Vol. 15(1), pp. 27-37, January-June, 2023
DOI: 10.5897/JETR2022.0734
Article Number: 40E721570881
ISSN: 2006-9790

http://www.academicjournals.org/JETR

Journal of Engineering and Technology Research

Full Length Research Paper

Effect of speed, feed rate and tray angle on the dehulling, cleaning and grain loss from an acha (*Digitaria exilis)* dehulling machine

Isaac N. Itodo, Paul O. Yusuf and Theresa K. Kaankuka

Department of Agricultural & Environmental Engineering, College of Engineering, Federal University of Agriculture, Makurdi, Nigeria.

Received 7 March, 2022; Accepted 1 July, 2022

This study determined the effect of cylinder speed, feed rate and tray angle on the dehulling efficiency and the effect of fan speed, feed rate and tray angle on the cleaning efficiency and grain loss from an acha (*Digitaria exilis)* dehulling machine in a 3 × 3 factorial experimental design in three replicates. The cylinder speeds were 1500, 2000 and 2500 rpm and the fan speeds were 160, 185 and 213 rpm. The feed rates were 20, 30 and 40 g min^{-1} and tray angles of 22.5°, 45°, and 67.5°. The results were analyzed using the analysis of variance at $p \leq 0.05$ to determine if the speeds and tray angle inclinations had a significant effect on the dehulling efficiency, cleaning efficiency and grain loss at the various feed rates. The Duncan's New Multiple Range Test was used to separate the means where there was significant difference. The feed rate had no significant effect on the dehulling and cleaning efficiencies and grain loss. The speeds and tray angles had a significant effect on the dehulling and cleaning efficiencies and grain loss. The dehulling efficiency was higher at higher tray angles. The cleaning efficiency was higher at the higher fan speeds and tray angles. The grain loss from the machine was higher at the higher fan speeds and lower at the higher tray angles.

Key words: Acha, dehulling machine, cleaning, grain loss, feed rate, tray angle

INTRODUCTION

Africans, in the past relied on fruits, roots/tubers and cereals as the major crops for their subsistence. Their choice crops were those that gave high yield with low labour input in terms of production and processing. Crops that required high labour input with low yield were neglected. However due to rapid population growth and declining soil fertility, some of the previously neglected crops are now being rediscovered. Acha or fonio (*Digitaria specie)* is one of such cereals that was neglected but has now been rediscovered. Acha is a typical West African cereal crop that is cultivated across the dry savannah region stretching from Cape Verde in the West to the Lake Chad in the East, from the edge of the Sahara in the north to the beginning of the rain forest in the south. Nigeria, Mali and Burkina Faso are the largest acha cropping and producing areas in West

*Corresponding author. E-mail: dritodo@gmail.com.

Africa, producing about 587 270 tons of acha were produced on 566 047 hectares in these regions in 2012 (Wilma et al., 2018). Acha produces rough grains, which still have their glume and lemmas after threshing (Cruz et al., 2016). At this stage the grain is known as raw or paddy acha. The paddy has an oval seed coating with slightly flattened side. The grain is very small measuring 1.5 mm in length, 0.9 mm in width and an average 1000 - grains weight of 0.5 g (Satimehin and Philip, 2012). Hulled acha grains have a shiny shin pericarp whose colours vary from white through yellow to purple depending on the variety (Rose, 2017). It has a hilum on one side and a relatively large germ containing fat reserves within the kernel (albumen) serving as the main storage organ made up of starch and small protein reserve (Cruz et al., 2016). Acha has been identified as a crop with several physiological and health benefits such as the prevention of cardiovascular diseases, obesity, and diabetes (Cruz et al., 2016) but its harvesting and post-harvesting handling is reported to be the major constraints for its utilization (Koreissi et al., 2013). The extremely small size of the grain leads to tedious and time-consuming post-harvest dehulling and cooking processes (Cruz et al., 2016). From field to consumption, most of the activities are manually performed, making harvesting and post-harvest activities more laborious and time-consuming (Wilma et al., 2018). Women could spend up to 2 hours to manually dehull only 2 kg of acha and use up to 400 litres of water for repeated washing in order to clean as little as 15 kg of the grains (Wilma et al., 2018). A recent survey on the prospects and constraints to the production and processing of acha in Nigeria by Idris et al. (2018) revealed that 100% of the planting process was still done manually using broadcasting method while 81.3% of the harvest process was also done with human labour.

The result of the survey showed that milling/ decortications tasks that are accomplished with the use of pestle and mortar was a major constraint in the production and processing of acha because of the tedious nature of harvesting and processing (Idris et al., 2018; Wilma et al., 2018). Acha has been designated as a medium priority commodity by the National Agricultural Research Board (NARB), which believes that the revitalization of acha production in Nigeria and Africa in general could enhance diversification and food security. However, currently, there seem to be no efforts in the mechanization of the planting and harvesting operations of the cereal. Postharvest processing seems to have received a renewed interest in West African in the last two decades as a result of the huge potential the crop holds. Some recent works on the dehulling of acha include that of Diakite (1992) who patented a fonio dehulling machine in Senegal. The feed rate, which is the volume of products being introduced into a machine operational unit, such as a burr, concave or air cleaning chamber, per given time has been thought to affect both dehulling and cleaning of agricultural materials (Kabir and Fedele, 2018). Reports indicate that the effect of feed rate on dehulling efficiency is a limiting function, increasing from a minimum limit with efficiency to a maximum point where further increase in the feed rate yield decreasing efficiency (Solanki et al., 2018). Generally, for grains of small sizes with tough hulls, the literature suggests that dehulling efficiency increases at lower feed rates. Idriss et al. (2018) reported a feed rate of 12 kg h^{-1} as optimal for dehulling of acha grains in Zaria, Nigeria. Diakite (1992) dehulled acha grains at a feed rate of 8 kg min^{-1} but did not indicate the effect of the feed rate on the machine performance. Tokan et al. (2012) reported a feed rate of 4 kg h^{-1} as optimal dehulling of acha in Bauchi, Nigeria. Solanki et al. (2018) evaluated the performance of an oat dehulling machine (*Avena sativa*) based on feed rate and other parameters. The range of the feed rates was 1.25 – 3.75 kg min^{-1} and the result of optimization indicated the optimal efficiency was attained at 1.30 kg min^{-1}. The feed rate is a function of the hopper design and regulates the quantity of grains that can enter the dehulling chamber as well as the speed of dehulling (Kabir and Fedele, 2018). There is an increase in the number of particles flowing into the concave of a dehuller; it results into turbulence while a decrease lowers the free stream turbulence intensity which allows the grains to be more effectively dehulled.

The cleaning of grains is also affected by the feed rate of grains passing through the air stream in the cleaning chamber. Okunola et al. (2015) found that separation losses of maize seeds decreased with increase in feed rate.

The seed size and the nature of the hulls can explain the variation in feed rate with smaller seed size occupying more void space than larger grains thus allowing the cleaning air to remove more impurities than in large size grains. The feed rate, which is the quantity of grains/seeds entering a machine per unit time, has been reported to affect the quality of dehulling and cleaning. Feed rate has been associated with decreasing dehulling efficiency and high losses. Ranjeet and Sukhdev (2013) found the decorticating efficiency increased with feed rate. Mathukia et al., (2015) evaluated the effect of different roller speed and feed rate on husk removed using the coefficient of hulling, coefficient of wholeness of kernel and hulling efficiency of pigeon pea as indicators. The result showed that the husk removal was significantly influenced by varying feed rates. The husk removal increased with increase in feed rate up to 60 kg h^{-1} and reduced thereafter. The feed rate of 60 kg h^{-1} gave significantly the highest husk removed (85.49%), which was statistically the same with the feed rate of 50 kg h^{-1}. On the other hand, the feed rate of 80 kg h^{-1} showed significantly lower husk removal. The coefficient of hulling was also significantly higher at 60 kg h^{-1} than at 80 kg h^{-1} feed rate and the wholeness of kernel was similarly significantly lower at 80 kg h^{-1} feed rate. Dalha et al. (2018) found that a combination of speed level and feed rates were best combination of shell efficiency of cowpea and groundnuts and reported minimum shelling efficiency at a feed rate of 12 kg min^{-1}, while the maximum was at 18 kg min^{-1}. The study also noted that at these feed rates, the pods of cowpea and groundnuts do not chock up the shelling chamber as the cowpea pods were not hard hence could easily be shelled; the feed rates significantly influenced the cleaning efficiency of the cowpea and groundnut shellers.

The angle of repose of seed determines the design of hoppers based on the seed flow characteristics. The range of this angle of repose for small seeds is reported to range from 20 to 32° (Kabir and Fedele, 2018). Another important parameter that determines how seed grains will behave on the surface of different materials under the effect of gravitational forces is the coefficient of internal friction.

The angle at which a grain seed falls in the pathway of a fluid such as air also determines how affective a seed lot is cleaned based on the density of the seed agglomerates in the seed lot. Kaankuka (2015) reported a deck angle of 45° for cleaning of acha grains. Air velocity has been identified as one of the main factors that affect purity and total losses in grain cleaning. The air velocity has to be maintained with the range of terminal velocity of the cleaned grain otherwise they will be blown off with the chaffs. Thus, the air velocity will increase with cleaning efficiency to the point until when it becomes higher than the critical velocity of the seed and then begins to increase the seed loss. Bako and Bradley (2020) found the mean terminal velocity of acha (*Digitaria exilis*) to be 3.97±0.015 m s^{-1} while Kaankuka (2015) reported terminal velocities of acha seed (*Digitaria exilis*), the acha hull and the velocity of the air required for the cleaning the hulls as 3.96, 1.9 and 2.5 m s^{-1} respectively. The objective of this study was to determine the effect of air velocity, feed rate and tray angle on the dehulling and cleaning efficiencies and grain loss from an acha dehulling machine.

MATERIALS AND METHODS

This study was undertaken to determine the dehulling and cleaning efficiencies, and grain loss performance of an acha dehulling machine. The cylinder speed, feed rate and tray angle were considered for dehulling efficiency, and fan speed, feed rate and tray angle were considered for the evaluation of cleaning in a 3 × 3 factorial experiment in three replicates. The dehulling efficiency was evaluated at the cylinder speeds of 1500, 2000 and 2500 rpm, while the cleaning efficiency and grain loss were evaluated at the fan speeds of 160, 183 and 213 rpm. The cleaning efficiency and grain loss were determined at the tray angles of 22.5°, 45°, and 67.5° at the feed rates of 20.0, 30.0, and 40.0 g min-1. The variance analysis at $p \leq 0.05$ was used to evaluate the experimental results and the DMRT was used to separate the means when there is a significant difference.

Description of the dehulling machine

The motorized acha machine dehulls and cleans in a single operation (Figure 1) is the exploded view of the machine (Figure 2) is picture of the machine. The machine has a hopper, a fixed dehulling chamber housing a rotating abrasive cylinder and a cleaning unit that is equipped with an axial blower fan. The machine components are held together unto a rigid rectangular frame by means of bolts and nuts and powered by a 1.5 kW electric motor which operates the machine components using bearings and pulley arrangements.

The components of the dehulling machine are the frame, hopper, dehulling chamber (concave housing a rotating cylinder/drum), cleaning unit (blower, adjustable incline tray, chaff outlet chute and grain delivery chute). The acha is loaded in the hopper which has an adjustable feed rate control mechanism that was calibrated by measuring the size of the opening that will allow a given amount of grain to enter the dehulling chamber per given time. As the feed rate control mechanism is set and the machine set into operation, the seeds flow into the dehulling chamber where a cylinder rotates in the concave. The abrasive cylinder surface rubs the hulled acha grains against the concave to cause the dehulling of the acha paddy with minimal damage. The dehulled grains then falls into the cleaning chamber on an adjustable tray that is inclined at the angle of repose of the acha grain to facilitate the separation of the hulls from the grains. As the blower rotates, it generates a stream of air current which enters the cleaning unit and blows off the lighter chaff through the outlet chute and allows the hulled seeds to pass across the air current to the seed delivery chute. Table 1 is the physical and technical specification of the dehulling machine.

Determination of feed rate

The level of feed rate was controlled through the hopper slut leading to the dehulling chamber by a mechanism that can shut off and restrict the opening aperture of the throat to allow the flow of acha from the hopper into the dehulling chamber. The openings were calibrated by varying the mechanism aperture at full, half, a third and quarter opening. One kilogram of acha paddy grains was feed into the hopper after running the dehulling machine at a constant rate; a stop watch was used to measure the weight of grains that passed into the dehulling unit during 60 seconds after which the flow of the grains was shut off. The difference in the weight of the grains in the hopper before and after operating the machine and shutting the flow off was weighed in 3 replicates and recorded. The average was taken to get the feed rates. The calibrated feed rates of 20, 30 and 40 g min^{-1} were used in evaluating the machine.

Determination of cylinder and fan speeds

The machine was operated and evaluated at the cylinder speeds of 1500, 2000 and 2500 rpm according to Kaankuka et al. (2015). The appropriate fan speeds for effective cleaning of the grains were determined from the terminal velocity of acha (paddy and groat), which ranges between 2.5 and 3.5 m s^{-1}. The terminal velocities of 2.5, 3.0 and 3.5 m s^{-1} corresponding to the fan speeds of 160, 186 and 213 rpm respectively were used in the study. The dehulling cylinder and fan were not operated from the same shaft. The fan shaft was powered from the shaft of the dehulling cylinder through a belt and pulley drive. The lower fan speeds were achieved by using appropriate pulley sizes to reduce

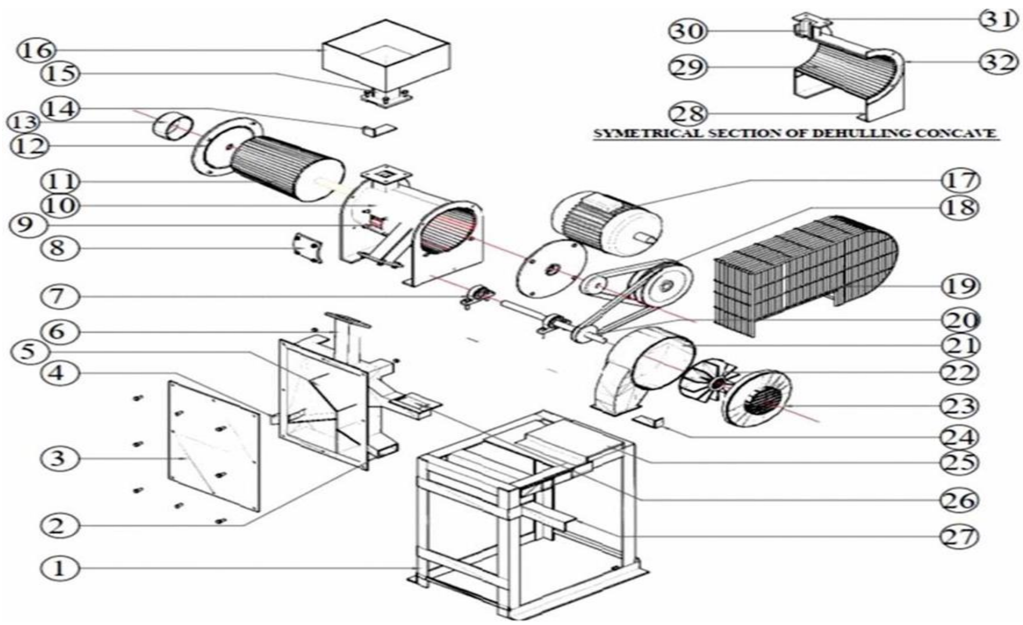

Figure 1. Exploded view of the acha dehulling machine. 1 - Frame; 2 - Grain outlet; 3 - Cleaning chamber cover;4 - Chaff outlet; 5 - Inclined deck tray; 6 - Cleaning unit inlet; 7 - Bearing; 8 - Viewing slot; 9 - Viewing slot cover; 10 - Dehuller concave; 11 - Dehuller cylinder; 12 - Dehuller chamber cover; 13 - Shaft guard, 14 - Feed rate control gate; 15 - Hopper discharge chute; 16 - Seed hopper; 17 - Electric motor; 18 - Belt and pulley; 19- Cleaning chamber cover; 20 - Belt guard; 21 - Fan housing unit; 22 - Fan; 23 - Fan cover; 24 - Air control device; 25 - Electric motor seat; 26 - Air inlet slot; 27 - Fan seat; 28 - Concave support; 29 - Rasp bar; 30 - Hopper outlet chute; 31- Hopper seat; 32 - Flange.
Source: Yusuf (2022).

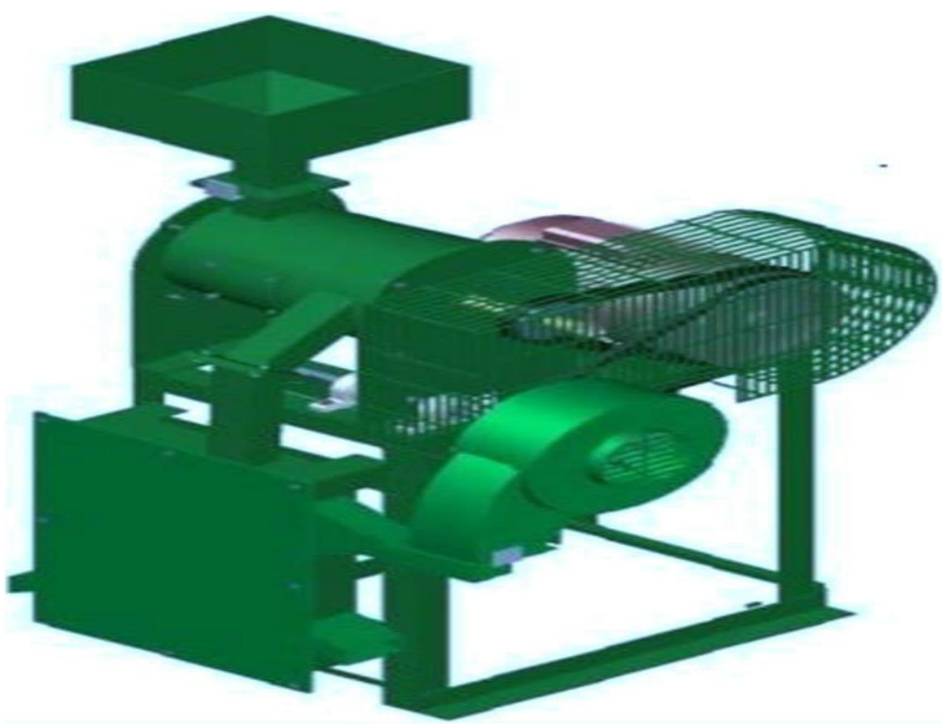

Figure 2. Picture of the acha dehulling machine.
Source: Yusuf (2022).

Table 1. Physical and technical specifications of the dehulling machine.

Machine component		Specification
Frame	Height	700 mm
	Length	577 mm
	Width	515 mm
	Weight	23 kg
Hopper	Length × width of upper frustum	250 mm × 250 mm
	Length × width of base	100 mm × 100 mm
	Diameter of base	24 mm
	Height	284 mm
	Angle of inclination of the sides	57°
Dehulling unit		
Concave	Diameter of housing	270 mm
	Diameter of concave	220 mm
	Length of concave	290 mm
Cylinder	Cylinder type	Abrasive rasp-bar
	Length of cylinder	266 mm
	Diameter of cylinder	200 mm
	Diameter of steel rods forming the cylinder	5.6 mm
	Spacing between the steel rods forming the cylinder	12 mm
	clearance between concave and cylinder	20 mm
Discharge chute	Diameter of chute	50 mm
	Angle of inclination of chute	49°
Cleaning unit	Length	500 mm
	Width	360 mm
	Height	660 mm
	Shape	Cuboid
	Number of ducts	4
Fan	Type	Axial flow fan
	Diameter	180 mm
	Number of blades	12
	Angle of inclination of blade	30°
	Fan housing diameter	260 mm

Source: Yusuf (2022).

the cylinder speeds to the determined fan speeds. The pulley sizes of 30, 37 and 50 mm were used to get the fan speeds of 160, 186 and 213 rpm.

Determination of tray angle

An adjustable hinged tray that can be inclined at different angles (0 - 180°) situated in the centre of the cleaning chamber was calibrated at 22.5°, 45°, and 67.5° using a compass. The inclined tray helps in dispersing the hull and kernels as they land on it and results in increased cleaning efficiency.

Determination of dehulling efficiency of machine

The dehulling efficiency was determined using equation 1 (Subedi et al., 2018).

$$D_e = \frac{M_h}{M_m} \times 100\% \quad (1)$$

Where:
De is the dehulling efficiency, %
Mh is weight of dehulled acha grains, kg
Mp is total weight of paddy acha fed into the dehulling machine, kg

Table 2. Summary of the dehulling efficiency (%) of the machine.

Tray angle (°)	Cylinder speed (rpm)			
	1500	**2000**	**2500**	**Mean**
Feed rate = 20.0 g min^{-1}				
22.5	54	83	96	78
45	75	84	87	82
67.5	85	84	85	83
Mean	71	84	88	81
Feed rate = 30.0 g min^{-1}				
22.5	59	84	86	76
45	63	90	82	78
67.5	87	86	86	86
Mean	70	87	85	81
Feed rate = 40.0 g min^{-1}				
22.5	63	87	85	78
45	70	88	86	81
67.5	89	86	86	87
Mean	74	87	86	82

Source: Yusuf (2022).

Determination of cleaning efficiency of machine

The cleaning efficiency was determined using equation 2 (Abubakar and Abdulkadir, 2012)

$$C_e = \left(\frac{M_h}{M_p} \times 100\%\right) - \left(\frac{M_p - M_h}{M_p}\right) \times 100\% \qquad (2)$$

Where: C_e is the cleaning efficiency, %; M_h is mass of cleaned grains (mass of grain after separation and cleaning), kg; M_p is mass of grains before cleaning, kg

Determination of grain loss of machine

The grain loss (C_L), which is an indication of inefficiency of the machine was computed using equation 3 (Abubakar and Abdulkadir, 2012).

$$C_L = \left(\frac{M_p - M_h}{M_p}\right) \times 100\% \qquad \textbf{(3)}$$

Statistical analysis

The ANOVA at $p \leq 0.05$ was used to analyze the effect of cylinder speed, tray angle and feed rate on dehulling efficiency, and the effect of fan speed, tray angle and feed rate on the cleaning efficiency and grain loss from the machine.

The DNMRT was used to separate the means where there was a significant difference.

RESULTS AND DISCUSSION

Effect of cylinder speed, tray angle and feed rate on the dehulling efficiency of the machine

Table 2 is a summary of dehulling efficiency of the machine at various cylinder speeds, feed rates and tray angles. The results showed that the dehulling efficiency was higher at higher cylinder speeds and tray angles at the various feed rates. The results showed that the cylinder speed and tray angle had a significant effect on the dehulling efficiency while the effect of the feed rate was not significant (Table 3). The feed rates of 20, 30 and 40 g min^{-1} had no significant effect on the dehulling efficiency of the machine (Table 4). This may be because the feed rates were within the optimal range of operation of the machine and also due to the high porosity and low bulk density of the acha grains. Solanki et al. (2018) reported that the dehulling efficiency of bulk wheat increased as the feed rate was increased from 20 to 40 g min^{-1} and then begun to decrease with further increases in the feed rate. The best dehulling efficiency of the machine was 88% at a feed rate of 20 g min^{-1} and cylinder speed of 2500 rpm. Kaankuka et al. (2014) reported an optimal feed rate of 17.6 g min^{-1} which is consistent with the finding of this study.

Table 4 showed that when the dehulling cylinder was operated at 2000 and 2500 rpm, the dehulling efficiencies were the same (86%) but significantly lower (72%) when it was operated at 1500 rpm. The

Table 3. ANOVA of the effect of feed rate, tray angle and cylinder speed on the dehulling efficiency of machine.

Source of variation	SS	df	MS	F	Sig.
Corrected Model	2728.667[a]	24	113.694	22.739	0.043[s]
Intercept	162417.771	1	162417.771	32483.554	0.000[s]
Tray angle (A)	319.100	2	159.550	31.910	0.030[s]
Feed rate (B)	27.883	2	13.942	2.788	0.264[ns]
Cylinder speed (C)	1290.527	2	645.264	129.053	0.008[s]
A×B	39.069	4	9.767	1.953	0.366[ns]
A×C	877.863	4	219.466	43.893	0.022[s]
B×C	51.976	4	12.994	2.599	0.297[ns]
A×B×C	146.808	6	24.468	4.894	0.179[ns]
Error	10.000	2	5.000		
Total	180372.000	27			
Corrected total	2738.667	26			

R^2 = 0.996 (Adjusted R^2 = 0.953); s - Significant at $p \leq 0.05$; ns - Not significant at $p \leq 0.05$.
Source: Yusuf (2022).

Table 4. Summary of the effect of cylinder speed and tray angle on the dehulling efficiency of the machine at various feed rates.

Feed rate (gm^{-1})	Cylinder speed (rpm)			Tray angle (°)		
	1500	2000	2500	22.5	45	67.5
20.0	71	84	88	78	82	83
30.0	70	87	85	76	78	86
40.0	74	87	86	78	81	87
Mean	72[a]	86[b]	86[b]	77[a]	85[a]	85[a]

Means with the same letter along the same row are not significantly different at $p \leq 0.05$ using the DNMRT.
Source: Yusuf (2022).

improvement in dehulling efficiency at the higher speeds may be related to increased inertia forces acting on the seed as they are rubbed between the dehulling cylinder and concave and among themselves leading to better quality of dehulling. Solanki et al. (2018) also noted this trend in the dehulling of tiny hard seeds.

This is consistent with the findings that tiny seeds are better dehulled at higher speeds (Pawankumar et al., 2018).

The result of this study agrees with that of Kaankuka (2015) that the efficiency of dehulling acha increases with increasing speed and is optimal at 2200 rpm.

Effect of fan speed, tray angle and feed rate on the cleaning efficiency of the machine

Table 5 is the summary of the cleaning efficiency of the machine at the various fan speeds, feed rates and tray angles. The efficiencies obtained at the feed rates of 20.0, 30.0 and 40.0 (g min^{-1}) were 81.0, 80.4 and 81.3% respectively. The feed rates of 1.2 kg hr^{-1} (20.0 g min^{-1}), 1.8 kg $hour^{-1}$ (30.0 g min^{-1}) and 2.4 kg $hour^{-1}$ (40.0 g min^{-1}) were similar and did not have significant effect on the cleaning efficiency (Table 6). This can be attributed to adequate hopper design and the incorporation of a venturi that was opened and shut at regulated intervals to prevent the grains from choking the dehulling unit and minimising the load intensity in the concave.

When there is an increase in the number of particles flowing into the concave of a dehuller, it results into turbulence while a decrease lowers the free stream turbulence intensity, which causes the drag coefficient to decrease and the machine to operate smoothly. The feed rates in this study of 1.2, 1.8 and 2.4 kg hr^{-1} are far lower than the values of 20.7 and 63.28 kg h^{-1} reported by Kaankuka (2015). The cleaning efficiency of the acha dehuller was significantly affected by the fan speed and tray angles (Table 6). The tray angle significantly affected the cleaning efficiency of the dehuller (Table 6).The cleaning efficiency of the machine increased as the angle of the tray beneath the cleaning unit was increased when the tray was inclined at 67.5º, the cleaning efficiency was 85.4%, which was significantly

Table 5. Summary of the cleaning efficiency (%) of the machine.

Tray angle (°)	Fan speed (rpm)			
	160	186	213	Mean
Feed rate = 20.0 g min^{-1}				
22.5	53.7	80.0	96.0	77.6
45	75.3	80.4	87.3	82.2
67.5	84.7	84.0	81.0	83.2
Mean	71.2	83.7	88.1	81.0
Feed rate = 30.0 g min^{-1}				
22.5	59.0	84.0	86.3	76.4
45	63.3	89.7	82.3	78.4
67.5	87.0	86.0	86.3	86.4
Mean	69.8	86.6	85.0	80.4
Feed rate = 40.0 g min^{-1}				
22.5	62.7	87.3	85.0	78.3
45	63.0	87.7	86.0	78.9
67.5	88.7	85.7	85.7	86.7
Mean	71.4	86.9	85.6	81.3

Source: Yusuf (2022).

Table 6. Summary ANOVA of the effect of fan speed, feed rate and tray angle on the cleaning efficiency of the machine.

Source variance	SS	df	MS	F	Sig.
Corrected Model	8902.395[a]	26	342.400	31.127	0.000[s]
Intercept	530307.605	1	530307.605	48209.782	0.000[s]
Fan speed(A)	4134.025	2	2067.012	187.910	0.000[s]
Feed rate (B)	10.099	2	5.049	0.459	0.634[ns]
Tray angle (C)	909.654	2	454.827	41.348	0.000[s]
A×B	110.716	4	27.679	2.516	0.052[s]
A×C	3020.938	4	755.235	68.658	0.000[s]
B×C	149.753	4	37.438	3.403	0.015[s]
A×B×C	567.210	8	70.901	6.446	0.000[s]
Error	594.000	54	11.000		
Total	539804.000	81			
Corrected total	9496.395	80			

R^2 = 0.937 (Adjusted R^2 = 0.907); s - Significant at $p \leq 0.05$; ns - Not significant at $p \leq 0.05$.
Source: Yusuf (2022).

higher than the 79.9% obtained at 45° and 77.4% at 22.5° (Table 7). This may be because at steeper elevation of the tray, the dehulled grains and chaff are separated and disperse more widely on striking the plate, and due to the difference in their densities the cleaning fan is able to blow off the chaff while the cleaned grain falls through the chute and are collected. Philip (2011) incorporated multiple fixed alternate trays in the cleaning chamber of an acha dehulling machine to increase the retention time as the grains and chaff fell through the cleaning chamber and allowed the fan adequate time to blow off the chaffs. The design of the machine used in this study incorporated a single adjustable tray that serves the same purpose and does not obstruct the air from the fan as in the machine with multiple trays. The cleaning efficiencies at the fan speeds of 213 rpm and 186 rpm were 88.2 and 85.7%, which were not significantly different (Table 7) and as the fan

Table 7. Summary of the effect of fan speed and tray angle on the cleaning efficiency of the machine at the various feed rates.

Feed rate	Fan speed (rpm)			Tray angle (°)		
(g m^{-1})	160	186	213	22.5	45	67.5
20.0	71.2	83.7	88.1	77.6	82.2	83.2
30.0	69.8	86.6	85.0	76.4	78.4	86.4
40.0	88.7	86.9	85.6	78.3	78.9	86.7
Mean	76.6[a]	85.7[b]	86.2[b]	77.4[a]	79.9[a]	85.4[b]

Means with the same letter along the same row are not significantly different at p ≤ 0.05 using the DNMRT.
Source: Yusuf (2022).

Table 8. Summary of the grain loss (%) from the machine.

Tray angle (°)	Speed (rpm)			
	160	186	213	Mean
Feed rate = 20.0 g min^{-1}				
22.5	15	4	24	14
45	14	11	19	15
67.5	14	16	14	15
Mean	14	10	19	15
Feed rate = 30.0 g min^{-1}				
22.5	14	12	29	18
45	9	15	27	17
67.5	12	12	12	12
Mean	12	13	23	16
Feed rate = 40.0 g min^{-1}				
22.5	11	14	27	17
45	11	12	24	15
67.5	13	13	11	12
Mean	11	13	21	15

Source: Yusuf (2022).

speed was reduced to 160 rpm, the cleaning efficiency decreased to 70.8% which was significantly lower than at 213 rpm and 186 rpm. The increase in cleaning efficiency at higher fan speeds may be due to fact that most chaff with lower terminal velocities than the acha grains were blown out through the discharge chute at higher fan speeds. This is consistent with the finding of Pawankumar et al. (2018) and Nura et al. (2017) that reported increase in cleaning efficiency with increased air velocity.

Effect of fan speed, tray angle and feed rate on grain loss from the machine

Table 8 is the summary of grain loss from the machine at various fans speeds, feed rates and tray angles. The grain losses at the various feed rates of 20, 30 and 40 (g min^{-1}) were 15, 16, and 15%, respectively and were also not significantly different (Table 9). This may be because the right feed rates were adopted in this study and possibly at these feed rates, there was a smooth motion of grains along the passage between the cylinder and inner periphery of dehulling section into the cleaning section allowing for efficient cleaning. The grain loss from the machine was lower at higher tray angles and higher fan speeds. The fan speed had a significant effect on the grain loss from the machine (Table 9). Grain losses at the speed of 213 rpm (20%) were significantly higher than at 186 rpm (12%) and 160 rpm (12%) (Table 10). This can be attributed to inadequate air velocities generated at lower fan speeds

Table 9. Summary ANOVA of the effect of fan speed, feed rate and tray angle on grain loss from the machine.

Source of variation	SS	df	MS	F	Sig.
Corrected Model	2849.580[a]	26	109.599	10.251	0.000[s]
Intercept	18617.086	1	18617.086	1741.32	0.000[s]
Feed rate (A)	21.210	2	10.605	0.992	0.378[ns]
Tray angle (B)	187.877	2	93.938	8.786	0.000[s]
Fan speed (C)	1347.136	2	673.568	63.001	0.000[s]
A×B	119.383	4	29.846	2.792	0.035[s]
A×C	111.901	4	27.975	2.617	0.045[s]
B×C	914.790	4	228.698	21.391	0.000[s]
A×B×C	147.284	8	18.410	1.722	0.114[ns]
Error	577.333	54	10.691		
Total	22044.000	81			
Corrected total	3426.914	80			

R^2 = 0 .832 (Adjusted R^2 = 0.750); s - Significant at p ≤ 0.05; ns - Not significant at p ≤ 0.05.
Source: Yusuf (2022).

Table 10. Summary of the effect of fan speed and tray angle on the grain loss from the machine at the various feed rates.

Feed rate (g m^{-1})	Fan speed (rpm)			Tray angle (°)		
	160	186	213	22.5	45	67.5
20.0	14	10	19	14	15	15
30.0	12	13	21	18	17	12
40.0	11	13	21	17	15	12
Mean	12[a]	12[a]	20[b]	16[a]	16[a]	12[b]

Means with the same letter along the same row are not significantly different at p ≤ 0.05 using the DNMRT.
Source: Yusuf (2022).

which is not sufficient to blow away the hull resulting in mixing with the grains. Solanki et al. (2018) reported that low air velocities result in lower discharge velocity with decrease conveying force which induces weak frictions between grain to grain and grain to chaff in a gravity separator. The grain losses at the tray angle inclinations of 22.5° (16%) and 45° (16%) were not significantly different but higher than at 67.5° (13%) (Table 10). This may be due to fact that the dehulled grains and chaffs stick together at the lower angles and the fan was unable to deliver adequate air that will clean them resulting in the losses. This result agrees with the finding of Solanki et al. (2018) for small grain seeds.

Conclusion

The cylinder speed of the dehulling unit of the machine had a significant effect on the dehulling efficiency, and the dehulling efficiency was higher at the higher tray angles. The fan speed of the cleaning unit had a significant effect on the cleaning efficiency and grain loss from the machine; the cleaning efficiency was higher at the higher fan speeds and tray angles. The grain loss from the machine was higher at the higher fan speeds and lower at the higher tray angles. The results showed that the feed rate of grains into the machine had no significant effect on the dehulling efficiency, cleaning efficiency and grain loss from the machine. The cylinder speed of 2000 rpm (fan speed of 186 rpm), tray angle of 67.5° and feed rate of 30 g min^{-1} had the best performance.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abubakar M, Abdulkadir BH (2012). Design and evaluation of motorized and manually operated groundnut shelling machine. International Journal of Emerging Trend in Engineering and Development 2(4):673-682.

Bako T, Bardey IA(2020). Engineering properties of acha (*Digitaria exilis*) grains in relation to the design of grain processing machines.

Agricultural Engineering International: CIGR Journal 22(2):159-170.

Cruz JF, Béavogui F, Dramé D, Diallo TA (2016). Fonio, an African cereal. Montpellier: Cirad P 154.

Dalha I, Saeed H, Mohammed US (2018). Development and performance evaluation of pulse shelling machine. 12th CIGR Section VI International symposium, Institute of International Tropical Agriculture, Ibadan, Nigeria.

Diakite S (1992). Fonio Husker Machine (Senegal). African Innovation Foundation. Available at http://En.m.wikipedia.0rg

Idris RM, Yawas DS, Abdulrahman AM (2018). Development and performance evaluation of a three rollers acha (*Digitaria exilis)* dehusking machine. Arid Zone Journal of Engineering, Technology and Environment 14(2): 261-271.

Kaankuka TK (2015). Comparative performance evaluation of an existing and modified acha dehullers. Global Journal of Engineering Research 14(1):9-15.

Kaankuka TK, Itodo IN, Obetta SE (2014). Effect of cylinder type and speed on acha (*Digitaria exilis*) dehulling. International Journal of Applied Engineering and Technology 4(2):125-131.

Kaankuka TK, Itodo IN, Awulu JO (2015). Design analysis of an existing acha (*Digitaria exilis*) dehulling machine. Journal of Science and Technology 35(4):1-10.

Kabir AA, Fedele OK (2018). A review of shelling, threshing, dehulling and decorticating machines. Journal of Agricultural Research 3(1):000148

Koreissi DY, Fanou_Fogny N, Hulshof O, Brouwer I (2013). Fonio (*Digitaria exilis*) landraces in Mali: Nutrient and phytate content, genetic diversity and effect of processing. Journal of Food Composition and Analysis 29(2):134 -143.

Mathukia RK, Sagarka BK, Jadav CN (2015). Integrated weed management in summer sesame. Indian Journal of Weed Science 47(2):150-152.

Nura A, Dahdivan N, Ardakani SA (2017). Physicochemical properties and applications of date seed and its oil. International Food Research Journal 24(4):1399-1406.

Okunola A, Okonkwo C, Olumhense AG, Ajao F(2015). Design, development and evaluation of a pneumatic cum eccentric drive cleaning machine: A response surface analysis. Asia Journal of Scientific Research 12(4):462-471.

Pawankumar PT, Goswami K, Priti L, Nitesh P (2018). Performance enhancement of pre-cleaner and gravity separator. International Journal of Pure and Applied Bioscience 6(6):838-852.

Philip TK (2011). Development of an acha (*Digitaria Exilis*) dehulling machine. Unpublished PhD thesis, University of Agriculture, Makurdi, Benue State, Nigeria.

Ranjeet S, Sukhdev M (2013). Development and evaluation of centrifugal sheller for muskmelon seed. International Research Journal of Biological Sciences 2(3):7-10.

Rose V (2017). Fonio: Tasty early - maturing cereal for diversified production systems in West Africa. Biodiversity International 7(2):234-241.

Satimehin AA, Philip TK (2012). Some physical properties of acha as affected by moisture content. Postharvest Technology and Process Engineering 14(4):233 -240.

Solanki CD, Mridula SK, Aleksha K, Gupta RK (2018). Buckwheat dehuller and optimization of dehulling parameters. International Journal of Current Microbiology and Applied Sciences 7(11):1041-1052.

Subedi M, Tabil LG, Vandenberg A (2018). Influence of seed coat color genes on milling qualities of red lentil (Lens culinaris Medik.). Journal of Agricultural Science 10(10):88-98.

Tokan A, Danladi YB, Shekarau MBE, Dada SG (2012). Design, fabrication and testing of a fonio de-husking machine. International Journal of Engineering Innovation and Research 1(6):2277-5668.

Wilma SS, Emeses BO, Rambo EK (2018). Prospects and constraints to acha production and processing in Bogoro Local Government Area of Bauchi State: Implication to relevant technology transfer. Journal of Agriculture and Veterinary Science 11(7):58-64.