Development of a paddy rice de-husking cum polishing machine

Adeniyi Tajudeen Olayanju[1], John Olusegun Ojediran[1], Clinton Emeka Okonkwo[1*], Syed Zameer Hussain[2], Adejoke Deborah Adewumi[1]

(1. Department of Agricultural and Biosystems Engineering, Landmark University, P.m.b. 1001, Omu-Aran, Kwara State, Nigeria

2. Division of Food Science and Technology, She-r-Kashmir University of Agricultural Sciences and Technology, Kashmir, India)

Abstract: Locally processed rice by small to medium scale processors are still not fully appreciated due to low quality. Paddy rice de-husking cum polishing machine was designed, fabricated and evaluated for its performance efficiency. The effects of paddy moisture content, speed of rotation, and polishing time on the machine performance and milling properties were evaluated. The economic analysis of the machine was also evaluated. Moisture content and speed of rotation of the shaft had effect on the throughput capacity (TC), head rice yield (HRY), percentage broken rice (BR), but not on the percentage un-dehusked (PUD) in production of brown rice. The moisture content, speed of rotation, and polishing time had effect on the BR and PUD, but not on the HRY in the production of polished rice. The minimum and maximum values for brown rice were TC (25.38 and 41.25 kghr^{-1}), PUD (15.77% and 46.42%), HRY (50.47% and 67.75%), BR (2.17% and 12.03%). Minimum and maximum values for polished rice were PUD (1.12% and 7.34%), HRY (78.97% and 90.50%), BR (2.77% and 10.41%). Economic evaluation shows that the developed de-husker cum polisher is beneficial and can be adopted by small to medium scale rice processors.

Keywords: brown rice, de-husking, moisture content, polished rice, polishing time, speed of rotation

Citation: Olayanju, A. T., J.O. Ojediran, C. E. Okonkwo, S. Z. Hussain, and A. D. Adewumi. 2023. Development of a paddy rice de-husking cum polishing machine. Agricultural Engineering International: CIGR Journal, 25 (1):59-76.

1 Introduction

Rice (*Oryza sativa*) is a monocot plant that belongs to the family *Poaceae* as a cereal grain (Ohen and Ajah, 2015). Rice can either be grown on upland or lowland fields depending on the varietal requirement (Falade and Christopher, 2015). It is a staple food for over half of the world population constituting over 3 billion people (Taghinezhad and Brenner, 2017). In Nigeria, rice stands as the fourth most important crop following sorghum, millet, and maize in terms of its cultivated landmass (Olayanju et al., 2019). Production of rice in Sub Saharan Africa in 2014 was 22.1 million tons, while in 2018; it increased to a capacity of about 27 million tons (Ndindeng et al., 2015).

Rice processing involves unit operations like; cleaning (dry and wet), parboiling, drying, tempering, de-husking (hulling), milling (polishing), grading (sorting) and de-stoning (Zabidin et al., 2018). The de-husked rice grain called "brown rice" is hulled from paddy (or rough

Received date: 2020-09-04 **Accepted date**: 2022-10-22

***Corresponding author: Clinton Emeka Okonkwo, MEng.,** Lecturer of Department of Agricultural and Biosystems Engineering, Landmark University, P.m.b. 1001, Omu-Aran, Kwara State, Nigeria.

Email: okonkwo.emeka@lmu.edu.ng.Tel:+234-8060545245.

rice) consisting of bran layers (6 %-7 % of its total weight), the embryo (2 %-3 %), and the starchy endosperm (about 90 %) (Bangphan et al., 2013). Polishing which is otherwise referred to as milling or whitening is the main difference between brown and white rice. The polishing process removes about 8-10 % of the outer bran layer of the brown rice, leaving behind a core which is made of mostly carbohydrate (Bangphan et al., 2013). Brown rice contains more of the following nutrients than white or polished rice depending on the degree of polishing; lipids, proteins, dietary fiber, vitamins, fatty acids, phytic acid, and GABA (γ-aminobutyric acid) (Lee et al., 2018). Although white rice is still much consumed than brown rice, it may be due to its smooth eating texture and preferred appearance (Li and Gilbert, 2018). In Nigeria, rice consumption has risen immensely at about 10 % per annum. However, it is reported that most Nigerians still prefer to consume imported polished rice than our local brown rice. This might be due to the lack of proper technology for rice processing to meet international standards (Ajala and Gana, 2015).

Some of paddy rice de-husking and polishing machines which have been developed in Nigeria still have low head rice yield and do not polish the rice, except after so many runs. Several runs hamper the rice quality and machine capacity; increase process time, breakages and energy consumption, which to a rice processor are not good parameters. The imported rice de-husking and polishing machines which are mostly used by rice processors in Nigeria have some limitations which include; high cost of purchase, not designed and evaluated with Nigerian rice varieties, require high technical know-how in usage and spare parts are not readily available. Small to medium scale rice millers most often cannot afford the imported rice de-husking and polishing machines due to the high cost of procurement. To meet up with the global market demand for both white and brown rice, it is pertinent that rice de-huskers are improved to handle our indigenous varieties. In this regard, Adegun et al. (2012) developed a mini rice processing machine for small scale farmers consisting of a de-husking and sieving unit. Dauda et al. (2012) evaluated a locally developed rice de-husking machine for its performance efficiency. Gbabo and Ndagi (2014) evaluated a rice milling machine that was developed in the National Cereals Research Institute (NCRI), Badeggi, Niger State. Cho et al. (2017) studied the milling characteristics of cutting-type rice milling machine using different cutting roller guide angles. Adisa et al. (2016) evaluated the effectiveness of teflon as a roller material for a prototype rice roller de-husking /de-stoning machine. Akintunde (2007) developed a friction type rice polishing machine. Caringal et al. (2016) developed a rice milling and grinding machine. Osore and Adio (2018) constructed a rice de-husking machine for Ofada rice. There is no information in the literature on the combination of de-husking and polishing operations. The need for technological intervention that will combine these operations in one is apt. This will increase the production capacity of small to medium scale rice processors, reduce high importation of rice, minimize drudgery and encourage local rice patronage. This study undertakes the design, fabrication and evaluation of a de-husking cum polishing machine.

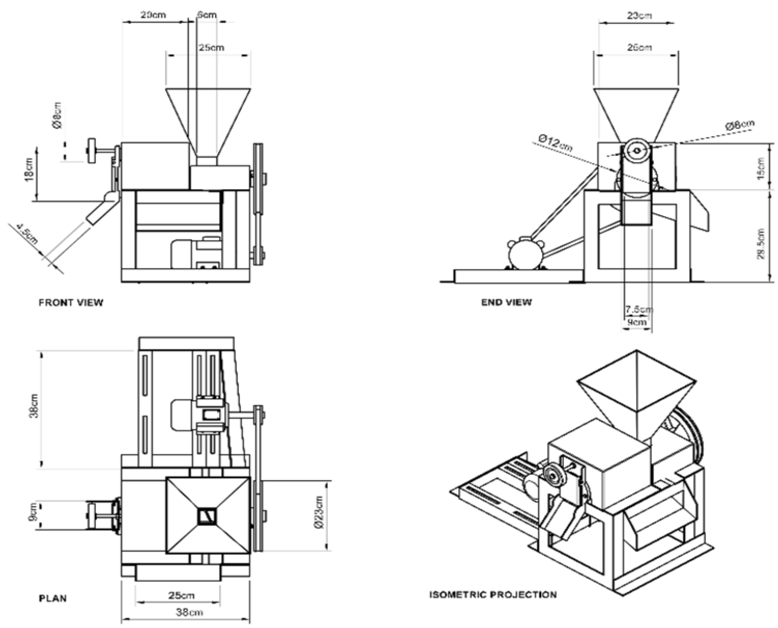
2 Materials and method

2.1 Sample preparation

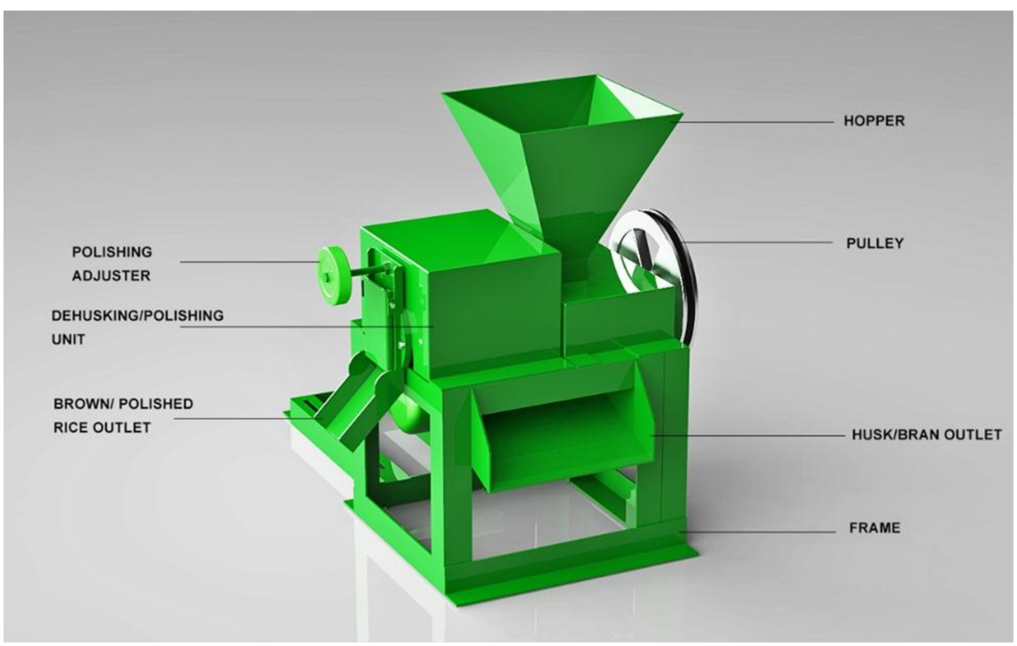
Thirty kilograms of FARO 58 paddy was obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State. Triplicate moisture content dry basis (MC %db) of the paddy before soaking, after soaking and after steaming were determined using the oven-dry method (i.e. drying at 110°C for 24 hours) (AOAC, 1980). Initial MC was 14.13%±0.3%, 59.35%±0.21% after soaking and 46.09%±0.35% after steaming. The paddy was washed with clean water to remove dirt and empty paddy. Soaking and steaming operations were carried out using the method stated by Danbaba et al. (2012) and Agidi et al. (2008) with little modification, soaking in water at 70°C for 12 hours and steaming for 40 min. The parboiled paddy was dried with an oven (Memmert U75 model) set at 70°C to three different moisture content levels before de-husking and polishing.

2.2 Design considerations

In the design of the machine, much consideration was devoted to designing a machine that would give the desired compactness. The various dimensions used for the individual parts of the machine were calculated before construction to reduce the size and weight, and for effective and efficient working conditions of the various parts as shown in Figure 1a. Ease of collection of the rice and husk, and ease of adjusting the polishing time was also considered.



(a) Orthographic and isometric



(b) 3-D view of the developed paddy rice de-husking cum polishing machine

Figure 1 Paddy rice de-husking cum polishing machine

2.3 Design calculations

2.3.1 Determination of belt length

The belt design was carried out using the formulae given by Khurmi and Gupta (2005).

The length of the B-belt used was calculated using Equation 1.

$$L=\pi(r_2+r_1)+2x+\frac{(r_2-r_1)^2}{x} \quad (1)$$

Where,

$r_2 =$ radius of the driven pulley (mm) $=$ 112.5 mm

$r_1 =$ radius of the driving pulley (mm) $=$ 50 mm

x = center to center distance of the belt = 470 mm

$$L=\pi(112.5+50)+2\times 470+\frac{(112.5-50)^2}{470}$$

$$= 1458.8110 \text{ mm} = 1.46 \text{ m}$$

2.3.2 Determination of power requirement

The power requirement (P, kW) of the machine was calculated by adding the power transmitted by the belt (P_B, kW) and the power required to de-husk or polish the rice (P_{DP}, kW) (Khurmi and Gupta, 2005; Ojediran et al., 2018). Power transmitted per belt (P_B) is calculated thus;

$$P_B=(T_1-T_2)v \quad (2)$$

Tension in the tight side of the belt (T_1);

$$T_1=T_b-T_C \quad (3)$$

Centrifugal tension of the belt (T_C)

$$T_C=mv^2 \quad (4)$$

Where,

$m =$ mass of the belt (Kg) $=$ 0.159 Kg

$v =$ maximum belt speed (ms^{-1}) $=$ 900 rpm $= 10.6 ms^{-1}$

$T_C = 0.159\times 10.6^2 = 17.865\ N$

Maximum tension in the belt (T_b)

$$T_b=\sigma\times A \quad (5)$$

Where,

$\sigma =$ allowable tensile stress $=$ 2.5 MPa, A $=$ belt area (m^2)

$T_b = 2.5\times 159 = 397.5$ N

$T_1 = 397.5-17.865 = 379.635$N

Tension in the slack side of the belt (T_2)

$$2.3log\left(\frac{T_1}{T_2}\right)=\mu\theta Cosec\beta \quad (6)$$

Where,

$\mu =$ coefficient of friction between the belt and pulley $=$ 0.25 (Khurmiand Gupta, 2005)

$\theta =$ angle of lap of the belt (rad) $=$ 2.8623 rad,

$\beta =$ Half of the wedge angle

The groove angles of V- pulleys = $2\beta = 35^0$, $\beta = 17.5^0$

$$2.3\log\left(\frac{379.635}{T_2}\right)=0.25\times 2.8623\times \text{Cosec } 17.5$$

$T_2 = 35.0543$ N

$$P_B=(379.635-35.0543)\times 10.6 = 3.653 \text{ kW}$$

Power required for de-husking and polishing the rice (P_{DP})

$$P_{DP}=T\omega \quad (7)$$

Where,

T = torque (Nm), $\omega =$ angular speed (rad)

$$T=\frac{\tau t b^2}{12} \quad (8)$$

Where,

$\tau =$ shear stress of parboiled paddy $= 3.02 \frac{N}{mm^2}$ as given by Baker et al (2012)

t = thickness of the parboiled long paddy = 1.95 mm

b = width of the parboiled long paddy = 2.47 mm

$$T=\frac{3.02\times 1.95\times 2.47^2}{12} = 2.994 \text{ Nm}$$

$$\omega=\frac{2\pi N}{60}=\frac{2\pi\times 900}{60}=94.248 \text{ rad}$$

$$P_{DP}=2.994\times 94.248=282.179 \text{ W}=0.282 \text{ kW}$$

Total power required

$$P=P_B+P_{DP}=3.653+0.282=3.935\ kW=5\ hp$$

Thus, a 5hp electric motor was used.

2.3.3 Determination of the number of belts

The number of V-belts was determined using the equation given by Khurmi and Gupta (2005).

Number of V-belts to be used (NV)

$$NV=\frac{P}{P_B} \quad (9)$$

Where,

P = total power transmitted = 3.776 kW

$P_B =$ power transmitted per belt $=$ 3.653 kW

$$NV=\frac{3.935}{3.653}=1$$

From the design, 1 V-belt was used.

2.3.4 Determination of the shaft diameter

The shaft diameter was determined based on strength, and it is assumed that the shafts are subjected to fluctuating torque and bending moments (Khurmi and Gupta, 2005).

$$T = \frac{P \times 60}{2\pi N} \quad (10)$$

Where,

T = torque transmitted by shaft (Nm)

P = power from the electric motor = 3730 W

N = number of revolutions per minute (rpm) = 900 rpm

$$\mathrm{T} = \frac{3730 \times 60}{2\pi \times 900} = 39.577\mathrm{Nm} = 39.577 \times 10^3 \text{ Nmm}$$

Total vertical load on the pulley

$$W_{TV} = T_1 + T_2 + W_P \quad (11)$$

Where,

$W_{TV} =$ total vertical load on the pulley (N)

$W_P =$ weight of the pulley (N) = 30 N

$W_{TV} = 379.635 + 35.054 + 30 = 444.69\ N$

Bending moment acting on the shaft

$$M = W_{TV} \times L \quad (12)$$

Where,

L = length of the de-husking cum polishing shaft = 300 mm

$$M = 444.69 \times 300 = 133406.79 \text{ Nmm}$$

Equivalent twisting moment

$$T_e = \sqrt{((K_m \times M)^2 + (K_t \times T)^2)} \quad (13)$$

Where,

$Km =$ combined shock and fatigue factor for bending

$K_t =$ combined shock and fatigue factor for torsion

For gradually applied load on a rotating shaft, K_m and K_t are 1.5 and 1.0 respectively (Khurmi and Gupta, 2005; Okonkwo et al., 2019).

$$\mathrm{T_e} = \sqrt{((1.5 \times 133406.79)^2 + (1 \times 39.577)^2)}$$
$$= 203878.25 \text{ Nmm}$$

The equivalent twisting moment can also be calculated using Equation14 as given by Khurmi and Gupta (2005).

$$T_e = \frac{\pi}{16} \times \tau_s \times d^3 \quad (14)$$

Where,

$d =$ diameter of the shaft (mm)

τ_s = allowable shear stress of the shaft = 40 MPa for shaft with keyway

$$203878.25 = \frac{\pi}{16} \times 40 \times \mathrm{d}^3$$

d = 29.6 mm

A shaft diameter of 30 mm was used.

2.3.5 Hopper design

The average bulk density of parboiled paddy (BD) was 535.9 kgm^{-3} (Reddy and Chakraverty, 2004).

Maximum allowable mass of the parboiled paddy (M_{pp}) = 1 kg

$$\text{The required volume of the hopper} = \frac{M_{pp}}{BD} = \frac{1}{535.9}$$
$$= 1.87 \times 10^{-3}\mathrm{m}^3$$

The hopper was made of mild steel material with $245 \times 50 \times 210$ mm at an inclination of 75^o. The total volume of the hopper was 2.57×10^{-3} m^3 with a maximum capacity of 1 kg.

2.3.6 Component parts of the paddy rice de-husking cum polishing machine

The developed paddy rice de-husking cum polishing machine as shown in Figure 1 and Figure 2,comprises of the following components;

2.3.6.1 De-husking cum polishing unit

This consists of a 30 mm diameter shaft of length 450 mm enclosed in a cylindrical-like rice screen coupled by means flanges to a hollow pipe from the right (Figure1). Two types of the auger are wound round the shaft; the first section from the right is an auger of 100 mm length that conveys the paddy to the screen section where de-husking/polishing takes place. In the screen section, the auger configuration is a spiral-like form of length 200 mm.

2.3.6.2 Polishing adjuster

This uses a spring mechanism (i.e. the contraction and expansion property of a spring). The spring mechanism and its accessories were constructed from locally source materials, as the spring contracts, the polishing time increase.

2.3.6.3 Paddy rice inlet

Paddy rice is fed through the hopper. The hopper was constructed from mild steel sheet of gauge “16”. The hopper was a pyramidal frustum of dimensions $245\times50\times210$ mm at an inclination of 75^0.

2.3.6.4 Husk/bran outlet

The husk/bran outlet is located directly beneath the de-husking/polishing screen, to collect the husk and bran during operation. This unit was constructed with a gauge "14" mild steel plate and welded permanently to the frame.

2.3.6.5 Brown/polished rice outlet

It is a rectangular shaped trough made from gauge “14” mild steel sheet and attached directly beneath the polishing adjuster at an angle of inclination to allow the brown or polished rice flow freely into the collecting bag or container.

2.3.6.6 Power transmission unit

This consists of a 5 hp electric motor of speed 1400 rpm coupled to the frame. The power from the electric motor is transmitted to the de-husking/polishing shaft via pulleys and belt.

2.3.6.7 Frames and cover

The frame and the cover of the de-husking/polishing machine were constructed with angle iron and gauge "14" mild steel sheet. This is to provide stability to the machine during its operation.

2.3.7 Principle of operation of the paddy rice de-husking cum polishing machine

The various parts of the de-husker cum polisher were assembled as shown in Figure 2, after which a suitable 5 hp electric motor was mounted and connected via belt and pulley system to the de-husking cum polishing chamber. The machine was used to produce both brown and polished rice. In the production of brown rice, the polishing adjuster was completely released during which the paddy was fed through the hopper to the de-husking/polishing unit, where de-husking is achieved by a spiral-like auger on the shaft. The brown rice comes out through the rice outlet while the husk comes out through the screen to the chaff outlet. In the production of polished rice, the same process is followed but the polishing adjuster is tightened to the level of polishing required.

Figure 2 Pictorial view of the developed paddy rice de-husking cum polishing machine

2.3.8Experimental design

The effect of moisture content, speed of rotation, and polishing time on the machine performance and milling properties of brown and polished rice were studied. The experimental designs adopted were 2×3 and 3×3 factorial Central Composite Face Centered Design (CCFCD) of response surface methodology (RSM) for brown and polished rice respectively. For brown rice, 13 experiments (Table 1) were generated consisting of 2^2 factorial central composite designs (CCD), 4 axial points, and 5 replications at the center points. For polished rice (Table 2), 20 experiments were generated consisting of 2^3 factorial CCD, 6 axial points, and 6 replications at the center points. The various ranges for each independent variable were selected based on preliminary experiments, and literature. Moisture content levels (10-14%db), speed of rotation (600-900 rpm) and polishing time (1-3 min) were used for brown/polished rice. Design Expert (version 12.0.1.0) software package was used for generating the experimental data points and response surface plots.

Table 1Machine performance and milling properties at the processing conditions (brown rice)

Run	MC (% db)	SR (rpm)	HRY (%)	BR (%)	UD (%)	TC (kgh^{-1})
1	10	600	62.500	9.848	22.727	25.385
2	12	900	56.250	9.559	23.897	41.250
3	14	600	66.429	6.786	22.500	35.600
4	12	750	52.308	9.231	15.769	33.000
5	12	750	55.110	6.569	33.942	34.000
6	12	750	52.113	6.690	36.620	34.000
7	12	600	59.449	7.480	27.165	30.000
8	14	900	67.754	3.986	25.725	39.556
9	10	750	57.143	12.030	25.188	27.500
10	12	750	55.073	11.594	27.536	30.909
11	12	750	53.252	3.374	42.683	33.111
12	10	900	63.603	5.882	27.941	30.000
13	14	750	50.467	2.171	46.417	33.364

Note: MC = moisture content, SR = speed of rotation, HRY = head rice yield, BR = percentage broken rice, UD= percentage un-dehusked paddy, TC = throughput capacity.

Table 2Machine performance and milling properties at the processing conditions (Polished rice)

Run	MC (% db)	SR (rpm)	PT (min)	HRY (%)	BR (%)	UD (%)
1	12	750	1	82.212	7.308	6.154
2	12	750	2	80.288	9.231	5.769
3	12	750	3	81.313	6.212	3.939
4	12	900	2	81.301	10.407	1.744
5	12	600	2	78.968	7.936	7.341
6	12	750	2	79.508	7.172	3.955
7	10	750	2	89.147	3.814	5.814
8	10	600	3	90.496	5.207	3.070
9	10	600	1	88.211	3.955	6.870
10	14	600	3	82.051	9.829	2.846
11	14	900	3	85.246	8.115	1.713
12	14	750	2	83.871	9.234	3.742
13	10	900	3	84.454	8.067	1.118
14	10	900	1	82.645	6.735	4.628
15	14	900	1	84.646	7.362	5.354
16	14	600	1	84.306	8.176	4.562
17	12	750	2	89.754	3.717	5.409
18	12	750	2	89.535	2.767	5.891
19	12	750	2	83.136	7.662	5.059
20	12	750	2	83.734	7.982	3.373

Note: MC = moisture content, SR = speed of rotation, PT= polishing time HRY = head rice yield, BR = percentage broken rice, UD= percentage un-dehusked paddy

2.4 Performance evaluation

2.4.1 Machine performance

Throughput capacity (*TC*) of the machine was determined as below (Ojediran et al., 2018).

$$TC = \frac{weight\ of\ paddy}{actual\ time\ used} \quad (15)$$

Percentage Un-dehusked

The percentage un-dehusked (PUD) was determined using the equation given by Hussain et al. (2018).

$$PUD = \frac{mass\ of\ un-dehusked\ paddy}{mass\ of\ paddy} \times 100 \quad (16)$$

2.4.2 Milling properties

The milling properties studied below for both the brown and polished rice are as given by Hapsari et al. (2016) and Chavan et al. (2017).

Head rice yield

The head rice (HRY) was those rice grains that are at least three-quarters of the actual kernel length.

$$HRY = \frac{mass\ of\ head\ rice}{mass\ of\ paddy} \times 100 \quad (17)$$

Percentage of Broken rice

The broken rice (BR) was regarded as those rice grains that are less than three-quarter but greater than one-fourth the original kernel length.

$$BR = \frac{mass\ of\ broken\ rice}{mass\ of\ sample\ at\ the\ milled\ rice\ outlet} \times 100 \quad (18)$$

2.5 Economic analysis

The economic parameters determined includes; breakeven point (BEP), payback period (PBP), and benefit-cost ratio (BCR) (Hussain et al., 2018; Okonkwo et al., 2019).

$$BEP = \frac{\frac{TFC}{DPF-TVC}}{WH \times DPC} \quad (19)$$

Where,

$TFC = \text{total fixed cost } (\$\text{hr}^{-1})$

$DPF = \text{de} - \text{husking or polishing fee } (\$\ \text{Kg}^{-1})$

$TVC = \text{total variable cost } (\$\ \text{hr}^{-1})$

$\text{WH} = \text{working hours}$

$DPC = \text{de} - \text{husking or polishing capacity } (\text{Kghr}^{-1})$

$$PBP = \frac{IVC \times WH}{TB \times WH} \quad (20)$$

Where,

$IVC = \text{initial investment cost } (\$)$

$TB = \text{total benefit } (\$)$

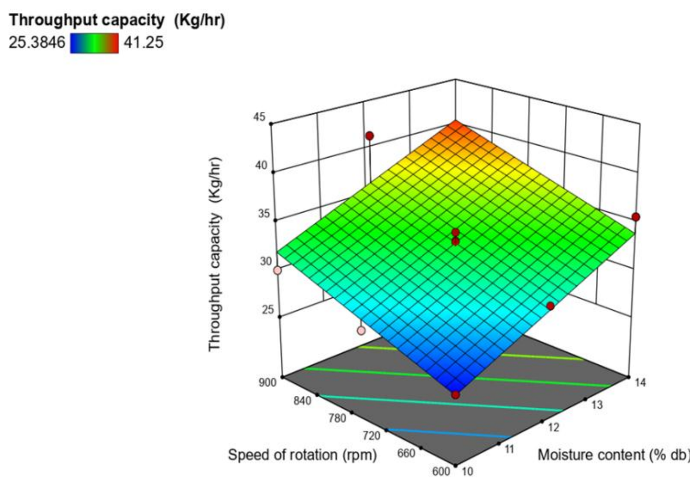
$$BCR = \frac{TB}{DPF \times DPC} \quad (21)$$

3 Results and discussion

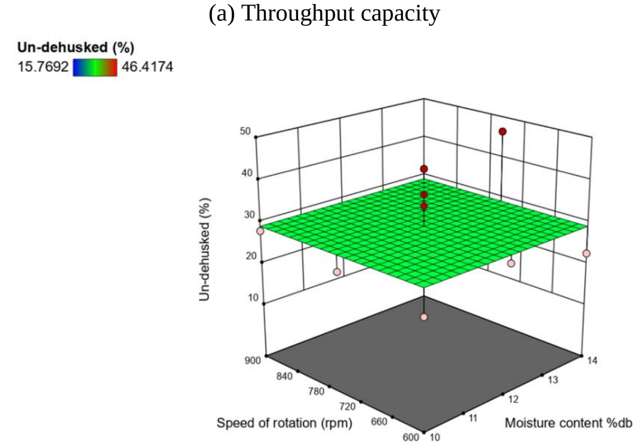
3.1 Effects of moisture content and speed of rotation on the machine performancefor brown rice

At a constant speed of rotation of the de-husking shaft, increase in moisture content of the paddy rice increases the throughput capacity (TC) (20 to 34 kghr^{-1}). This is because at high moisture content the capacity of husked rice decreases. This is similar to the findings of Adisa et al. (2016) for a prototype rice de-husking machine who reported an increasing TC with increased moisture content (12% to about 17.99%), but TC decreased afterward. Fadale and Aremu (2016) noticed a fluctuating TC across the moisture content range used for Moringa shelling machine, the TC decreased with increased moisture content from about 8% to 16%, it then increased as moisture content increased from16% to 30% and decreased afterward. At the same moisture content, increase in speed of rotation (600 to 900 rpm) increases the TC (20 to 32 kghr^{-1}) as shown in Figure 3a. This is expected as more shaft revolution is made per min, with more volume of paddy conveyed out of the de-husking unit. This is consistent with Olayanju et al. (2019), who reported an increased threshing capacity was realizedat higher speed. The interactive effect of the moisture content and the speed of rotation show that a combined increase in speed and moisture content increases the TC of the machine. The maximum TC (34 kghr^{-1}) of the developed machine is higher than that reported by Musa et al. (2012) (16.47 kghr^{-1}) and Adisa et al. (2016) (18.53 kghr^{-1}) for paddy rice de-husking machine.

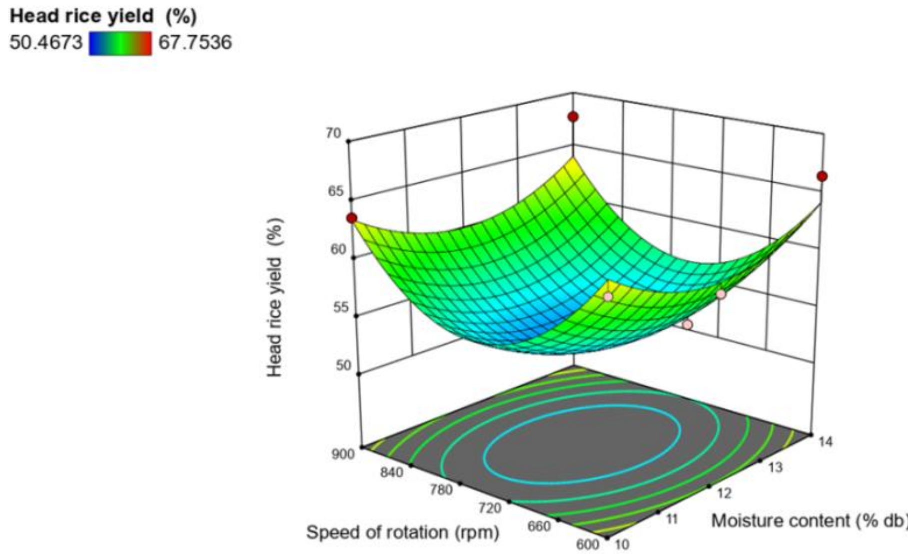
At a constant speed of rotation of the de-husking shaft, an increase in the moisture content of the paddy rice from 10% to 14% MC db increases the percentage un-dehusked (PUD) from 20% to 31%. As noticed, at high moisture content the capacity of husked rice decreases. This is consistent with the result reported by Adisa et al. (2016) on a prototype paddy rice dehuller, where dehulling efficiency of some paddy varieties decreased with increased moisture content. Payman et al. (2006) on hulling index of paddy rice reported that hulling index decreased slightly (69% to 68%) with increased moisture content (9.5% to 14%). Firouzi et al. (2010) on husking index of paddy rice noted husking index decreased (71.64% to 61.81%) as moisture content increased (13% to 14.61%). Fakayode et al. (2019) working on moringa dehuller, recorded the highest dehulling efficiency at the lowest moisture content. At the same moisture content, increase in speed of the developed machine (600 to 900 rpm) increases the PUD from 20% to 27% as shown in Figure 3b. At high speed, the parboiled paddy is conveyed out of the de-husking chamber at a faster rate reducing operational time in the machine. Firouzi et al. (2010) on the effect of speed on the husking index of paddy, reported that as the speed of the machine increased, the husking index initially increased, but decreased afterward. Other similar reports were Olayanju et al. (2019), increased threshing efficiency of paddy with increased threshing speed; Fakayode et al. (2019), dehulling efficiency of moringa increased with increased speed from 600 to 900 rpm but decreased afterward. The interactive effect of the moisture content and speed of rotation show that increase in moisture content and speed slightly increases the PUD. This observation is expected due to the gummy nature of the husk to the rice grains at high moisture content, and less de-husking time. This agreed with the findings of Fakayode et al. (2019), who reported that increased moisture content and speed decreased the dehulling efficiency of small-sized moringa seeds this is not so for medium to big sized moringa seeds.



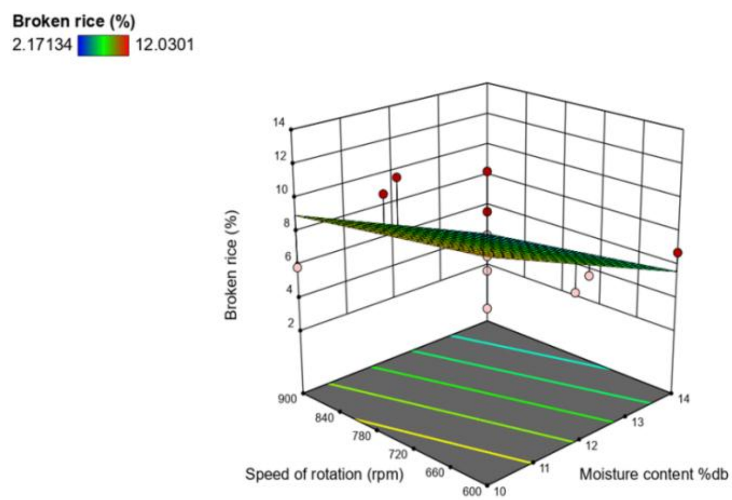
(a) Throughput capacity



(b) Percentage un-dehusked and milling properties



(c) head rice yield



(d) percentage broken rice of brown rice

Figure 3 Response surface plot of the machine performance for brown rice

3.2 Effect of moisture content and speed of rotation of shaft on the milling propertiesof brown rice

At a constant speed of shaft rotation, increase in moisture content has a fluctuating effect on the head rice yield (HRY). HRY decreased slightly (62% to 60%) with increase in moisture content (10% to 12% MC db), and increased (60% to 64%) afterward as shown in Figure 3c. Moisture content from 12 to 14% was observed to have a greater effect on the HRY due to the high moisture content. This accounts for the greater the resistance to breakage. This is consistent with the findings of Adisa et al. (2016) on HRY as affected by moisture content, who reported that HRY increased with increased moisture content from 12% to 15.99% but decreased afterward. The highest HRY was 55.36%. Nasirahmadi et al.(2014) working on the effect of moisture content on HRY noted that as moisture content increased from 8% to 12%, the HRY decreased for *Tarom* and *Fajr* rice varieties, maximum HRY was 65.5%. At constant moisture content, an increase in the speed of rotation also has a fluctuating effect in the HRY. Increase in speed of rotation (600 to 780 rpm) decreased the HRY (62% to 55%) of milled rice, thereafter; increase in the speed of rotation (780 to 900 rpm) increases the HRY from about 55% to 63.5%. This means that rice breakage is not felt between 780 to 900 rpm speed. The interactive effect of moisture content and speed of rotation shows that increase in moisture content and speed to 12%db and 780 rpm initially decreased the HRY, but increased afterward. Payman et al. (2006) reported the fluctuating effect of linear speed on HRY; it decreased and increased across the moisture content range considered.

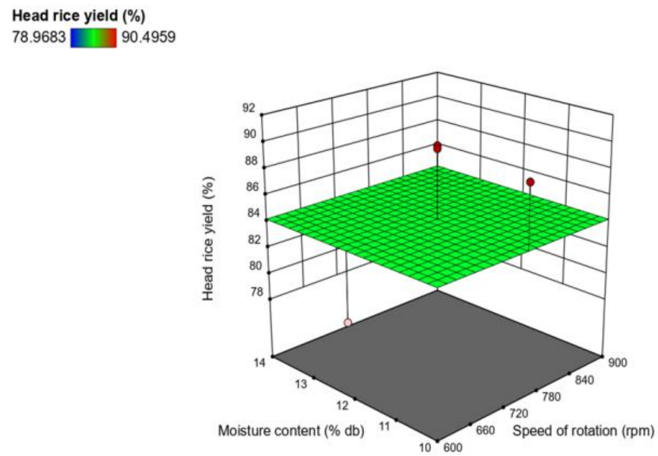
At the same speed of rotation, an increase in the moisture content from 10% to 14%db decrease the percentage of broken rice (PBR) from about 9% to 7.5%. This is because at high moisture content, rice grains exhibit plastic behavior. Similar findings were reported by Adisa et al. (2016) on paddy de-husking machine, as PBR decreased for FARO 35 with increase in moisture content (12% to 18%); Fadele and Aremu (2016) on moringa shelling machine, as percentage broken moringa seed decreased with increased moisture content (11.38% to 34.59%). At the same moisture content, increase in speeds lightly increases the percentage of broken rice (PBR). This is consistent with the findings of Firouzi et al. (2010) on a rubber roll paddy husker that percentage broken rice decreased as speed increased from 1.5 to 5 ms^{-1}. The combined effect of the moisture content and speed of rotation shows that increase in moisture content and speed of rotation reduces the PBR as shown in Figure 3d. This is expected, d since moisture content shows a higher significant effect on the PBR than the speed. The least percentage breakage of the developed machine (7.5%) was lower than that reported by Adisa et al. (2016) (15.44%) and Firouzi et al. (2010) (9.97%).

3.3 Effects of moisture content, speed of rotation, and polishing time on milling properties of polished rice

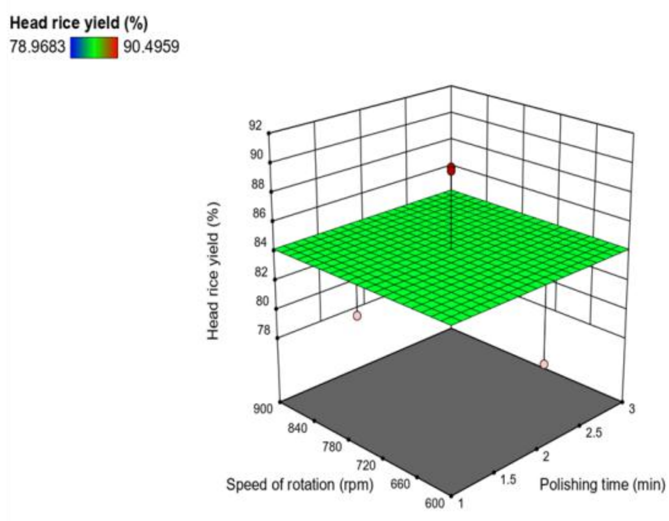
The increase or decrease in the moisture content, speed of rotation, and polishing time did not affect the HRY as observed from Figure4 (a-c) for the developed machine. The minimum and maximum HRY obtained is 78.97% (at 12%db, 600 rpm, 2 min) and 90.50% (10%db, 600 rpm, 3 min), respectively. This shows that at the lowest moisture content, lowest speed and the highest polishing time, HRY was maximum. Similar findings were reported by Nasirahmadi et al. (2014) on the influence of moisture content on the milling quality of rice grains; maximum HRY was obtained at the lowest moisture content of 8% for *Tarom* and *Fajr* rice varieties. This is not consistent with the findings by Ahmad et al. (2017) on the influence of milling intensity (i.e. polishing time) on HRY for Catahoula rice where HRY decreased with increased milling intensity and maximum HRY (89.77%) was obtained at light milling intensity. Sandhu et al. (2018) working on effect of the degree of milling (i.e. polishing) on the physicochemical properties of short and long and short-grain *indica* rice cultivars reported increased degree of milling decreased the HRY, maximum HRY of 69.06% was obtained at 2% degree of milling. Saleh and Meullenet (2013) also reported a decrease in the HRY with increased milling duration (polishing time).

Increase in moisture content (10% to 14%db) increased PBR (Figure 4d). This result is not similar to the behavior of the machine with brown ricefor whichPBR decreaseswith increase in moisture content. The observed difference might be due to increase milling. Fadele and Aremu (2016) reported an increase and decrease in percentage broken moringa seeds as moisture content increased.Increase in the speed of rotation (600 to 900 rpm) increases the PBR (Figure 4e). This is as a result of increasing impact action. This is consistent with the findings of Sharma et al. (2013) on the shelling of Tung fruit as increased speed (1600 to 2100 rpm) resulted in increased percentage breakage. Increase in polishing time (1 to 3 min) increases the PBR (Figure 4f). Similar findingis reported by Ahmad et al. (2017) on the influence of milling intensity (i.e. polishing time) on percentage broken Catahoula rice where PBR increased with increased milling intensity, maximum PBR (11.95%) was obtained at heavy milling intensity. The interactive effect of (moisture content × speed of rotation), (moisture content × polishing time), and (speed of rotation × polishing time) increase the PBR from 2.77% to 9.2%, 2.77% to 9%, and 2.77% to 8% respectively as shown in Figure 4 (d-f). The minimum and maximum

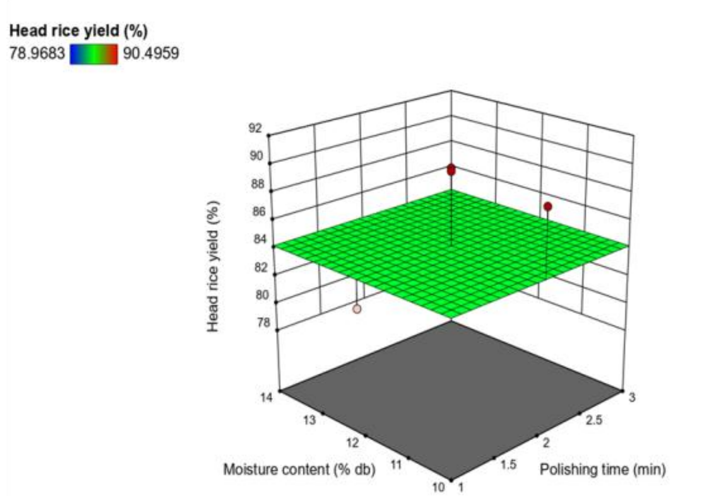
PBR in all cases are 2.77% and 10.41%. The maximum PBR is lower than that reported by Adisa et al. (2016) (15.44%).



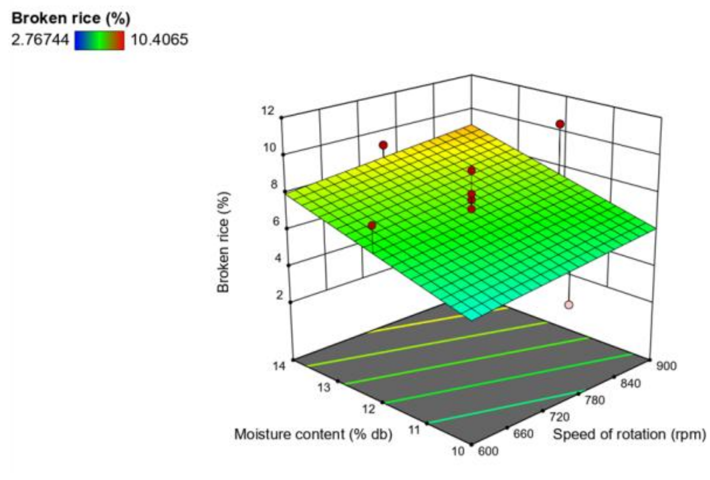
(a) moisture content versus speed of rotation



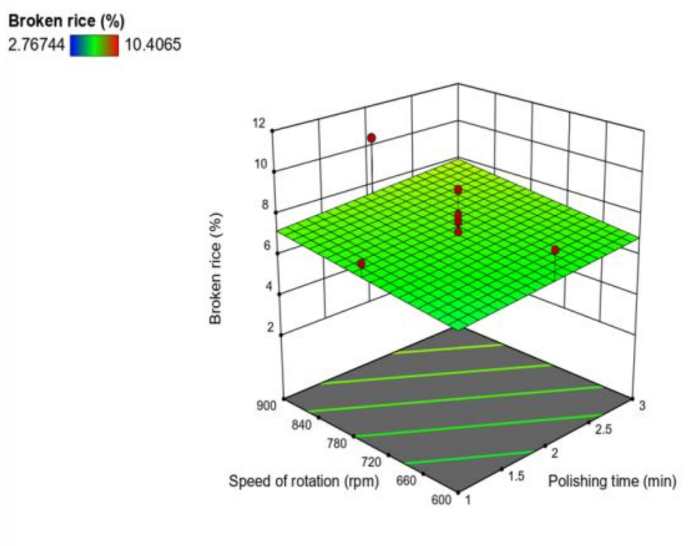
(b) speed of rotation versus polishing time



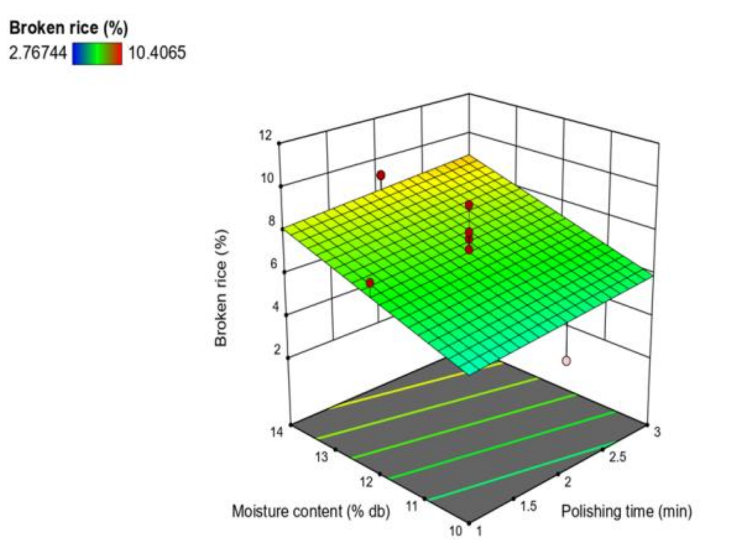
(c) moisture content versus polishing time



(d) moisture content versus speed of rotation



(e) speed of rotation versus polishing time

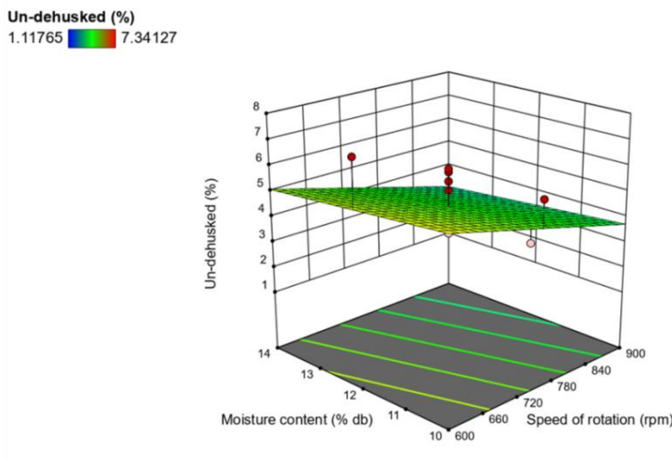


(f) moisture content versus polishing time for polished rice

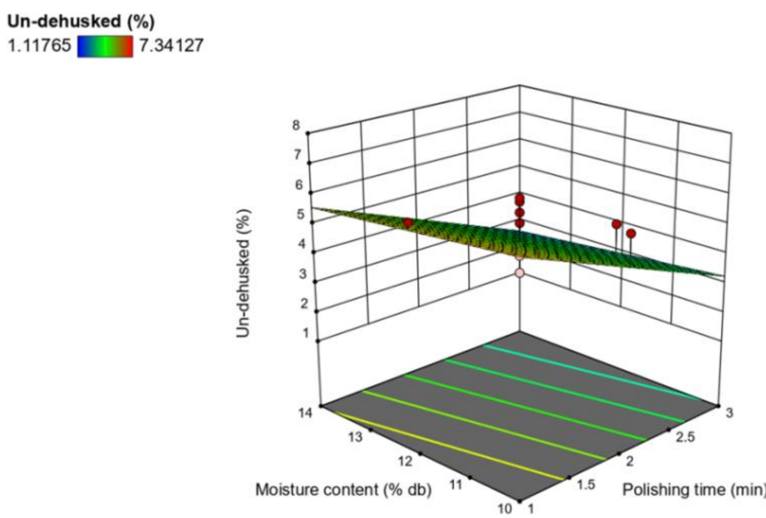
Figure 4 Response surface plots of the milling properties for polished rice

3.4 Effects of moisture content, speed of rotation, and polishing time on percentage un-dehusked (Polished rice)

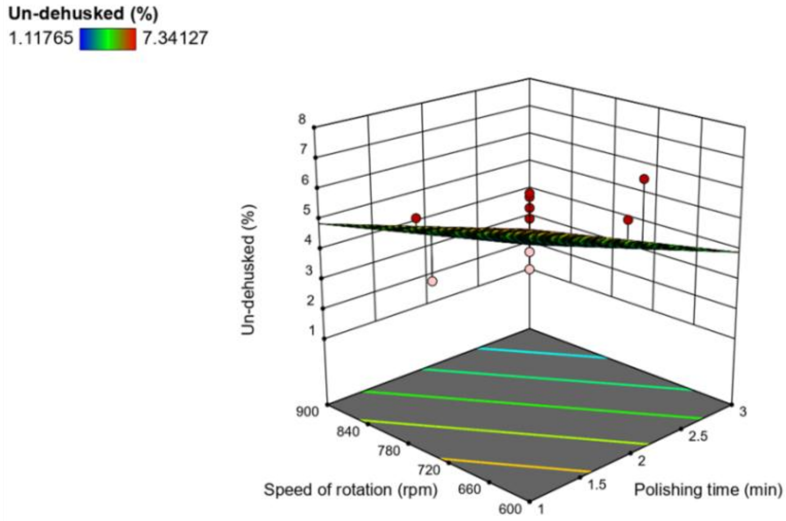
At the same speed of rotation and polishing time levels, increase in moisture content increases the PUD (Figure 5a). This is similar to the observation made during de-husking, though the PUD is lower during polishing. At the same moisture content and polishing time levels, increase in the speed of rotation decreases the PUD (Figure 5b). This is not similar to the machine behavior for brown rice, due to the inclusion of polishing time variable. Similar findings are reported by Firouzi et al. (2010), effect of speed on the husking index of paddy rice where husking index initially increased and then started to decrease as speed of the machine increased; Sharma et al. (2013) effect of speed on an impact-type tung fruits decorticator where percentage un-shelled fruit decreased with increased speed. At the same speed of rotation and moisture content levels, increase in polishing time decreases the PUD (Figure 5c). This is as a result of increase milling duration. The interactive effect of (moisture content × speed of rotation), (moisture content × polishing time), and (speed of rotation× polishing time) are shown in Figure 5(a-c). Increase in moisture content and speed of rotation decreases the PUD. This is not similar to the behavior of the machine for only de-husking operation. This may be as a result of increase milling duration and agrees with the findings of Fakayode et al. (2019) for moringa seeds, that increased moisture content and speed increased the dehulling efficiency up to 900 rpm, after which it decreased.Increase in moisture content and polishing time decreases thePUD. Increase in speed of rotation with the polishing time decreases the PUD. The minimum and maximum values for the PUD were 1.12% and 7.34% respectively. This value was lower than that reported during de-husking for the production of brown rice.



(a) moisture content versus speed of rotation



(b) moisture content versus polishing time



(c) speed of rotation versus polishing time for polished rice

Figure 5 Response surface plots of percentage un-dehusked after polishing

Table 3 Bill of Engineering measurement and evaluation for the developed machine

S/N	Component	Material	Specifications	Quantity	Unit Price ($)	Quantity Price ($)
1	Frame	Mild steel angle iron	50 by 50 mm	1	10	10
2	Hopper, de-husking/polishing chamber cover, rice and chaff outlet	Mild steel sheet (G14)	4 by 8 ft	1/2	13.5	13.5
3	De-husking cum polishing shaft	Mild steel (Φ30 mm)	500 mm long	1	8.5	8.5
4	Polishing adjuster	Rubber control		1	5	5
5	Pillow bearing		205	2	4.5	9
			M13	5	0.05	0.25
6	Bolts and nuts	Mild steel	M17	6	0.06	0.36
			M19	4	0.08	0.32
	Consumables;					
7	Electrode	Mild steel	Gauge 16	1 packet	4.5	4.5
	Cutting disc	Mild steel	Gauge 10	3	2	6
	Grinding disc	Mild steel	Gauge 10	1	1	1
8	Paint and thinner		Auto base	1 liter	4.5	4.5
9	Prime mover		Single phase (5hp)	1	58.5	58.5
			M13	1	0.3	0.3
10	Drilling bits		M17	1	0.5	0.5
			M19	1	0.5	0.5
	TOTAL					123

3.5 Economic analysis

The cost estimate of the developed machine is as shown in Table 3. A total sum of $123 was used for the construction of the machine. The analysis of the economic parameters (BCR, PBP, and BEP) reveals that the developed paddy rice de-husker cum polisher can be optimally adapted for utilization due to the positive indicators. A BCR greater than 1 indicates that the usage of the machine would be theoretically beneficial. BCR of 2 was obtained for the developed machine, showing it is highly beneficial. Hussain et al. (2018) reported a BCR of 1.12 for a power-operated walnut cracker; Dixit et al. (2012) reported a BCR of 2.07 for a foot-operated maize Sheller. The BEP for the developed machine is estimated to be 12086 kg. The inference drawn is that the usage of this developed machine will certainly be more rewarding for small to medium scale rice processing units. Hussain et al. (2018) reported a BEP of 8601 kg for a power-operated walnut cracker; Dixit et al. (2012) reported a BEP of 875 kg for a foot-operated Maize Sheller. PBP refers to the period at which the investment made would be realized. PBP for the developed machine was estimated to be 206 days (6.87 months), indicating that the developed machine can be profitably used for commercial purposes. Hussain et al. (2018) reported a PBP of 3.10 months for a power-operated walnut cracker; Dixit et al. (2012) reported a PBP of 4 months for a foot-operated maize Sheller. Hence, from the economic analysis, it was concluded that the developed paddy rice de-husker cum polisher is economically viable and suitable for small to medium scale rice processing industries.

4 Conclusions

Paddy rice de-husking cum polishing machine was designed and developed to increase the production capacity of small to medium scale rice processors, reduce high importation of rice, minimize drudgery and encourage local rice patronage. The de-husker cum polisher was evaluated for its efficiency in producing brown and polished rice. An economic analysis of the developed machine was evaluated. The effect of moisture content, speed of rotation, and polishing time on the machine performance and milling properties were also evaluated. In the production of brown rice, speed of rotation and moisture content affected the throughput capacity, head rice yield, percentage broken, percentage of un-dehusked rice was unaffected. Whereas in the production of polished rice, speed of rotation, moisture content, and polishing time had an effect on the percentage broken and percentage un-dehusked, but did not affect the head rice yield. The economic analysis and evaluation of the results show that the paddy rice de-husking cum polishing machine developed is highly beneficial, and can be adopted by small to medium scale rice processors.

References

Adegun, I. K., S.A. Adepoju, andJ. A. Aweda.2012. A mini rice processing machine for Nigerian farmers. *Journal of Agricultural Technology*, 8(4): 1207-1216.

Adisa, A. F., O. N. Eberendu, A. O. Aderinlewo, andI. S. Kuye.2016. Effectiveness of Teflon as roller material for a prototype rice processing machine. *CIGR Journal*, 18(4): 107-118.

Agidi, G., S. M. Dauda, andJ. C. Igbeka.2008. Effect of variety, pressure and specific volume of steam on the head rice yield of milled parboiled rice. *Journal of Food Science and TechnologyMysore*, 45(3): 282.

Ahmad, U., L. Alfaro, M. Yeboah-Awudzi, E. Kyereh, B. Dzandu, F. Bonilla, A. Chouljenko,andS. Sathivel. 2017. Influence of milling intensity and storage temperature on the quality of Catahoula rice (Oryza sativa L.). *LWT*, 75: 386-392.

Ajala, A. S., andA. Gana.2015. Analysis of challenges facing rice processing in Nigeria. *Journal of Food Processing*, 2015: pp 6. Article ID 893673.

Akintunde, M. A. 2007. Development of a rice polishing machine. *Assumption University (AU) Journal of Technology,* 11(2): 105-112.

AOAC.1980.*Official Methods of Analysis*.13th Ed**.** Washington, DC: AOAC.

Baker, A., R. S. Dwyer-Joyce, C. Briggs,andM. Brockfeld.2012. Effect of different rubber materials on husking dynamics of paddy rice. In *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, 226(6): 516-528.

Bangphan, S., P. Bangphan, andT. Boonkang.2013. Implementation of response surface methodology using in small brown rice peeling machine: part I. *Magnesium*, 7(2): 514-5180.

Caringal, B. K. M., Z. S. D. Rosa, K. V. R. Maan, andN. C. Camello.2016. Design and development of rice milling and grinding machine. *EPH-International Journal of Science and Engineering*, 2(8): 6-14.

Chavan, P., S. R.Sharma, T. C. Mittal, G. Mahajan, andS. K. Gupta.2017. Optimization of parboiling parameters to improve the quality characteristics of Pusabasmati 1509. *Journal of Food Process Engineering*, 40(3): e12454.

Cho, B., T. Kang,D. Lee,J. Won,H. Lee,and C. Han.2017. Milling characteristics of cutting-type rice milling machine-according to cutting roller induced guide angles. *Journal of BiosystemsEngineering*, 42(2):112-116.

Danbaba, N., J. C. Anounye, A. S. Gana, M. E. Abo, M. N. Ukwungwu, andA. T. Maji.2012. Physical and pasting properties of ‘ofada’rice (*Oryza sativa* L.) varieties. *Nigerian Food Journal*, 30(1): 18-25.

Dauda, S. M., P. A. Adeoye, K. Bello, A. A. Agboola, andA. Abdulfatai.2012. Performance evaluation of a locally developed rice dehulling machine.*International Journal of Agronomy and Agricultural Research*, 2(2): 15-21.

Dixit, J., S. K.Lohan, R. A.Parray, andM. A. Malla. 2012. Design, development and performance evaluation of a foot operated maize cob sheller. *AMA-Agricultural Mechanization in Asia Africa and Latin America*, 43(4): 32.

Fadele, O. K., andA. K. Aremu.2016. Design, construction and performance evaluation of a Moringaoleifera seed shelling machine. *Engineering In Agriculture, Environment and Food*, 9(3): 250-256.

Fakayode, O. A., D. E. Akpan, andO. O. Ojoawo.2019. Size characterization of moringa (Moringaoleifera) seeds and optimization of the dehulling process. *Journal of Food Process Engineering*, 42(6): e13182.

Falade, K. O., andA. S. Christopher.2015. Physical, functional, pasting and thermal properties of flours and starches of six Nigerian rice cultivars. *Food Hydrocolloids*, 44:478-490.

Firouzi, S., M. Alizadeh, andS. Minaei.2010. Effect of rollers differential speed and paddy moisture content on performance of rubber roll husker. *International Journal of Natural andEngineering Sciences*, 4(3): 37-42.

Gbabo, A., andB. Ndagi.2014. Performance evaluation of a ricemill developed in NCRI. *International Journal of Engineering Research*, 3(8): 482-487.

Hapsari, A. H., S. J. Kim, andJ. B. Eun.2016. Physical characteristics of parboiled Korean glutinous rice (Olbyeossal) using a modified method. *LWT-Food Science and Technology*, 68: 499-505.

Hussain, S. Z., B. Ammatullah, V. Kanojia, M. Reshi, B. Naseer, andH. R. Naik.2018. Design and development of technology for walnut cracking. *Journal of Food Science and Technology*, 55(12): 4973-4983.

Khurmi, R.S.,and J.K. Gupta.2005.*Machine Design*.14thed. Ram Nagar, New Delhi: S. Chand and Company Ltd.

Lee, S. M., H. J.Lim, J. W. Chang, B. S. Hurh, andY. S. Kim.2018. Investigation on the formations of volatile compounds, fatty acids, and γ-lactones in white and brown rice during fermentation. *Food Chemistry*, 269: 347-354.

Li, H., andR. G. Gilbert.2018. Starch molecular structure: the basis for an improved understanding of cooked rice texture. *Carbohydrate Polymers*, 195: 9-17.

Musa, D. S., A. P. Aderemi, B. Kehinde, and A. A. Adesina.2012. Performance evaluation of a locally developed rice dehulling machine. International Journal of Agronomy and Agricultural Research (IJAAR), 2(1):15-21

Nasirahmadi, A., B. Emadi, M. H. Abbaspour-Fard, and H. Aghagolzade.2014. Influence of moisture content, variety and parboiling on milling quality of rice grains. *Rice Science*, 21(2): 116-122.

Ndindeng, S. A., J. E. G. Mbassi, W. F. Mbacham, J. Manful, S. Graham-Acquaah, J. Moreira, J. Dossou,andK. Futakuchi.2015. Quality optimization in briquettes made from rice milling by-products. *Energy for Sustainable Development*, 29: 24-31.

Ohen, S. B., andE. A. Ajah.2015. Cost and return analysis in small scale rice production in Cross River State, Nigeria. *International Research Journal of Agricultural Science and Soil Science*, 5(1): 22-27.

Ojediran, J. O., C.E. Okonkwo, O. A.Afolabi, andA. A. Samuel.2018. Development of a motorized rice de-stoning machine. *CIGR Journal*, 20(4): 202-209

Okonkwo, C. E., A.Olaniran, J. O. Ojediran, T. A. Olayanju, F. Ajao, andA. S. Alake.2019. Design, development, and evaluation of locust bean seed dehuller. *Journal of Food Process Engineering*, 42(3): e12963.

Olayanju, T. M. A., C. E. Okonkwo, J. O. Ojediran, S. A. Alake, E. A. Alhassan, and A. A. Okunola.2019. Design, development and evaluation of a tangential-flow paddythresher: a response surface analysis. *Asian Journal of Scientific Research*, 12(3):396-405.

Osore, O.A., andM.A. Adio.2018. Design and development of an ofada rice hulling machine.*International Research Journal of Engineering and Technology*,5(11):284-291.

Payman, M., I. Bagheri, M. R. Alizadeh, andR. Roohi.2006. Effective parameters of broken rice during paddy hulling using rubber roll huller. *Journal of Biological Sciences*, 7(1): 45-71.

Reddy, B. S., andA. Chakraverty.2004. Physical properties of raw and parboiled paddy. *Biosystems Engineering*, 88(4): 461-466.

Saleh, M., & Meullenet, J. F. (2013). Broken rice kernels and the kinetics of rice hydration and texture during cooking. *Journal of the Science of Food and Agriculture*, *93*(7), 1673-1679.

Sandhu, R. S., N. Singh, R. S. S. Kaler, A. Kaur, and K. Shevkani.2018. Effect of degree of milling on physicochemical, structural, pasting and cooking properties of short and long grain Indica rice cultivars. *Food Chemistry*, 260: 231-238.

Sharma, V., R. C. Pradhan, S. N. Naik, N. Bhatnagar, andS.

Singh.2013. Evaluation of a centrifugal impaction-type decorticator for shelling tung fruits. *Industrial Crops and Products*, 43: 126-131.

Taghinezhad, E., andT. Brenner.2017. Mathematical modeling of starch gelatinization and some quality properties of parboiled rice based on parboiling indicators using RSM. *Journal of Food Process Engineering*, 40(3): e12483.

Zabidin, Z., F. N. Omar, H. S. Hafid, N. S. H. M. Yunos, M. A. P. Mohammed, A. S. Baharuddin, T. Omura, andM. Wakisaka.2018. Micromechanical investigation of milled and unmilled rice grains through experimental study and finite element analysis. *Biosystems Engineering*, 176: 48-58.