieved an output capacity of 20kg/day at 54% dehulling efficiency and 49% separation efficiency. The advantage of this dehuller over traditional methods is not in doubt. As it is not technically feasible to achieve above 65% efficiency for prototypes, these results point to successful mechanization of breadfruits seeds dehulling. Further studies with consistent research efforts directed at speed of horizontal output shaft ,internal configurations of the dehulling chamber and effects of physical parameters of roasted seeds due to pretreatment conditions is encouraged. Optimization results showed positive agreement between empirical and predicted values, which is suggests the technical feasibility of upgrading the developed dehuller of roasted African breadfruit seeds.

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Conflict of interest

The author confirm there are no conflict of interest involve with any parties in this research study.

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