Effectiveness of Teflon as roller material for a prototype rice processing machine

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Abstract: The main aim of this research was to assess the effectiveness of using Teflon material in search of locally available quality/effective roller material for a prototype rice roller dehusking /destoning machine developed in Nigeria making use of four locally cultivated rice varieties. This required determination of the effectiveness of Teflon material as roller for the developed prototype dehusker/destoner. Microsoft Excel 2007 and Minitab 16were used for the analysis of variance of the two main factors (paddy varieties; Faro 35, 44, 55 and Ofada and moisture content levels; 12.00%-13.99%, 14.00%-15.99%, 16.00%-17.99%, 18.00%-19.99% and 20.00%-21.99%). The dehusker cleaning efficiency was found to be 94.73%, coefficient of dehusking was 0.63, coefficient of wholeness was 0.85, dehusking efficiency was 50.54%, dehusking capacity was 10.56 kg/h respectively. The effect of moisture content and test paddy on coefficient of wholeness and dehusking efficiency were significant at $p \leqslant 0.05$,while only moisture content effect was significant on cleaning efficiency.

Keywords: Teflon, paddy rice, roller material, dehusker/destoner, dehulling recovery, hulling efficiency, hulling capacity

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

1 Introduction

The mature rice is harvested as a covered grain (rough rice or paddy), in which the caryopsis is enclosed in a tough hull or husk composed mostly of silica. The hull protects rice grain caryopsis from insect infestation and fungal damage. Johnson et al. (2013) reported that rice has become one of the most important staple food in Nigeria which is ranked the first among all staple food items in terms of expenditures and second only to cassava in terms of quantity consumed. Thailand sells high, medium, and low-quality rice and is the largest exporter of glutinous rice, specialty rice grown mostly in Southeast Asia. Vietnam exports mostly low and medium-quality regular milled white rice, with Southeast Asia a top market. Nigerians consumed about 5.9 million metric tons of milled rice, while local production amounted to about 2.8 million tons of milled rice in year 2012, while 2.7 million metric tons was imported (USDA, 2012).

The key problem facing the rice sub-sector in Nigeria is the lack of competitiveness resulting from low and uneconomic productivity, poor access to inputs which are expensive (especially modern processing machines, fertilizers and credit), low capacity to meet quality standards and little or no encouragement of private sector participation. Poised to reverse this trend, the Government of Nigeria developed farmer-friendly policies with the Presidential initiative on rice (USAID, 2010).

1.1 Rice processing

Paddy in its raw form cannot be consumed by human beings except suitably processed for obtaining rice. Rice processing is the post-harvest technology applied on paddy rice which involves two basic stages; pre-milling and milling which are embedded in the processing

Received date: 2015-07-06 **Accepted date:** 2016-10-21
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methods. Pre-milling activities are carried out both on and off-farm including threshing, cleaning, parboiling and drying. In Nigeria, where rice is grown, these activities are undertaken in a small-scale with local tools resulting in time wasting and drudgery (Adewunmi et al., 2007).

The milling stage is the point where actual dehulling (or dehusking) occurs. Dehusking is the removal of husk or hull. The rice milling operation is the separation of the husk (dehusking) and the bran (polishing) to produce the edible portion (endosperm) for consumption (Mejia, 2003). There are mainly three methods of rice dehulling (or dehusking) in Nigeria. These are traditional or hand-pounding method, the small-mill processing method and the large-mill processing method (Adewunmi et al., 2007).

1.2 Rice dehulling technologies

According to International Rice Research Institute (IRRI, 2009), three different husking technologies are commonly used: steel husker, under runner disk husker and rubber roller husker. IRRI (2009) reported their description and performance, as well as advantages and disadvantages as follows:

The steel husker, the Engleberg coffee huller modified for milling rice removes the husks and whitens the rice in one pass. Paddy rice is fed into the machine and passes between a revolving steel shaft and a cylindrical shaped mesh screen powered by a 5 to 20 hp engine and is very simple to operate and relatively cheap. The performance is reported to be 53%-55% for total milled rice recovery because of high breakage, and head rice recovery is in the order of 30% of the milled rice.

In under runner disk husker, paddy is fed through the center of the upper stationary disk and it flows between the abrasive stone surfaces of the two disks. The friction between the stone surfaces and the paddy grain causes the hull to rip and release the brown rice kernel. Brown rice and husks are discharged circumferentially over the revolving stone and produces moderate amount of cracked grains with a husking efficiency of 85%-95% but with lesser capacity than rubber roller type and more power efficient than steel huller (IRRI, 2009). It does not work well with paddy mixed varieties.

Rubber-roll hullers have an aspirator in the base of the machine to separate the hulls from the brown rice. The roll diameter varies from 150 to 250 mm and the roller width from 60 to 250 mm. The correct clearance is dependent on the varietal characteristics and the width and length of paddy. This method of hulling can achieve hulling efficiencies of 85% to 90% with minimum broken or cracked grain. This type of machine is now widely used in developed countries.

1.3 Milling efficiency

Evaluation and comparison of milling efficiency are based on the entire milling process rather than on the hulling unit. Many of the rice milling systems in the tropics do not, however, have a complete line of standard components such as rough rice cleaners, separators etc. Table 1 shows some generalized data on the efficiency of four milling systems (Esmay et al., 1979).

Table 1 Milling efficiency of rice as affected by four milling systems

Milling process	Husk,%	Bran,%	Total Husk and bran,%	head,%	Broken,%	Total head and broken,%
Hand pounding	–	–	40.0	40.0	20.0	60.0
Steel hullers	–	–	36.6	46.5	16.9	63.4
Disc shellers	–	–	32.5	55.9	11.6	67.5
Rubber roller	22	8	30.0	62.0	8.0	70.0

Note: source: Esmay et al. (1979).

1.4 Drive to increase locally produced rice in Nigeria

Nigeria is the world's second importer of rice, spending about ₦356 billion (US $1.62 billion) for about two million metric tonnes of milled rice. The world's rice market is highly volatile.

Nigeria largest supplier, Thailand, is poised to increase price by over 50%, which implies that her import bill may also go up by 50% if Nigeria does not produce her own rice. (Guardian newspaper, business page, 10th August, 2012).The study by Ogunfowora (2007) identified poor mastery of parboiling and milling techniques as a major factor exacerbating rice quality problems, resulting in low market price, which in turn led to very low returns to rice processing activities. It was clear from his study that the major challenge to improvement in rice quality was the development of low cost but technically efficient and cost effective parboiling and milling technologies. Raising the quality of local rice might discourage rice importation, whilst boosting local production.

Machinery development assessment program requires functional and physical tests of the materials selected, components and machines, both in the laboratory and in the field. The field and laboratory measurement and evaluation performance are very essential to determine whether the design performs as intended or not. Engineering tests require validation of important analysis of field tests as required by the end user which is part of design process that heavily depends upon the feedback for machinery development perfection (Adisa, 1987). In March 2010, a team of researchers at Federal University of Agriculture, Abeokuta in Ogun State, South West of Nigeria commenced rice dehusking machine project development under Institute of Food Security Environmental Resources and Agricultural Research (IFSERAR) for use in rural areas where most of the local production in Nigeria comes from. The performance assessment for the roller material selected for this prototype dehusking, cleaner and destoning machine for development perfection was the major research work of this study.

2 Methodology

This study was conducted at Federal University of Agriculture (FUNAAB), Abeokuta, Ogun State, Nigeria. About 2.8 kg each of FARO 35, 44, 55 were obtained from NCRI (National Cereal Research Institute) Ibadan, Oyo state, Nigeria; while Ofada variety was obtained from a rice farmer in Ofada Town, Ogun State, Nigeria. The quantity of paddy obtained for dehulling falls within the range of that taken to the mills by rural rice processors, which in practice, according to Bassey and Mbengue (1993) is said to vary from 0.5 to over 20 kg which were used for trial running the prototype dehusking *Teflon* rollers/destoning machine until at least a reasonable yield of paddy was dehusked.

2.1 Machine modification

Two rollers made of *Teflon* were used to replace the initial leather/rubber fiber rollers in the machine. The initial rollers began to peel off during dehulling trial and got worn out within short time as a result of friction (dehulling of about 15% of paddy with 50% wholeness) which then resulted in the search for an alternative locally sourced roller material with a superior property. These lead to the use of *Teflon* material now being put in place to replace leather/rubber fiber rollers of the existing worn out roller as is shown in Figure 1 and Figure 2 respectively.

Figure 1 *Teflon* /rubber fibre rollers

Figure 2 Initial worn out leather roller

Locally fabricated prototype Teflon roller rice dehusking/destoning machine sponsored by IFSERAR (Institute of Food Security Environmental Resources and Agricultural Research) and Abeokuta, Nigeria, required some adjustments and settings before the performance test assessment was carried out (Figure 3).Several shoe making leather/ fiber rubber materials were used to cover steel drum with adhesive as rollers for trial runs.

Figure 3 Prototype rice dehusking/destoning machine

2.2 Roller specifications

The specifications of the *Teflon* rollers of the prototype rice dehuller/destoner were as follows:

Material: Knolled *Teflon* rollers

Material properties: Rigidity at high temperature, good dimensional stability, machinability, processing stability, melting point of 327 ℃.

Dimension: 1474 mm outside diameter.

Speed: 995.5 r/min (fixed roller), 725 r/min (adjustable roller)

Spacing: 1.50 mm (Faro varieties), 1.78 mm (Ofada variety).

2.3 Equipment

1. Two Stopwatches.

2. Vernier calipers.

3. Tachometer (Lutron DT-2234B phototype 0.1 r/min-5 ≈ 999.9 r/min; 1 r/min-1000 ≈ 99,999 r/min).

4. Set of spanner for machine adjustment.

5. Re-sealable Nylon bags for collecting brown rice samples and sub samples.

6. Labelling tags.

7. Weighing scale (Amput electronic scale, sensitivity 0.01 g).

8. Electric oven dryer (General-Model 5222 NE, 230 V).

9. Mercury in glass thermometer.

2.4 Moisture content determination of grain

Moisture content of parboiled and sundried paddy varieties was determined using the air-oven method. Samples of 10 g in three replicates of each paddy variety were placed in separate aluminum dishes and heated in the oven at 130^{o}C for about 16 h in accordance with the method of IRRI (1996), the moisture content was computed using Equation 1. The average of three replicates was taken as the MC.

$$MC_{Wb} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100 \qquad (1)$$

3 Measurement of rice parameters

Three replicates of rice sub samples, each weighing 100 g, were separated, handpicked and subjected to test for the quality of rice. Some of their physical properties were also measured in accordance with NCRI and WARDA (2007).

3.1 Determination of grain length, breadth and thickness

Physical dimensions (length, breadth and thickness) of paddy and grain were determined by randomly picking twenty whole grains, measured by means of vernier calipers and magnifying lens. The mean of these dimensions was then calculated in accordance with Otegbayo et al. (2001) and classified based on International Organization for Standardization (ISO) for paddy using Equation 2 below:

Length to width ratio $(\frac{L}{W}) = \frac{Average\ paddy\ length, mm}{Average\ paddy\ width, mm}$ (2)

3.2 Machine performance parameters

Four varieties of paddy, 500 g each were fed into the prototype huller at different moisture content levels of 12.00%-13.99%, 14.00%-15.99%, 16.00%-17.99%, 18.00%-19.99% and 20.00%-21.99%. Three replicates of 100 g rough rice samples (sub samples) were each taken from samples of the paddy varieties received at the hopper outlet for the determinations of the following parameters:

3.2.1 Determination of coefficient of dehulling

Three replicates of 100 g subsamples of dehusked rice drawn from samples received from hopper outlet were separated into unhulled rice and brown rice, the weights of the components were recorded. The mean weight of the unhulled paddy was used to determine the coefficient of dehulling during a single dehulling pass (Camacho *et al.*, 1978) using Equation 3:

$$eh = 1 - \frac{Wu}{Ws} \quad (3)$$

Where;

eh= Coefficient of dehulling;

W_u = Weight of unhulled paddy, g;

W_s= Weight of paddy sample (mixture of brown rice and unhulled paddy), g.

3.2.2 Determination of coefficient of wholeness

Three replicates of 100 g subsamples of dehusked rice drawn from sample received from hopper outlet were separated into broken rice and whole rice, the weights of the components were recorded. The mean weight of the rice grains with at least ¾ of the length of the whole grain was used to determine the coefficient of wholeness using Equation 4:

$$ew = \frac{Ww}{Wt} \quad (4)$$

Where;

ew = Coefficient of wholeness;

W_w = Weight of whole brown rice in the sample, g;

W_t = Weight of the total brown rice hulled (whole and broken), g.

3.2.3 Determination of dehulling efficiency

The coefficient of dehulling and coefficient of wholeness calculated from components of each subsample were multiplied, and the mean from the three replicates were taken as the dehulling efficiency for each rice variety. This was determined using the Equation 5:

$$E_h = e_h e_w \times 100 \quad (5)$$ (PAES 215, 2004)

Where;

E_h = dehulling efficiency, %;

e_h= coefficient of dehulling;

e_w = coefficient of wholeness;

3.3 Determination of dehulling capacity

In order to evaluate the dehulling capacity of the machine, the input and output streams were carefully timed. The time taken to dehusk the paddy was measured using two stop watches to take the readings, the average time was used and rate of output calculated on the basis of the results as presented in data sheet table using the Equation 6:

$$He = \frac{\mathrm{Ho \times eh}}{\mathrm{To}} \quad (6)$$

Where;

He = dehulling capacity, kg/h;

Ho = total dehuller output, kg;

e_h= dehulling coefficient;

To = Operating time, h.

3.4 Determination of output capacity

To determine the output capacity, the weight of total grain received at hopper outlet was taken and the results were recorded as Equation 7:

$$\text{Output capacity (kg/hr)} = \frac{Ho}{To} \quad (7)$$

3.5 Capacity utilization (CU)

To determine the capacity utilization of the dehuller, the weight of paddy fed into the hopper and the weight of dehusked grain received at hopper outlet was taken and recorded as determined by Musa et al. (2012). This was calculated as Equation 8:

$$\text{Capacity utilization (CU)} = \frac{output\ capacity}{input\ capacity} \times 100 \quad (8)$$

3.5.1 Determination of cleaning efficiency (grain purity)

In order to determine the cleaning efficiency, no impurity was removed when the paddy was purchased from sources (NCRI and local farmers). The paddy was parboiled and dried for dehulling without removing any dockage. Four varieties of 500 g each of dried paddy were fed into the dehuller and samples were collected at hopper outlet. The dockage was handpicked from each three replicates of 100 g subsample for the varieties of rice from the hopper outlet. Cleaned grains and material other than grain from subsamples were collected and weighed with electronic weighing balance. The difference gave weight of impurities; the total weight was obtained and then computed as this was used to determine cleaning efficiency as Equation 9:

$$\text{Cleaning Efficiency} = \frac{We}{Ws} \times 100 \qquad (9)$$

Where;

We = Weight of clean rough rice sample, g;

Ws = Weight of paddy sample (mixture of brown rice, unhulled paddy and dockage), g.

3.6 Machine testing

Trial runs for different roller materials were carried out, *Teflon* rollers performed best, while shoe making leather/fiber rubber materials were peeling off and there was a high speed of wearing rate within short time of operation due to heat of friction. Detailed performance assessment was hence carried out only with Teflon roller material with overall weight of 18.5 kg of paddy for this research.

3.7 Procedure for verifying and adjusting gap between rollers and dehulling rice

A vernier caliper was used to gauge the space between the rollers till a maximum amount of whole grains with less damage to the bran layer and minimal broken rice were obtained (approximately 1.78 mm for Ofada, 1.5 mm for Faro varieties) during samples trial running. About 6 kg was used for trial running and determination of moisture content. The speed of the rollers was checked with the aid of phototype tachometer and recorded.

For each variety of parboiled paddy, 500 g samples at each MC level ranging from about 12.00% to 21.99% were fed into the destoner which has a reciprocating motion driven by V- belt and pulley. The destoner was made up of two perforated decks mounted at an angle greater than the repose angle of paddy and operated by a reciprocating motion, thus shaking the paddy downwards, while sieving the stones and other large impurities greater than the parboiled paddy. The paddy flowed into the metering unit, which fed the paddy evenly to the roller unit for dehusking. The dehusking unit consists of two rollers rotating in opposite directions at different speeds. Both rollers have the same diameter, but one roller rotated at about 27% faster than the other. The difference in peripheral speeds subjects the paddy grains falling between the rolls to a shearing action that strips off the husk. One roller was fixed in position and the other was adjustable laterally in order to increase or decrease the clearance between the two rollers. A large amount of air was blown from the fan in the aspirator unit beneath as the mixture of dehusked rice (brown rice), remaining undehusked paddy that has been split off the paddy comes out of the dehuller. The blower has three outlets, the volume of air blows the materials lighter than the dehusked grains through horizontal outlet, the dehusked grains through the 60℃ outlet to the horizontal, while materials like stones that are heavier than dehusked grains dropped through the vertical outlet underneath the blower using terminal velocity speed principle. This mixture is subjected to separation-cum aspiration to separate light weight paddy husk which are discharged through horizontal opening and other impurities from the heavier paddy and rice received at hopper outlet at the lower end. The samples received at the hopper outlet were carried in labeled sealed bags to the laboratory for further analysis of rice quality, where weights of samples and subsamples were taken and recorded in order to evaluate the performance of the machine dehusking and cleaning under test.

3.8 Statistical analysis

Microsoft Excel 2007 was used for the graphs, charts and tables of the experimental data while Minitab 16 was used to run and interpret the two - way ANOVA of two factors (paddy varieties and moisture content levels).

4 Results and discussion

4.1 Dimensions of Paddy

The result of dimensional properties (grain length, breadth and thickness) of the four varieties of dehulled rice under study is shown in Table 2. The findings from this research suggested that due to the lengths and shapes, Faro 35 and 55 varieties were classified as medium grains, Faro 44 was classified as long grain with a slender shape, while Ofada variety had grains classified as short grain with a medium shape based on the standards of IRRI (1996).

From Table 3, Table 4 and Table 5, the moisture content had a significant effect on rice breakage

Table 2 Average dimensions of studied parboiled paddy at 12.00%- 13.99% MC

Variety	Faro 35		Faro 44		Faro 55		Ofada	
Type	Paddy	Dehulled	Paddy	Dehulled	Paddy	Dehulled	Paddy	Dehulled
Length(L) , mm	8.78	6.20	8.90	6.79	8.12	6.31	7.13	5.44
Width(W), mm	2.60	2.19	2.20	2.12	2.35	2.22	3.37	2.38
Thickness, mm	2.22	1.84	1.81	1.43	1.91	1.58	1.89	1.59
L/W ratio	3.34	2.83	4.05	3.20	3.46	2.84	2.12	2.29
Shape		Medium		Slender		Medium		Medium
Length classification		Medium		Long		Medium		Short

Table 3 Effect of prototype Teflon roller dehuller on average brown rice weights at different moisture content

Moisture content (w.b.), %	12.00-13.99				14.00-15.99				16.00-17.99				18.00-19.99				20.00-21.99			
Paddy varieties	F35	F44	F55	Ofada	F35	F44	F55	Ofada	F35	F44	F55	Ofada	F35	F44	F55	Ofada	F35	F44	F55	Ofada
Weight of sample input, kg	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Sub sample weight, g	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Weight of dockage, g	0.15	0.00	0.09	0.12	0.13	0.15	0.10	0.09	0.13	0.30	0.09	0.06	0.01	0.16	0.15	0.00	0.01	0.03	0.18	0.00
Weight of brown rice, g	57.92	24.56	43.59	46.99	57.96	33.19	40.20	46.59	45.06	41.81	37.85	46.20	26.08	29.76	33.74	39.89	25.50	17.72	30.66	30.48
Weight of whole brown rice, g	31.16	16,11	33.01	39.71	34.86	18.37	28.33	36.36	38.10	20.64	23.79	33.02	17.49	13.59	18.61	23.98	16.59	6.55	13.58	16.00
Weight of broken brown rice, g	26.76	8.45	10.58	7.28	17.10	14.81	11.87	10.23	6.96	21.17	14.06	13.18	8.59	16.17	15.12	15.91	8.91	11.17	17.09	14.48
Weight of unhulled paddy, g	36.69	70.18	43.26	44.86	38.17	57.91	47.27	43.98	40.85	45.64	52.82	43.10	61.50	57.60	52.67	48.00	60.97	69.56	54.06	57.12
Operating time, min.	2.41	2.05	2.42	2.02	2.30	2.10	2.46	1.74	2.32	2.16	2.49	1.47	2.02	2.00	2.51	2.19	2.01	1.85	2.53	2.20
Weight of sample at outlet, kg	0.465	0.472	0.454	0497	0456	0.470	0.469	0.461	0.482	0.468	0.481	0.454	0.449	0467	0461	0.444	0.449	0.466	0.438	0.431

Note: Where F35= Faro 35, F44= Faro 44 and F55= Faro 55

Table 4 Prototype dehuller effect on milling efficiency of rice varieties

Moisture content (w.b.), %	12.00–13.99				14.00–15.99				16.00–17.99				18.00–19.99				20.00–21.99			
Paddy varieties	F35	F44	F55	Ofada	F35	F44	F55	Ofada	F35	F44	F55	Ofada	F35	F44	F55	Ofada	F35	F44	F55	Ofada
Dockage, %	15.00	0,00	9.00	12.00	13.00	15.00	10.17	9.00	13.00	30.00	9.00	6.00	1.00	16.33	14.67	0.33	1.0	2.67	18.00	0.33
Broken Rice, %	46.21	34.42	24.26	15.49	32.91	44.64	29.52	21.96	15.44	50.64	37.15	28.53	32.93	54.33	44.83	39.88	34.95	63.05	55.72	47.51
Head Rice, %	53.79	66.58	75.74	84.51	67.09	55.36	70.48	78.04	84.56	49.36	62.85	71.47	67.07	45.67	55.17	60.12	65.05	36.95	44.28	52.49
Dehulling Recovery, %	61.22	25.92	50.19	51.16	57.65	36.43	45.96	51.44	52.45	47.81	41.74	51.73	29.78	34.07	39.04	45.39	29.49	20.30	36.19	34.79

Table 5 Performance parameters of the dehuller on paddy varieties

Moisture content (w.b.), %	12.00–13.99				14.00–15.99				16.00–17.99				18.00–19.99				20.00–21.99			
Paddy varieties	F35	F44	F55	Ofada	F35	F44	F55	Ofada	F35	F44	F55	Ofada	F35	F44	F55	Ofada	F35	F44	F55	Ofada
Operating Time, min	2.41	2.05	2.42	2.02	2.30	2.10	2.46	1.74	2.32	2.16	2.49	1.47	2.02	2.00	2.51	2.19	2.01	1.85	2.53	2.20
Coefficient of Dehulling	0.63	0.30	0.57	0.55	0.62	0.42	0.53	0.56	0.59	0.54	0.47	0.57	0.39	0.42	0.47	0.52	0.39	0.30	0.46	0.43
Coefficient of Wholeness	0.54	0.67	0.75	0.84	0.70	0.58	0.70	0.78	0.85	0.50	0.63	0.72	0.67	0.44	0.54	0.60	0.65	0.38	0.44	0.53
Dehulling Efficiency, %	34.14	19.99	42.69	46.56	43.05	24.61	36.80	43.70	50.54	27.14	29.65	40.73	25.83	18.59	25.73	31.33	25.45	11.49	20.39	22.58
Dehulling Recovery, %	61.22	25.92	50.19	51.16	57.65	36.43	45.96	51.44	52.45	47.81	41.74	51.73	29.78	34.07	39.04	45.39	29.49	20.30	36.19	34.79
Cleaning Efficiency, %	94.60	94.73	86.84	91.85	90.12	91.08	87.46	90.57	85.90	87.44	90.66	89.28	87.56	87.35	86.40	87.88	86.45	87.26	84.72	87.59
Output Capacity, kg/h	11.58	13.84	11.25	14.77	11.92	13.42	11.45	15.87	12.46	13.02	11.60	18.53	13.37	14.01	11.01	12.15	13.39	15.17	10.38	11.77
Hulling Capacity, kg/h	7.33	4.13	6.38	8.15	7.36	5.65	6.04	8.89	7.37	7.08	5.47	10.56	5.15	5.94	5.21	6.32	5.23	4.62	4.77	5.05
Capacity Utilization, %	93.05	94.36	90.72	99.46	91.22	93.94	93.72	92.17	96.34	93.52	96.10	90.88	89.81	93.40	92.15	88.71	89.81	93.40	92.15	88.71

because the optimum MC for Faro 35 was at 16.00%-17.99% MC range, rice breakage for Faro 35 decreased with the increasing of paddy moisture content from 12.00%-13.99% till it reached a level of 16.0%-17.99% MC range, after which its breakage increased (Table 4). The range of 12.00%-13.99% MC was the optimum moisture content for paddy varieties at the time of dehulling, because majorly, the lowest rice breakage occurred at this range for Faro 44, Faro 55 and Ofada.

The maximum cleaning efficiency (which is related to dockage) was about 94% while the minimum was 84% (Table 5). At the husk outlet, negligible amount of whole grains, broken rice, and unhulled paddy were blown away with the chaff.

As is shown in Figure4, rice breakage for Faro 35 was least at 16.00%-17.99% MC with maximum breakage at 12.00%-13.99% MC, minimum was at the 12.00%-13.99% MC for Faro 44, 55 and Ofada with maximum breakage at 20.00%-21.99% MC. The range of 12.00% to 13.99% was the optimum moisture content for three paddy varieties because the lowest rice breakage occurred at this range except for Faro 35 (at an average of 1.5 mm roller clearance spacing). It was due to the level of MC in some grains which gave some kind of resistance to breakage as reported by Dilday (1987) that rice breakage during the milling process decreased with the increasing paddy moisture content in the range of 12% to 16% MC as observed in Faro 35 and probably because it is thicker compared to the other varieties used. Also Ofada had less breakage at the chosen roller spacing, thus agreeing with Matthews et al. (1970) who reported that rice breakage was mostly due to mechanical stresses rather than thermal stresses, thus less roller spacing would yield more breakage and in turn less head rice.

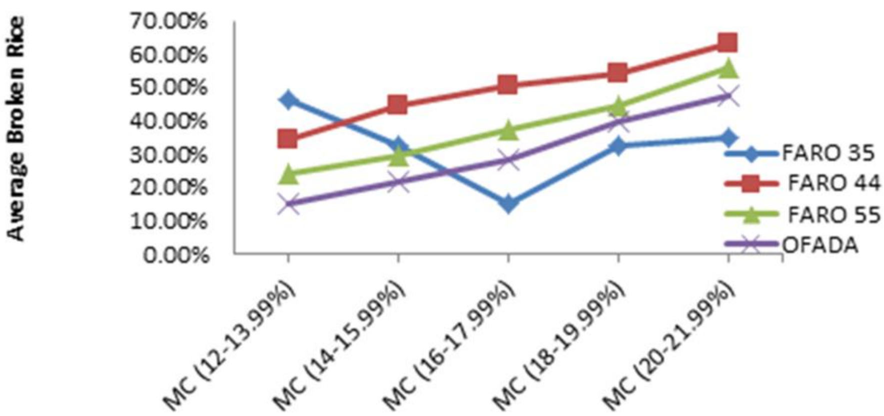

Figure 4 Effect of moisture content on rice breakage

The highest percentage of whole rice, in increasing order, at a single pass, and at point of maximum yield of whole grains was obtained at 12.00%- 13.99% MC for Faro 44, Faro 55 and Ofada and their least percentages of whole rice was obtained at 20.00%- 21.99% MC. Thus for these three varieties the shortest grain (Ofada) had the most whole grain while the longest (Faro 44) had the least whole grain (Table 5). This may be due to the fact that long grains are more susceptible to breakage during milling (Goodman and Rao, 1985). The highest percentage of whole rice for dehuller was observed for Faro 35 at 16.00%-17.99% MC. Dilday (1987) reported that rice breakage during the milling process decreased with the increasing paddy moisture content in the range of 12% to 16% as observed in Faro 35.

Maximum coefficient of wholeness for Ofada, Faro 55 and 44 was observed at 12.00%-13.99% MC (Table 5). The maximum coefficient of wholeness of the dehuller was observed in Faro 35 at 16.00%-17.99% MC; Faro 35 had the most paddy thickness (Table 2). The coefficient of wholeness observed in Faro 35 at moisture range of 16.00%-17.99% could be as a result of increased moisture reinforcing its resistance. This agrees with Dilday’s (1987) report that rice breakage during the milling process decreased with the increasing paddy moisture content in the range of 12% to 16%.

The coefficient of dehulling for Faro 35 decreased as MC increased. For the other paddy varieties, the coefficient of dehulling significantly increased and then decreased after reaching 16.00%-17.99% MC. Maximum coefficient of dehulling for Faro 44 was observed at 16.00%-17.99% MC (Table 5). It was likely that an increase in MC led to an increase in paddy width such that there was greater friction for dehulling. An increase in MC after 16.00%-17.99% MC, and higher cohesion of the hull to the brown rice for all varieties, resulting in the adhesion of the paddy grains to the rollers was due to increased moisture content. This result agrees with that reported by Firouzi et al. (2010) under field conditions and Payman et al. (2007) under laboratory conditions. Also, at 12.00%-13.99% MC and 1.5 mm roller clearance for all Faro varieties, Faro 44 had the least coefficient of dehulling, this was significant and may be due to its paddy grains having the least width for unhulled rice (Table 2).

The minimum dehulling efficiency (DE) occurred for all paddy varieties at 20.00% to 21.99% MC (Table 5). This may be due to excessive moisture resulting in increased width and stickiness since the dehuller DE is a function of the coefficient of hulling and coefficient of wholeness.

At the least MC level (12.00%-13.99%), Ofada had the highest DE, followed by Faro 55, Faro 35, and then Faro 44 in that order. While longer grains have the least DE as seen in their physical properties (paddy width), short grains and medium grains have optimum DE at the least MC range (12.00%- 13.99% MC). The dehuller DE was least for Faro 44 which had the least width and thickness (Table 4); thus for the same gap of 1.50 mm for all Faro varieties, Faro 44 had lots of undehulled grain, thereby reducing huller efficiency. This agrees with Reichert et al. (1979) that dehulling efficiency is affected by moisture content and machine parameters.

There was an increase in overall dehulling capacity for all paddy varieties as MC increased and then the dehulling capacity decreased after reaching 16.00%-17.99% MC level (Figure5). The dehuller least hulling capacity was at 20.00%-21.99% MC for all varieties because at high MC, the husks were soft and the paddy difficult to dehull, hence the rate of dehulling/discharge was reduced; but at lower moisture content, the paddy was less sticky and was able to flow much more freely. This agrees with Audu et al. (2004). Overall, dehuller capacity was observed at 16.00%-17.99% MC range. The varying results were due to the timing of the rate of output as agreed by Musa et al. (2011), which was highly affected by vibration as well as coefficient of dehulling of paddy.

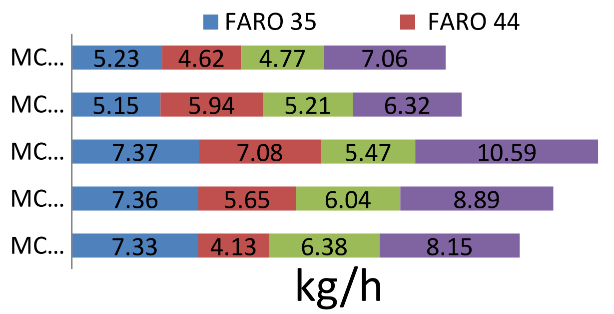

Figure 5 Effect of moisture content on dehuller hulling capacity

Table 5 shows that Faro 55 and Ofada had maximum output capacity of 11.65 and 18.53 kg/h respectively at MC 16.00%-17.99%, while Faro 35 and 44 had maximum output capacity of 13.39 and 15.17 kg/h respectively at 20.00%-21.99% MC. The varying results seen in output capacity agrees with Hunt (1977) that throughput is not always a constant base for comparison, as it varies with crop moisture conditions, and thus throughput ratings should be accompanied by a material moisture report. Since output capacity is a function of dehuller output as well as the time required to give a yield of such output, if the operation is not properly timed, it could reduce or increase the machine capacity. This result agreed with that reported by Musa et al. (2011). Maximum overall average output capacity was observed at 16.00%-17.99% MC range (Figure 5).

The parameters that are critical to the operation of the Teflon roller dehuller are shown in Table 6 at rollers and blower speeds and roller gap setting. The speed of the rollers implied that the adjustable roller was at a speed of about 27% less than the fixed one. Firouzi et al. (2010) reported that the adjustable roller normally runs at about 30% slower than the fixed one to create shearing effect. As reported in PAES 215 (2004), the adjustable roller normally runs at about 25% slower than the fixed one; thus 27% slow speed of adjustable roller of the prototype dehuller was within the range of the average speed suggested in past studies. Furthermore, Ofada had less breakage at 1.78 mm gap between roller than at 1.50 mm gap, thus agreeing with Matthews et al. (1970) who reported that rice breakage was mostly due to mechanical stresses rather than thermal stresses, thus the least dimension for Ofada (1.58 mm) which is greater than 1.50 mm roller gap would yield more breakage and in turn less head rice.

Table 6 s Critical operating parameters of the prototype dehuller

Performance parameters	Maximum values
Coefficient of dehulling	0.63
Coefficient of wholeness	0.85
Dehulling efficiency,%	50.54
Dehulling Recovery,%	61.22
Cleaning Efficiency,%	94.73
Input capacity, kg/h	20.41
Output capacity, kg/h	18.53
Hulling capacity, kg/h	10.56
Capacity Utilization(CU), %	99.46

At 5% level of significance (α=0.05), the coefficient of probability and F value of MC and Test Paddy (TP) are shown in Table 7. The results of the ANOVA show that the effect of both the MC and test paddy on rice

Table 7 Analysis of variance

Factors	Source	F-value	P-value
Coefficient of dehulling	MC	2.96	0.065
	TP	3.46	0.051
Coefficient of wholeness	MC	3.64	0.036*
	TP	3.91	0.037*
Dehulling efficiency	MC	9.05	0.001*
	TP	10.41	0.001*
Dehullingrecovery	MC	4.83	0.015*
	TP	3.76	0.041*
Cleaning efficiency	MC	4.55	0.018*
	TP	1.40	0.289
Output capacity	MC	0.30	0.875
	TP	4.77	0.021*
Dehulling capacity	MC	4.41	0.020*
	TP	5.43	0.014*
Capacity utilization	MC	1.30	0.326
	TP	0.81	0.514
Broken rice	MC	3.37	0.045*
	TP	4.05	0.033*

Note: *significant at $p \leq 0.05$

breakage, dehulling recovery, coefficient of wholeness, hulling efficiency, and hulling capacity were significant, thus, H_O was rejected and H_A was accepted. Also, the effect of both the MC and test paddy on coefficient of hulling and capacity utilization were not significant, so, Ho was accepted and H_A was rejected. Furthermore, MC had no significant effect on operating time and output capacity (accept H_O, reject H_A), but only the effect of test paddy was significant on both operating time and output capacity, thus, H_O was rejected and H_A was accepted. On the contrary, only MC effect was significant on cleaning efficiency (reject H_O, accept H_A), while paddy effect was not significant (accept H_O, reject H_A).

5 Conclusions

The results suggested that the machine was efficient since it was able to produce good rice quality for various varieties and moisture content. The machine adjustments, for example, spacing of the roller as well as the operator ease of handling was also determinant of good dehuller performance. These results show that the effect of moisture content and test paddy on coefficient of wholeness and dehusking efficiency were significant at $p \leqslant 0.05$, while only moisture content effect was significant on cleaning efficiency. It was therefore concluded that the Teflon roller material dehusking efficiency was 50.54% effective with good machinery settings/adjustments. Areas of further research findings aimed at improving the operation of the prototype dehuller most especially, prototype dehulling efficiency and machine settings for various grain varieties, ultimately leading to an improvement of its performance should be investigated.

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