Assessment of a modified mixer for wet dehulling of cowpea (*Vigna unguiculata*)

Ogunnigbo C. O.[1*], Adetan D. A.[1], Olusunmade, O. F.[2]

(1. *Department of Mechanical Engineering, Faculty of Technology, Obafemi Awolowo University,PMB 13, Ile-Ife, Nigeria*;
2. *Department of Mechanical Engineering, College of Engineering, University of Agriculture,PMB 2373 Makurdi*, *Nigeria*)

Abstract: This study evaluated the performance of a modified flour mixer for use as a wet bean de-hulling device. The effect of soaking time, running time and operating speed was investigated. The machine was run at 150, 200, 250, 300 and 350 rpm, for operating times 1, 2, 3, 4 and 5 mins in dehulling beans soaked in water at ambient temperature of 29°C ± 2°C for 2, 4, 6, 8 and 10 min. The results showed that soaking time, operating speed and machine running time have significant effect (at 5% significance level) on all the performance indices of the machine. The highest de-hulling efficiency obtained as the ratio of the mass of completely dehulled wet cowpea to the total mass fed into the de-hulling chamber was 84.83% with percentage seed breakage obtained as the mass ratio of the broken wet cowpea to the total mass fed into the de-hulling chamber was 19.66% observed for black eye pea; corresponding values for brown beans were 83.95% and 22.93% respectively. These values were obtained at seed soaking time of six minutes, operating speed of 350 rpm and machine running time of four minutes.

Keywords: dehulling, black eye pea, Ife brown, soaking time, running time, percentage breakage

Citation: Ogunnigbo, C. O., D. A. Adetan, and O. F. Olusunmade. 2018. Assessment of a modified mixer for wet dehulling of cowpea (*Vigna unguiculata*). Agricultural Engineering International: CIGR Journal, 20(2): 239–247.

1 Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.] is a popular leguminous crop in Africa. It is popularly known as ‘beans’ in Nigeria. The name cowpea probably originates from the fact that the plant is an important source of hay for cows in the South-eastern United States and in other parts of the world. Some important local names for cowpea around the world include “*niebe*,” “*wake*,” and “*ewa*” in much of West Africa and “*caupi*” in Brazil. In the United States, other names uses to describe cowpeas include “southern peas”, “black-eyed peas”, “pinkeyes”, and “crowders”. These names reflect traditional seed and market classes that developed over time in the southern United States (Timko et al., 2007).

In Nigeria as well as most West African countries, cowpea is eaten in various forms: as porridge along with fried or boiled yam or plantain; as bean cake called *akara* or *kosei* among Yoruba and Hausa respectively; as *moin – moin* which is prepared by steam–cooking wet–milled cowpea mixed with cooking ingredients; it is also used in preparing a popular cowpea stew called gbegiri (Babatunde, 1995). Cowpea seeds are now being processed into packaged dry cowpea flour which may be further processed into various forms of cowpea food products. The grain is rich in protein up to around 30% in some varieties. In addition, the grain contains micronutrients such as iron and zinc which are necessary for healthy living (Bouker et al., 2010). It is for these reasons that societies endowed with cowpea have evolved different ways of utilising the grain for food. It is the food value of cowpea that has earned the crop its high economic value.

Dehulling of cowpea seeds plays a major role in the processing of cowpea seeds. Akinjayeju and Ajayi (2011) and Kurien et al. (1972) defined dehulling as the removal of the seed coat (hull) which results in the separation of

Received date: 2016-08-30 **Accepted date:** 2018-08-25

* **Corresponding author: Ogunnigbo, C.O.,** Department of Mechanical Engineering, Faculty of Technology, Obafemi Awolowo University, Ile-Ife, Nigeria. Tel: +2347063553894. Email: charles_olawale@yahoo.com.

the cotyledon. There are two major methods of dehulling: wet dehulling and combined dry and wet dehulling methods.

In the rural sector, the dehulling process is still a part of the housewife's work in food preparation. Because the hull is firmly attached to the cotyledons, water soaking is used to facilitate hull removal. The hulls absorb moisture and swell, thereby facilitating dehulling by gentle rubbing of the seed by hand or pounding inside a mortal. The hulls are easily separated from cotyledons by floatation. At this stage, the cotyledons are wet and must be used immediately or dried and stored for further processing into desired food products.

A number of researchers have studied related properties of cowpea and developed large village scale cowpea dehuller (Ogunnigbo et al., 2018; Osei Twumasi – Ankra, 2014; Princewill and Ezinne, 2014; Beck et al., 2005). Others have worked on the development of different types of commercial scale dehulling systems for various edible fruits like melon, maize, cocoa pod, sunflower and groundnut (Aduba et al., 2013; Olaoye, 2011, Reichert et al., 1979). Some have also developed both manually operated and motorized dehulling machines for cowpea (Olowonibi, 1999; Kolade, 2003), though of the commercial scale.

The major problem in mechanised de-hulling that has not been properly addressed is the high percentage breakage of cotyledons. The broken cotyledons go with the hulls during separation (Adejuyigbe and Bolaji, 2005). Furthermore, the available de-hulled beans production machines in Nigeria are of the commercial scale and they are therefore expensive, beyond the reach of most Nigerian households and indeed inappropriate for domestic use. There is therefore the need to simplify the design to cater for the ever-increasing demand of de-hulled beans for a typical Nigerian household.

This study therefore assesses a household flour mixer in order to adapt it for de-hulling wet cowpea on a domestic scale by redesigning its mixing tool. The specific objectives of the study is to design and construct a de-hulling tool capable of giving high efficiency of de-hulling and carry out the performance evaluation of the modified machine on two variety of cowpea.

2 Materials and methods

2.1 The dehulling device adapted from a modified flour mixer

A 300W domestic scale flour mixer (Russell Hobbs, 18960) is purchased based on designed power requirement for dehulling for an average household consumption. The mixer is illustrated in Figure 1. The major parts of the mixer are the power unit, frame, mixing tool and the mixing bowl.

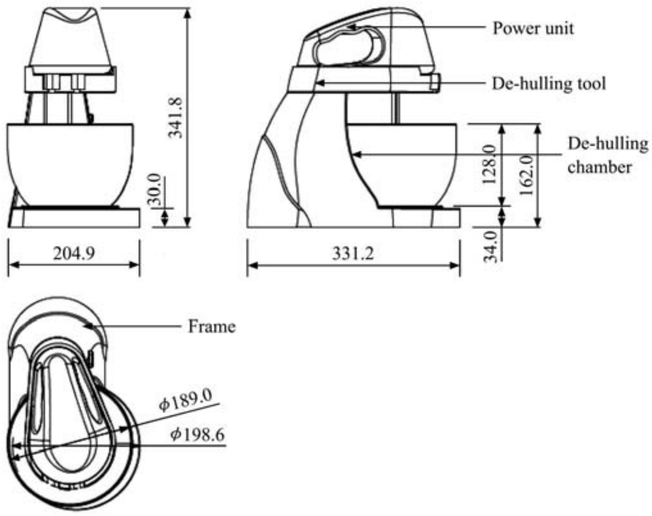

Figure 1 Autographic views of the flour mixer

The functions of the principal units of the modified flour mixer is as follows:

i. Frame: This is a standard part of length 320 mm, breadth 200 mm and height of 250 mm. The top part of the frame forms the platform for carrying the drive motor.

ii. De-hulling tool: The tool is made from stainless steel shaped in the form of gear/impeller with pitch of 20 mm and diameter of 47 mm. This tool is covered with a rubber material to minimise beans breakage.

iii. De-hulling chamber: The mixing bowl of the flour mixer is used as the de-hulling chamber; it is made from a 1 mm thickness stainless steel. It is shaped like a truncated hemisphere having a base diameter of 165 mm and a top diameter of 225 mm. The internal surface of the bowl is covered with rubber material. A lid is provided for the chamber to prevent wet bean seeds from jumping off the chamber during operation.

iv. Power unit: The electric motor is the prime mover of the machine.

2.2 Principle of operation of the dehulling device

Figure 2 shows the mixing tool that came with the purchased device while Figure 3 illustrates the modified de-hulling tool. Two de-hulling tools are carried on parallel counter-rotating shafts such that they mesh with each other like in a gear arrangement while running inside the de-hulling chamber filled with pre-soaked cowpea seeds (Figure 4). This gear-like arrangement provides the necessary frictional and impact forces to de-hull the wet cowpea seeds at the instance of sufficient centrifugal force exerted by the rotating tools on the samples inside the de-hulling chamber. After each batch of cowpea is run, the resulting mixture of de-hulled cowpea and hull is manually separated in water using the principle of buoyancy.

Figure 2 Mixer tool and motor

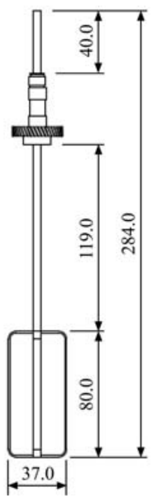

Figure 3 Modified de-hulling tool

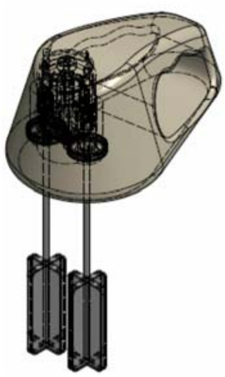

Figure 4 Assembly of shaft, de-hulling tool

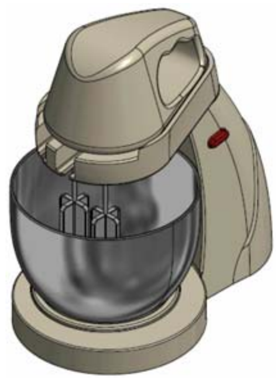

Figure 5 Assembly drawing of the wet bean dehuller

2.3 Some theory of the design process

2.3.1 Volume of cowpea in de-hulling chamber (V_b)

The volume of beans (V_b) in the de-hulling chamber is obtained by subtracting the volume of the de-hulling tool (V_{dt}) in the de-hulling chamber from the volume of the de-hulling chamber (V_{dc}).

$$V_b = V_{dc} - V_{dt} \tag{1}$$

where, V, V_{dc} & V_{dt} are all expressed in cm^3.

2.3.2 Weight of cowpea in de-hulling chamber

Weight of beans, W_b, is given by

$$W_b = m\,g \tag{2}$$

where, m = mass of beans in gramme and g is the acceleration due to gravity in m s^{-2}.

Also,

$$m = \rho V_b \tag{3}$$

where. ρ = bulk density of beans expressed in g/cm^3.

2.3.3 Power required to drive the shaft

(I) Power required to dehull the sample, *Ph*

Torque and power for samples

$$T = F\,r \tag{4}$$

where, F is the force required to shear the wet beans and r is the radius of the dehulling tool/impeller. But according to Davies and Zibokere (2011), shearing force of wet beans is related to moisture content through this relation;

$$F = -1.54Mc + 91.9 \tag{5}$$

where, F in N is the shearing force and Mc in % is the moisture content of the beans in wet basis.

(a) For brown beans

$$F = -1.54(23.83) + 91.9 = 55.22 \text{ N}$$

Optimum operating speed ω is 350 rpm = 36.65 rad s^{-1},

$$r = 21 \text{ mm} = 0.021 \text{ m}$$

$$T = 55.22\times0.021 = 1.16 \text{ N m}$$

$$Ph = T\omega \tag{6}$$

$$Ph = 1.16\times36.65 = 42.514 \text{ W}$$

(b) For white beans

$$F = 35.21 \text{ N}, \omega = 36.65 \text{ rad s}^{-1}$$

$$r = 0.021 \text{ m}$$

$$T = F\, r = 0.770 \text{ N m}$$

$$Ph = 28.208 \text{ W}$$

(II) Power required to drive the shaft, Ps

$$Ps = (\mu\ Wg)\ Vc \tag{7}$$

$Vc = r\omega_s$, where ω_s is the angular speed of shaft = 36.65 rad s^{-1}; μ is the coefficient of friction; Wg is the weight of the two gears carrying shaft (N); Vc is the linear velocity, m s^{-1}; r is the shaft radius in m.

(a) For brown beans

$$r = 0.00275 \text{ m}, Wg = 10 \text{ g}, \mu_b = 0.7089$$

where, μ_b is the coefficient of friction for brown beans.

$$Ps = (0.7089\times0.1)\ 0.00275\times36.65 = 0.07089\times0.1007875$$
$$= 0.0071448 \text{ W}$$

(b) For white beans

$$r = 0.00275 \text{ m}, Wg = 10 \text{ g}, \mu_w = 0.6169$$

where, μ_w is the coefficient of friction for white beans.

$$Ps = (0.6169\times0.1)\ 0.00275\times36.65 = 0.06169\times0.1007875$$
$$= 0.006218 \text{ W}$$

(III) Power required to revolve the bowl, P_b

$$F_b = \mu_{bl} W \tag{8}$$

where, F_b = force required to revolve the bowl (N); μ_{bl} = coefficient of friction at the bowl base = 0.3012; W = weight of the bowl = 0.534×10 = 5.34 N.

$$F_b = 0.3012\times5.34 = 1.608 \text{ N}$$

$$T = F_b\, r \tag{9}$$

where, r = radius of the bowl = 112 mm = 0.112 m; T is the torque (N).

$$T = 1.608\times0.112 = 0.18 \text{ N m}$$

$$P_b = T\omega \tag{10}$$

where, ω the angular speed of the bowl is relatively small, hence P_b is negligible.

Total power required is calculated by using equation as specified by Akintunde et al. (2005).

$$P_T = P_h + P_s + P_b \tag{11}$$

P_b is negligible since the speed at which the bowl rotates is small.

where, P_h and P_s is the power required to dehull and drive the shaft respectively

Therefore, $P_T = P_h + P_b$

$$P_T = 42.51 + 0.0071448 = 42.517 \text{ W or } 0.057 \text{ Hp}$$

(Maximum values of power selected)

Using the factor of safety of 2, power required is 0.114 Hp = 85.5 W, therefore a motor of 0.4 Hp, 300 W is chosen to power the shaft and de-hull the beans.

2.4 Experimental evaluation procedure

The device was run at various operating speeds of 150 rpm, 200 rpm, 250 rpm, 300 rpm and 350 rpm determined using a digital tachometer (DT, 2236B). The two commonly available cowpea varieties (Black eye pea and Ife brown) were used for the experiment. The selected cowpea varieties were weighed in three replications of 300 g each using a top pan weighing balance (Mettler Toledo AB 54 GmbH, Greifensee, Switzerland, 0.01 g). The weighed quantities of cowpea were soaked for times of 2 mins, 4 mins, 6 mins, 8 mins and 10 mins. The moisture content at each soaking time was then measured following the ASAE S352.2 standard testing procedure for ungrounded grains and seeds (ASAE, 2003). The soaked and weighed cowpea seeds batches were fed into the de-huller which was run at various speeds for times varying between 1 and 5 mins in steps of 1 min. Thereafter, weight of the de-hulled seeds, weight of the unde-hulled seeds, weight of broken seeds and weight of chaff were measured and recorded. Estimated numbers of broken seeds were manually sorted out from the complete de-hulled seeds and weighed on the digital weighing balance.

2.5 Experimental design and statistical analysis

A completely randomized design using the analysis of variance (ANOVA) was used in this study. The effect of operating conditions on the performance of the cowpea de-hulling machine was investigated. Parameters considered are the soaking time, operating speed and running time of the machine per batch of the cowpea. The effect of the operating conditions were checked on the dehulling efficiency and percentage breakage for the locally available variety. The treatment combinations in the design layout for the experiment were 2×5^2 factorial design experiments. To determine the differences in the mean treatment effect of operating speed, New Duncan's Multiple Range Test (NDMRT) was conducted. All calculations were conducted using the Statistical Package for Social Science (SPSS) using Tukey and Fisher's Approach at $p<0.05$.

2.6 Performance indices

The dehulling efficiency and percentage seed breakage were calculated using Equations 12 and 13 obtained from the format of the standard test code for groundnut sheller (NIS 321, 1997; Babatunde, 1995).

i. Dehulling efficiency, *DE* (%): The de-hulling efficiency was obtained as the ratio of the mass of completely dehulled wet cowpea to the total mass fed into the de-hulling chamber. It is given as

$$DE = \frac{M_1}{M_T} \times 100 \qquad (12)$$

where, M_1 = Mass of wet cowpea completely de-hulled (g); M_T = Mass of the cowpea fed into the de-hulling chamber (g).

ii. Percentage seed breakage, P_b (%): The percent breakage, P_b, is the mass ratio of the broken wet cowpea to the total mass fed into the de-hulling chamber. It is given as

$$P_b = \frac{M_2}{M_T} \times 100 \qquad (13)$$

where, M_2 = Total mass of de-hulled broken seeds (g).

3 Results and discussions

3.1 De-hulling efficiency

The ANOVA for data on de-hulling efficiency is presented in Table 1. From the results, it could be inferred that the soaking and running times have statistically significant effect on de-hulling efficiency. However, on the average as seen in Figure 6 and 7, the de-hulling efficiency increases up to a soaking time of 6 mins as the device is run between 1 to 3 mins thereafter a trend in plot was observed. From Table 1, it can be observed that at 5% significance level, operating speed had no significance difference in the dehulling efficiency for brown beans while speed had some measure of statistical significance on the de-hulling efficiency for black eye pea.

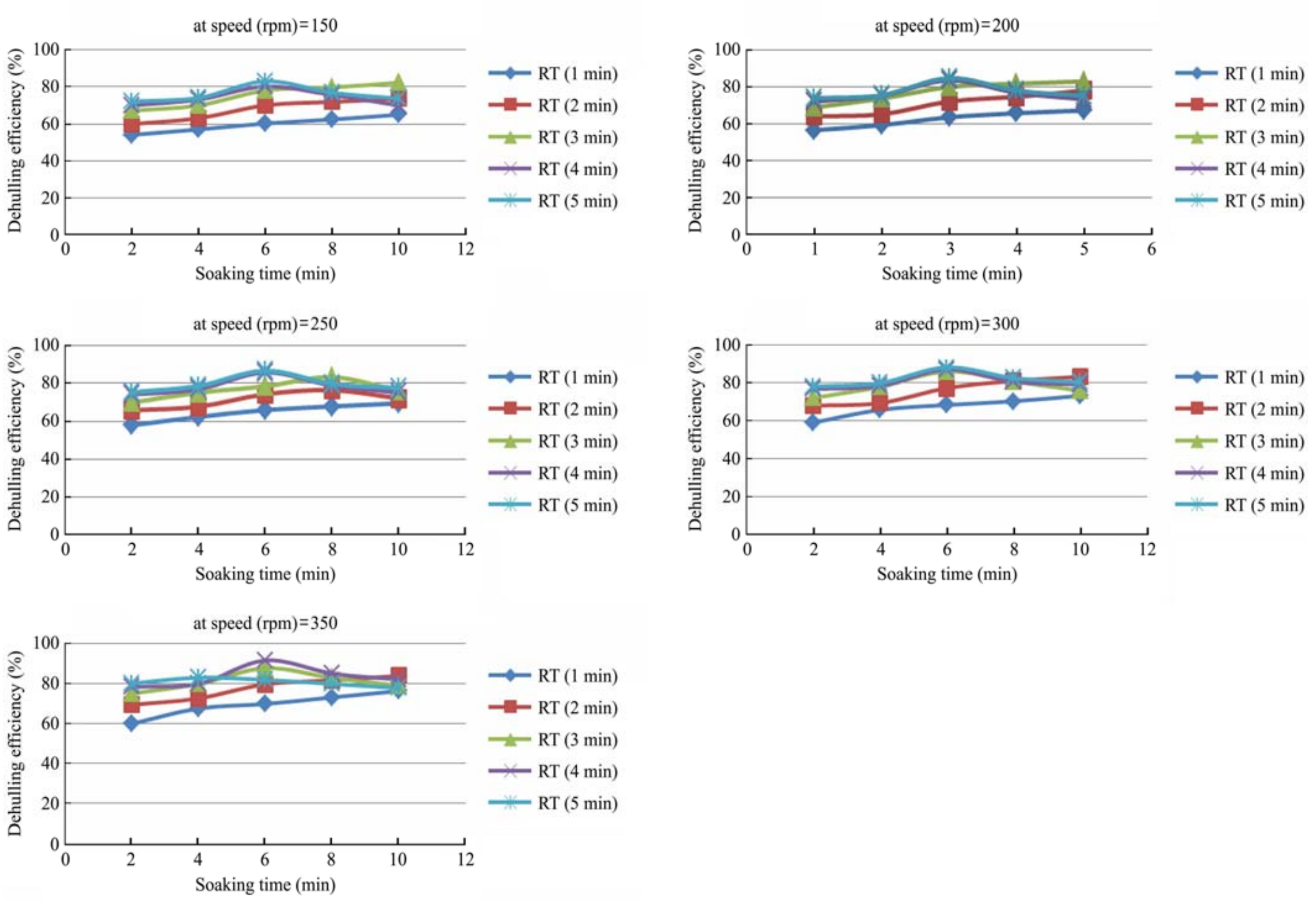

Figure 6 Variation between de-hulling efficiency and soaking time at different speed and running time (RT) for brown beans

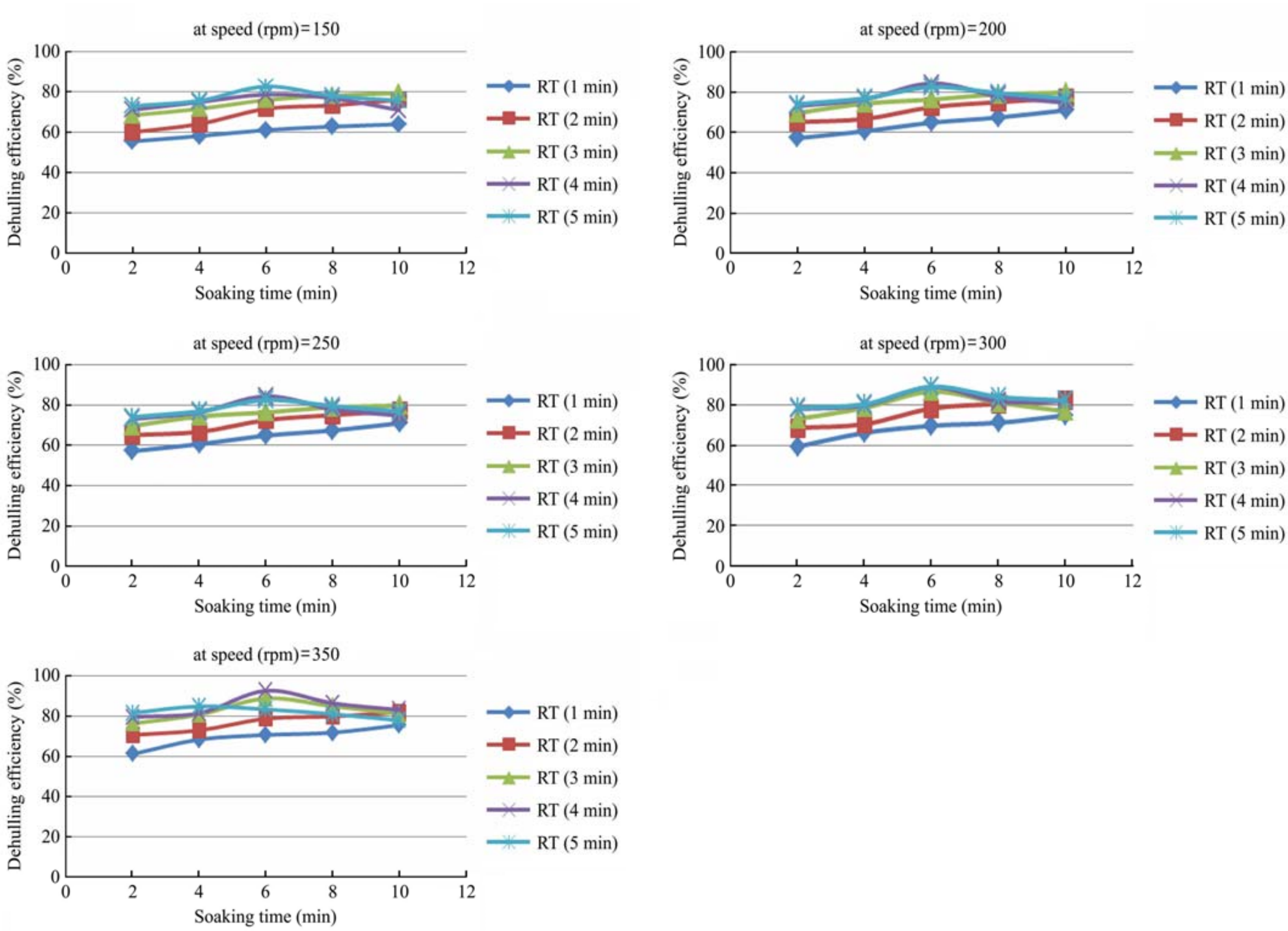

Figure 7 Variation between dehulling efficiency and soaking time at different speed and running time (RT) for black eye pea

The result of the comparison among the five levels of speed revealed that de-hulling efficiency increases with increase in soaking time up to 6 mins when run between 4 and 5 mins for black eye pea and brown beans varieties and that the mean differences observed for each level of speeds are significantly different from each other, except for speed levels 200 rpm and 250 rpm. As shown in Table 2, maximum de-hulling efficiency of 84.83% was observed at 350 rpm when run for 5 mins while a minimum de-hulling efficiency of 65.58% was observed at 150 rpm at 1 min running time for brown beans variety; corresponding values for white beans are 83.95% and 65% respectively. The low mean de-hulling efficiency value at low speed level of 150 rpm observed in this study might be attributed to the fact that the residence time of the soaked cowpea seeds inside the de-hulling chamber was so short that there is no enough time for the seeds to rub against each other and the wall of the de-hulling chamber for efficient de-hulling. In contrast, Aduba et al. (2013) reported that de-hulling efficiency of a cowpea de-huller decreases with increase in operating speeds, although he worked at different speed levels of 250, 300 and 350 rpm. Furthermore, Kamaldeen et al. (2017) reported that de-hulling of cowpea seeds at lower speed is more efficient than de-hulling at higher speed.

Generally, black eye peas had the highest mean value of de-hulling efficiency. This might be because they are characterised by weaker adhesion force between the hull and the cotyledon making detachment of the hull from the cotyledon easier during the process of de-hulling. Aduba et al. (2013) reported that cowpea seeds differ from variety to variety in terms of seed coat texture. The seed coat texture could be an important selection index when processing cowpea seeds into flour, especially for ease of soaking and de-hulling operations. Hence the difference in the response of the two selected cowpea varieties seeds during the experiment might be as a result of their different seed coat characteristics.

Table 1 ANOVA Table for de-hulling efficiency

Source	Dependent Variable	Type III Sum of Square	df	Means Square	F	Sig
Model	Dehull_Eff_Br	146799.298[a]	13	11292.254	3098.715	0.000
	Dehul_Eff_Wt	150290.502[b]		11560.808	4389.457	0.000
Soaking Time	Dehull_Eff_Br	1001.462	4	250.366	68.703	0.000
	Dehul_Eff_Wt	1464.108	4	366.027	138.975	0.000
Running Time	Dehull_Eff_Br	1233.232	4	308.331	84.609	0.000
	Dehul_Eff_Wt	1300.602	4	325.150	123.455	0.000
Operating Speed	Dehull_Eff_Br	38.325	4	9.581	2.629	0.087
	Dehul_Eff_Wt	37.535	4	9.384	3.563	0.039
Error	Dehull_Eff_Br	43.730	12	3.644		
	Dehul_Eff_Wt	31.605	12	2.634		
Total	Dehull_Eff_Br	146843.028	25			
	Dehul_Eff_Wt	150322.108	25			

Note: Significant at $p≤0.05$. a. R Squared = 1.000 (Adjusted R Squared =0.999); b. R Squared = 1.000 (Adjusted R Squared = 1.000).

Table 2 NDMRT for mean de-hulling efficiency

Variety		Black eye pea	Brown beans
Running time (min)	1	65.5760[a]	65.0000[a]
	2	71.5400[b]	71.0980[b]
	3	79.3300[c]	78.4040[c]
	4	82.7660[d]	81.7120[d]
	5	84.8300[e]	83.9520[e]
Soaking time (min)	2	64.4900[a]	66.8640[a]
	4	71.3520[b]	70.1540[b]
	6	80.9580[c]	79.2780[c]
	8	82.8260[d]	81.0800[d]
	10	84.4160[e]	82.7900[e]
Operating speed (rpm)	150	74.5700[a]	74.1320[a]
	200	76.7920[b]	75.5460[b]
	250	76.8420[b]	75.9040[b]
	300	77.8000[c]	76.7320[c]
	350	78.0380[d]	77.8520[d]

Note: Mean with the same alphabet are not significantly different from each other at 5% level of significance.

3.2 Percentage of seed breakage

The result of ANOVA for percentage seed breakage is presented in Table 3. The results show that at significance level $p>0.05$ the speed of operation, machine running time and the soaking time have significant effects on the percentage seed breakage for the two varieties of cowpea seeds run in the machine. This is because as the processing parameter is varied, it results in different corresponding values of percentage seed breakage. The results of the NDMRT are presented in Table 4 for the two varieties of cowpea studied. These results show that percentage seed breakage increases with increase in the speed of operation and the highest mean percentage breakage was recorded at 350 rpm operating speed. This agrees with the findings of Aduba et al. (2013) which showed higher percentage breakage for cowpea when using a treadle operated abrasive-cylinder de-huller at the higher speeds of operation. This could mean that the de-hulling tool beat the seeds inside the de-hulling chamber harder and faster thereby increasingly weakening the seeds with time as the speed continues at 350 rpm. At lower speed levels however, the de-hulling tool gently impacts the seeds inside de-hulling chamber causing more of the seeds to maintain their integrity. From Table 4, it could be seen that the percentage seed breakage that some levels of speed having the same alphabet has is not significantly different at $p≤0.05$.

The NDMRT also shows the difference in the levels of the percentage breakage of the de-huller between both varieties of cowpeas studied. The highest percentage breakage of 22.934% is obtained at 10 minutes soaking time and this was for the white black eye pea variety.

Table 3 ANOVA for percentage seed breakage

Source	Dependent variable	Type III sum of squares	Df	Mean square	F	Sig.
Corrected model	Percent_Breakage	217.349[a]	12	18.112	2.696	0.049
	Percent_BreakageWhite	330.070[b]	12	27.506	4.561	0.007
Intercept	Percent_Breakage	7482.942	1	7482.942	1113.705	0.000
	Percent_BreakageWhite	11294.163	1	11294.163	1872.949	0.000
Soaking time	Percent_Breakage	94.266	4	23.567	3.507	0.041
	Percent_BreakageWhite	74.251	4	18.563	3.078	0.058
Running time	Percent_Breakage	52.600	4	13.150	1.957	0.166
	Percent_BreakageWhite	189.654	4	47.414	7.863	0.002
Operation Speed	Percent_Breakage	70.483	4	17.621	2.623	0.088
	Percent_BreakageWhite	66.165	4	16.541	2.743	0.079
Error	Percent_Breakage	80.628	12	6.719		
	Percent_BreakageWhite	72.362	12	6.030		
Total	Percent_Breakage	7780.919	25			
	Percent_BreakageWhite	11696.595	25			
Corrected Total	Percent_Breakage	297.977	24			
	Percent_BreakageWhite	402.432	24			

Note: a. R Squared =0.729 (Adjusted R Squared =0.459); b. R Squared =0.820 (Adjusted R Squared =0.640).

Table 4 NDMRT for mean percentage seed breakage

Variety		Black eye pea	Brown beans
Soaking time (min)	2	18.6840[a]	14.7200[a]
	4	19.7140[b]	15.3200[b]
	6	22.2600[c]	18.0340[c]
	8	22.6820[c]	18.7660[d]
	10	22.9340[c]	19.6640[e]
Running time (min)	1	16.7500[a]	15.0880[a]
	2	19.6220[b]	16.3300[b]
	3	22.0320[c]	17.5240[c]
	4	23.9180[d]	18.4280[d]
	5	23.9520[d]	19.1340[e]
Operating speed (rpm)	150	18.8680[a]	14.5800[a]
	200	20.6340[b]	17.0660[b]
	250	21.2920[c]	17.3340[b]
	300	21.5700[c]	17.6740[b]
	350	23.9100[d]	19.8500[c]

Note: Means with the same alphabet are not significantly different from each other at 5% level of significance.

4 Conclusion

From the study, the following conclusions can be drawn: de-hulling efficiency of cowpea increased up to soaking time of 6 mins with increase in speed. Maximum de-hulling efficiencies of 84.83% and 83.95% was observed at a speed of 350 rpm for black-eye pea and brown beans varieties respectively. Maximum soaking time of 2 mins was appropriate for minimal percentage of broken seeds of the machine under study. The percentage of broken seeds of the cowpea de-huller increased as the operating speed increased. Pre-dehulling cowpea soaking time of 10 minutes gave rise to percentage breakage of 22.93% and 19.66% respectively for black eye pea and brown beans when the machine was run for 5 mins. The output capacity of the machine was also seen to be affected by the appropriate manipulation of the machine speed of operation and soaking time of the cowpea. The optimum performance setting of the machine for dehulling cowpea is at seed soaking time of 6 mins and operating speed of 350 rpm which effectively gives the de-hulling efficiency of 83.95% for black eye pea and 84.83% for brown beans.

5 Recommendations

From the study, the following recommendations can be drawn:

i. The adopted dehulling tool design system should be optimized to improve the dehulling efficiency

ii. Future work should focus not only on the dehulling aspect of the wet cowpea but also on the separation of the hull from the beans in a single unit for easy use.

The investigation of the performance of the machine in dehulling other crops should also be examined.

References

Adejuyigbe, S. B., and B. O. Bolaji. 2005. Design, fabrication and performance evaluation of beans dehuller. *Journal of Science and Technology* (*Ghana*), 25(1): 125–132.

Akintunde, B. O., F. A. Oyawale, and T. Y. Tunde-Akintunde. 2005. Design and fabrication of a cassava peeling machine. *Nigerian Food Journal*, 23(1): 231–238.

Aduba, J. J., F. B. Olotu, and J. O. Olaoye. 2013. Effect of operative processing condition on the performance of cowpea dehuller using selected cowpea varieties. *International Journal of Basic and Applied Sciences*, 2(3): 71–78.

Akinjayeju, O., and O. F. Ajayi. 2011. Effects of dehulling on functional and sensory properties of flours from black beans (*Phaseolus Vulgaris*). *Food and Nutrition Sciences*, 2(4): 344–349.

Beck, A., N. Dalbec, and J. Zoes. 2005. Design of manually operated mixing machine for Shea Butter application. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.463.6116&rep=rep1&type=pdf. Accessed 23 April 2016.

ASAE Standards. 2003. S352.2. Moisture measurement – unground grain and seeds. St. Joseph, Michigan: ASAE.

Babatunde, O. O. 1995. Development and performance evaluation of a manually operated cowpea dehulling, machine for soaked cowpea. *Journal of Agricultural Engineering and Technology*, 3(1): 1–7.

Boukar, O., F. Massawe, S. Muranaka, J. Franco, B. Maziya-Dixon, and C. Fatokun. 2011. Evaluation of cowpea germplasm lines for minerals and protein content in grains. *A Repository of Agricultural Research Outputs: CGIAR Journal*, 9(4): 515–522.

Davies, R. M., and D. S. Zibokere. 2011. Effect of moisture content on some physical and mechanical propertiesof three varieties of cowpea (*Vigna unguiculata* (L) Walp). *Agricultural Engineering International: CIGR Journal*, 13(1): Manuscript No.1700.

Kamaldeen, O. S., E. F. Asagu, M. Isiaka, and K. A. Arowora. 2017. Performance evaluation of the cowpea Wet de-hulling machine. *Journal of Applied Mechanical Engineering*, 6(1): 1000248.

Kolade, B. A. 2003. Design and construction of a motorized maize/cowpea dehuler/cleaner. Unpublished project report submitted to the University of Ilorin in partial fulfilment of the requirements for the award of bachelor of engineering in agricultural engineering.

Kurien, P. P., H. S. R. Desikachar, and H. A. B. Parpia. 1972. Processing and utilization of grain legumes in India. *Tropical Agriculture Research Series*, 6: 225.

NIS 321. 1997. Standard test code for groundnut shellers. Ikoyi, Lagos: Standard Organization of Nigeria (SON).

Ogunnigbo, C. O., D. A. Adetan, and O. F. Olusunmade. 2018. Effect of soaking time on some engineering properties of cowpea (*Vigna unguiculata*). *Agricultural Engineering International: CIGR Journal*, 20(1): 143–149.

Olaoye, J. O. 2011. Development of small scale equipment for depulping locust bean seeds. *International Journal of Engineering and Technology IJET-IJENS*, 11(06): 145–155.

Olowonibi, M. M. 1999. Development and evaluation of a hand operated cowpea and soya bean testa remover. *Agrimech, Research and Information Bulletin of NCAM*, 1(1): 42–47.

Princewill, O. P., and O. E. Ezinne. 2014. The effect of soaking time on some engineering properties of brown-speckled African yam bean. *International Journal of Engineering and Technology*, 4(12): 700–708.

Twumasi-Ankra, O. 2014. Effect of moisture on selected physical properties of “*Padi-Tuya*” and “*Songotra”* cowpea varieties. M.S. thesis, the Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Timko, M. P., D. E. Jeff, and A. R. Philip. 2007. A book on cowpea. In *Genome Mapping and Molecular Breeding in Plants*. Heidelberg, Berlin: Springer Verlag.