ISSN: 2716-9227 Algerian Journal of Engineering and Technology 07 (2022) 019–026 e-ISSN: 2716-9278

Algerian Journal of Engineering and Technology

Journal homepage: https://jetjournal.org/index.php/ajet

Original Article

Evaluation of rice milling quality and energy requirement via a developed vibratory rice grader

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ARTICLE INFO

Article history:
Received 28 May 2022
Revised 28 September 2022
Accepted 29 September 2022

Keywords:
Energy intensity;
Energy requirement;
Milling quality;
Grader;
Rice.

ABSTRACT

In one of the approaches used in processing rice, rice is usually parboiled before milling operation and grading is one of the milling operations required to classify rice into different grades of importance viz. the head and broken rice. In this study, a vibratory rice grader was developed. The effect of processing conditions on the milling quality (milling recovery, head milled rice and broken rice), grading time, energy requirement and energy intensity were evaluated. Taguchi experimental design ($L_9 3^3$) was used to interact the soaking time (4 – 6 h), steaming time (30 – 40 mins) and rice variety (FARO 15, FARO 60 and FARO 62). Standard equations were used to evaluate the effect of processing conditions on the milling quality, energy requirement and energy intensity. Milling recovery ranged from 53% to 70%, head milled rice (41% - 67%), broken milled rice (3% - 12%), grading time (4.4 – 5.8 mins), energy requirement (2.632 MJ to 2.649 MJ) and energy intensity (1.20 – 1.58 MJ/kg). An increase in soaking time and steaming time increased the grading time, milling recovery, head milled rice, energy requirement and energy intensity but reduced the broken milled rice. The estimated cost of the developed vibratory rice grader was $151. This study provides valuable information on a simple way of designing and developing a rice grader that could be adopted for grading rice into whole rice or head rice and broken rice.

1. Introduction

Rice is the most significant cereal crop globally, feeding more than half of the world's population [1]. In many underdeveloped and developing nations, it is the most commercially important food crop, and it has also become an essential crop in many industrialized countries where consumption has expanded dramatically [2]. Rice production and consumption in Nigeria are crucial for the government's goal to alleviate food scarcity and increase food self-sufficiency for domestic consumption and export trade [3, 4]. To achieve savings to eat rice, it must be processed via two major processes: parboiling and milling after unwanted materials must have been separated from paddy rice. Parboiling is a process that involves thermal treatment of paddy rice via soaking, steaming, and drying to modify the milling quality of rice. Soaking is a process of hydrating paddy rice by allowing hot water migration into it to about 30%, which causes its starch molecules to fuse and swell irreversibly [5]. Steaming is a heat treatment process that causes gelatinization of starch molecules in soaked paddy rice by using hot steam, while drying

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Peer review under responsibility of University of El Oued.

involves using hot air to reduce the moisture content to a suitable level required for milling [6, 7]. Soaking is a processing condition that depends on temperature and time. Hence, increasing soaking temperature might requires a decrease in soaking duration [8]. Different kinds of literature have been reported on the effect of rice parboiling processes on rice quality. Bhattacharya [9] stated that permutations of temperature and time for parboiling have a great impact on determining the attributes of parboiled rice. Elbert *et al.* [10] studied the effects of steaming on the milling attributes of some *indica* rice varieties. Ayamdoo *et al.* [11] reviewed the effects of different parboiling conditions on the physical qualities of some popular rice varieties in Ghana. According to Sanusi et al. [12], some of the fundamental indicators used to assess milling quality are milling recovery and head milled rice. Genotypic variations among rice cultivars, environmental conditions during rice cultivation, milling machinery and milling procedures can also affect milling quality [13].

Grading is one of the milling operations that aids in separating milled rice according to head milled rice and broken milled rice. Several studies have been done related to the development and use of rice graders. For instance, Chathurika and Upul [14] used neural networks to study rice grain classification. Piramlin *et al.* [15] used the Moore-Neighbor Tracing method to investigate rice grain grading categorization based on the perimeter. Okunola *et al.* [16] also designed and developed an industrial grader while Yayock and Ishaya [17] developed a grain grading machine that graded grains into different sizes. Energy plays an important role in the total cost of production of any product. Therefore, it is necessary to analyze energy requirement and intensity while grading milled rice to head milled rice and broken milled rice in the milling industry. Roy *et al.* [18] stated some factors that determine the energy required for milling are; rice type, rice hardness, process, and equipment used. Despite the tremendous work of these researchers, literature is sparse on the development of a vibratory rice grader. Furthermore, studies on the effects of soaking time, steaming time and rice variety type on milling quality, grading time, energy requirement and energy intensity have not been extensively studied. Therefore, this study aimed to develop a vibratory rice grader and analyze the energy required and energy intensity. The specific objectives were to design and construct a vibratory rice grader, evaluate the milling quality of rice varieties (FARO 15, FARO 60 and FARO 62), grading time, energy requirement and energy intensity.

2. Materials and Methods

2.1 Construction Location

The design and fabrication of the vibratory rice grader was carried out at the Engineering Central Workshop, University of Ilorin. Three rice varieties FARO 15 (short grain), FARO 60 (medium grain) and FARO 62 (long grain), were obtained from the National Cereals Research Institute (NCRI) Badeggi, Niger State, Nigeria. The performance evaluation was carried out at the Department of Food Engineering Pilot Plant II, University of Ilorin, Nigeria.

2.2 Materials Selection Consideration

The materials used for the fabrication of the rice grader were carefully selected based on firmness, rigidity, availability and non-corrosive nature. Food grade materials were selected for direct contact with the rice due to their inertness with food-based products.

2.3 Description of Vibratory Rice Grader

Figure 1 shows the developed vibratory rice grader's exploded view and pictorial view (bi and bii). The vibratory rice grader consists of a hopper, mainframe and sieve support frame, three sieves of different mesh sizes, electric motor vibrator, four vibrating spring support, control box and electric cable. The mainframe and sieve support frame, hopper, sieves, and vibrating spring were made with mild steel, galvanized steel, and stainless steel. The hopper serves as a feeding chute through which the milled rice is fed. The mainframe is the body that holds the entire components of the grader, while the sieve support frame holds the sieves during the vibration that aid the grading process. An electric motor was placed at the base of the sieve support frame to agitate the sieves, causing a vibratory motion. The electric motor aid the vibration of the four vibrating springs attached to the base of the sieve support. This vibration makes the sieves agitate, which separates whole rice or head rice from broken rice. The electric cable is connected to an electric source to allow the passage of current to the rice grader. The control box controls the flow of current to the rice grader by opening and closing the circuit. Once the grader is switched on from the control box, current flows to the electric motor, which initiates the sieve frame's agitation and brings about the vibration of the sieves. The sieve's frame vibrates in a periodic motion, allowing the separation of broken rice from whole rice. The mesh size is in proportion to the size of rice it holds during the grading operation.

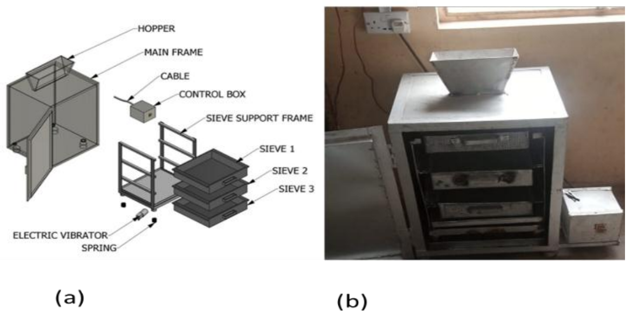

Fig. 1. Exploded view and pictorial view of the developed vibratory rice grader

2.4 Design and Calculation

The general design of the vibratory rice grader machine was based on separating head rice from broken rice. The sieve mechanism of different mesh sizes was adopted to efficiently separate the milled rice into different grades; first head rice, second head rice and broken rice. The assumed sieve mesh sizes used in the grading system are 3.0 mm, 2.5 mm, and 2.0 mm diameter for the first head, second head, and broken rice. Figure 2 shows the rice grader's orthographic top view, front view, and side view.

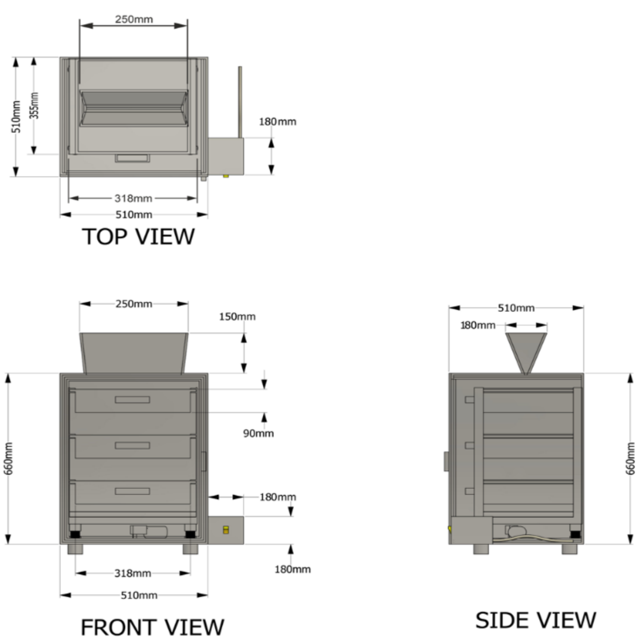

Fig. 2. Orthographic top view, front view and side view of the rice grader

Determination of hopper capacity

The volume (V) of the hopper was calculated using Equation 1 [19]

$$V = \frac{H}{3}(A + \sqrt{AB} + B) \quad (1)$$

where V is the volume of the hopper, A and B are the areas of the upper face and the area of the lower face respectively. H is the height between the top face and bottom face. The area of the upper face (A) and the area of the lower face (B) was calculated using Equations 2 and 3 as described by Bird [19].

$$A = L \times W \quad (2)$$

$$B = l \times b \quad (3)$$

where L is the length of the upper face (250 mm), W is the breadth of the upper face (180 mm), l is the length of the lower face (165 mm), b is the breadth of the lower face (13 mm). Therefore, A is equivalent to 45,000 mm^2 and B is 2145 mm^2.

Substituting Equations 2 and 3 in Equation 1, the volume of the hopper (V) was estimated to be 2848485.69 mm^3

Hence, the capacity of the hopper was determined using Equation 4 as described by Young *et al.* [20].

$$\rho = \frac{m}{v} \quad (4)$$

where ρ is the assumed density of polished rice is 1430 $kgmm^{-3}$ [21], v is volume of the hopper 2848485.69 mm^3 and m is the mass of rice it can hold. From Equation 4, the mass of the rice the hopper can hold was estimated to be 40130.3 g. Hence, the approximated value of the hopper capacity 4 kg

Determination of sieve capacity

The volume of the sieve was determined using Equation 5 [19]

$$V = l_s \times b_s \times h_s \quad (5)$$

where is V is the volume of the sieve, l_s is the length of the sieve (355 mm), b_s is the breadth (318 mm) of the sieve, h_s is the height of the sieve (90 mm). Hence, the volume was estimated to be 1.01601 x $10^7 mm^3$. Using Equation 4, the mass of rice the sieve can hold was estimated to be 14732.2 g. Therefore, the capacity of the sieve was approximately 14.7 kg.

The electric motor

The required power (P) of the electric motor was calculated using Equation 6 as described by Young *et al.* [20].

$$P = F \times v \quad (6)$$

where F is the force required by the grader and v is the velocity of the grader. The force was calculated using Equation 7 and Equation 8 was used to calculate the total mass

$$F = m_t \times g \quad (7)$$

$$m_t = m_{mr} + m_{sg} + m_s \quad (8)$$

where m_{mr} is the mass of the milled rice for one sieve (14.7 kg), m_{sg} is the mass of the sieve frame (5 kg), m_s is the total mass of the sieve (4.5 kg), m_t is the total mass and g is the acceleration due to gravity (9.91 m/s^2). Therefore, the force required is 237.402 N and the total mass is 24.2 kg.

The velocity of the grader was calculated using Equation 9 [20].

$$v = \sqrt{2gh} \quad (9)$$

where h is the height of the grading chamber (660 mm ≡ 0.66 m). Therefore, the velocity of the grader is 3.60 m/s. Therefore, by substituting Equations 9 and 7 in Equation 6, the power is estimated to be 1.12 hp. Hence, a 1.2 hp electric motor was selected. Table 1 shows the bill of engineering measurement and evaluation of the rice grader

2.5 Performance Evaluation

Three rice varieties FARO 15, FARO 60 and FARO 62 were cleaned to remove stone and debris. The rice varieties were processed to milled rice under different soaking and steaming time. Taguchi experimental design $L_9 3^3$ was used to interact the rice variety, soaking time and steaming time as shown in Table 2.

Table 1. Bill of Engineering Measurement and Evaluation (BEME) of the rice grader

S/N	Material Description for the rice grader	Material Specification	Qty	Cost ($)
1	Stainless steel Sieves	2 mm mesh size 2.5 mm mesh 3 mm mesh size		43
2	Angle Iron	2’’	1	12
3	Mild Steel Plate	2mm thickness	2 sheets	29
4	Spring for vibrator		4	12
5	Mild Steel Shaft	Ø20		7
6	Vibro-rotator motor	1.2 *hp*	2	36
7	Electric Cable	Flexible		5
8	Paint	Ash Colour		7
		Total		151

Table 2. Interaction of rice variety, steaming time and soaking time using Taguchi design

Process Factors	Unit	Level 1	Level 2	Level 3
Rice variety		1	2	3
Steaming Time	h	4	5	6
Soaking Time	mins	30	35	40

where 1, 2 and 3 under rice variety are FARO 15, FARO 60 and FARO 62

The soaking of the rice varieties was done for 4 h, 5 h and 6 h at water temperature of 80°C, while paddy rice was steamed for 30 mins, 35 mins and 40 mins at 100°C steaming temperature in a fabricated dual-powered rice parboiler. The paddy rice was dried in an oscillatory rice dryer at 40°C to 14% paddy moisture content. To obtain milled rice, the dried paddy rice was milled in a rice miller (Model MLNJ-15-13, India). The mass of milled rice was determined using a digital weighing scale (Model: Camery, China) and was fed into the developed rice grader from the hopper and allowed to be graded. The time taken for grading each rice sample into head rice and the broken rice based on the experimental design was recorded. The milling recovery, head milled rice and broken milled rice of each sample were estimated using Equations 10, 11 and 12 as described by Sanusi *et al.* [12].

$$MR = \frac{MMR}{MP} \times 100 \quad (10)$$

where MR is the milling recovery, MMR is mass of milled rice and MP is the mass of paddy rice

$$HMR = \frac{MHR}{MP} \times 100 \quad (11)$$

where HMR is the head milled rice, MHR is mass of head milled rice and MP is the mass of paddy rice

$$BMR = \frac{MBR}{MP} \times 100 \quad (12)$$

where BMR is the broken milled rice, MBR is mass of broken milled rice and MP is the mass of paddy rice.

2.6 Energy requirement

The energy required and energy intensity during the grading of each rice sample was determined using Equation 13 and 14. Similar approach was reported by Sanusi and Akinoso [7].

$$E_g = [0.75N\,x\,0.0167(t)] + [3.6\,x\,P\,x\,\emptyset\,] \quad (13)$$

$$E_I = \frac{E_g}{MMR} \quad (14)$$

where N is the number of operators, t is the time of grading, p is the power rating of the electric motor (0.895 kw), $\emptyset$ is the power factor (0.8) of the motor with a conversion value of 3.6 into MJ, E_g is the energy requirement in grading, E_I is the energy intensity and MMR is the mass of the milled rice.

3. Results and Discussion

3.1 Grading time

The time required for grading milled rice is an important parameter that helps to deduce the period required to separate recovered milled rice into the head or broken rice using a rice grader. Figure 3 shows the effect of processing conditions on the grading time of milled rice. The grading time for FARO 15 ranged from 4.4 mins to 5.8 mins, FARO 60 (4.5 mins to 5.4 mins) and FARO 62 (4.5 mins to 5.4 mins). The highest grading time (5.8 mins) was observed in FARO 15 at 6 h soaking time and 40 mins steaming time, while the lowest grading time (4.4 mins) was observed in FARO 15 at 4 h soaking time and 30 mins steaming time. The difference in the soaking time and steaming time of the rice varieties was observed to be responsible for variation in the grading time of the rice varieties. Proper soaking time and steaming time usually lead to adequate starch gelatinization and thus allow the cementing of the fissures, resulting in high milling recovery. Therefore, the difference in the grading time could also be attributed to the variation in the mass of recovered rice. The greater the mass of the recovered rice, the longer the grading time.

3.2 Effect of Processing Conditions on Milling Recovery

Figure 4 shows the effect of processing conditions on the milling recovery. The milling recovery observed in FARO 15 ranged from 53% to 70%, FARO 60 (55% to 66%) and FARO 62 (55% to 66%). Both the lowest and the highest milling recovery were observed in FARO 15. Processing conditions of 4 h soaking time and 30 mins steaming time resulted in the lowest milling recovery (53%) while processing conditions of 6 h soaking time and 40 mins steaming resulted in the highest milling recovery (70%). The variation in the milling recovery of the nine rice samples could be attributed to the difference in the soaking time and steaming time. It could be deduced that processing conditions had a significant effect on the milling recovery. Sanusi and Akinoso [7] reported an increase in brown rice recovery of FARO 44 as soaking and steaming time were increased. Bello *et al.* [22] reported that processing conditions affect milling yield, while Nasirahmadi *et al.* [23] reported a similar increase in the milling recovery as steaming time was increased during parboiling of two rice cultivars.

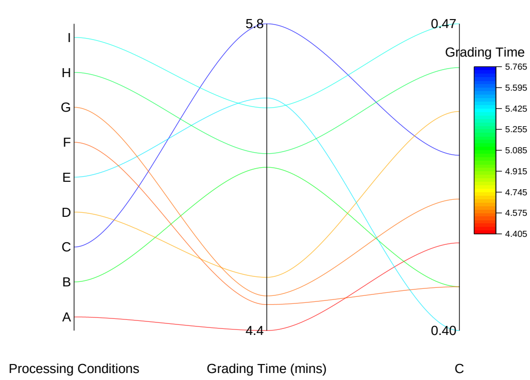

Fig 3. Effect of processing conditions on grading time

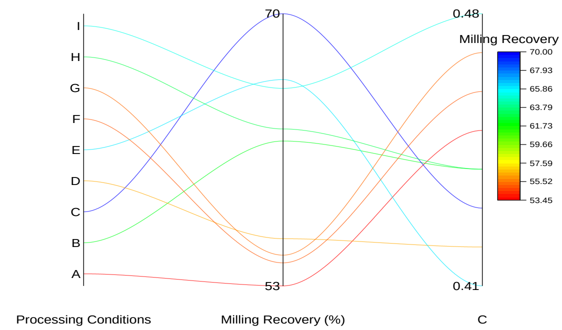

Fig 4. Effect of processing conditions on milling recovery

Note: A (FARO 15, 4 h Soaking time, 30 mins Steaming time), B (FARO 15, 5 h Soaking time, 35 mins Steaming time), C (FARO 15, 6 h Soaking time, 40 mins Steaming time), D (FARO 60, 4 h Soaking time, 35 mins Steaming time), E (FARO 60, 5 h Soaking time, 40 mins Steaming time), F (FARO 60, 6 h Soaking time, 30 mins Steaming time), H (FARO 62, 4 h Soaking time, 40 mins Steaming time), H (FARO 62, 5 h Soaking time, 30 mins Steaming time) and I (FARO 62, 6 h Soaking time, 35 mins Steaming time).

3.3 Effect of Processing Conditions on Head Milled rice

Head milled rice is an important parameter in rice processing that contributes to the determination of milling quality. Figure 5 shows the effect of processing conditions on the head milled rice. The head milled rice obtained ranged from 41% to 67%. In FARO 15, it ranged from 41% to 67%, FARO 60 (51% to 63%) and 51% to 62% in FARO 62. Soaking for 4 h and steaming time for 30 mins yielded the lowest head milled rice (41%). Contrarily, soaking paddy rice for 6 h and steaming for 40 mins yielded the highest head milled rice. Like the milling recovery, there were variations in the head milled rice, and the highest and lowest head milled rice was obtained in FARO 15. There was variation in the head milled rice as the samples were processed under different conditions. The increase in the head rice yield caused by increasing the soaking time and steaming time could be attributed to the soaking effect, which caused expansion in the paddy rice and subsequent gelatinization through steaming. These combined effects made the parboiled paddy rice compact and partially pulled out of the husk after drying. Increasing the soaking time and steaming time of FARO 15 caused a progressive increase in the head rice yield. However, suppose the periods for conditioning are greater. In that case, it is possible to affect the head milled rice, thereby causing reduction due to the fusion of the paddy rice absorbing much moisture. Sanusi and Akinoso [4] reported that an increase in soaking and steaming time for FARO 60 resulted in higher head milled rice. Danbaba *et al.* [24] reported an increase in head milled rice when the steaming time was increased and attributed the increase to the gelatinization of starch in rice to form a strong structure. Parnsakhorn and Noomhorm [25] also reported a similar increase in head milled rice due to increased processing conditions (soaking and steaming). Based on this study, it was observed that head milled rice varied inversely with broken milled rice. Hence, a decrease in broken rice increases the head milled rice [26].

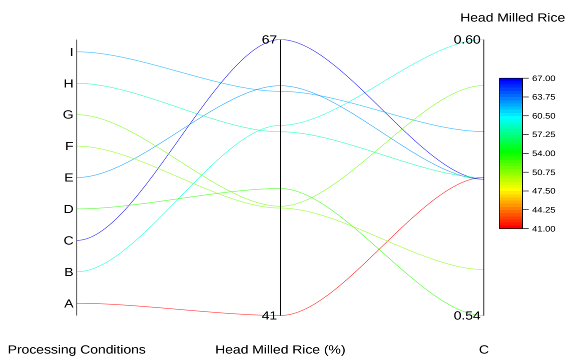

Fig 5. Effect of processing conditions on head milled rice

3.4 Effect of Processing Conditions on Broken Milled Rice

Broken milled rice is an essential factor that signifies milling loss. It might be caused by several factors such as rice type, fissure in rice and moisture content of paddy rice before milling [7]. Figure 6 shows the effect of the processing conditions on the broken milled rice. The range of broken milled rice obtained from the rice samples was between 3% and 12%. Processing of paddy rice by conditioning it for 4 h soaking time and 30 mins for steaming time resulted in the broken milled rice (12%). In comparison, conditioning paddy rice for 6 h soaking time and 40 mins for steaming time resulted in the least broken milled rice (3%). The highest and lowest broken milled rice were observed in FARO 15. The result obtained signifies that processing conditions affected the broken milled rice of the rice samples as there was an observable decrease in its value. This decreases in broken milled rice (from 12% to 3%), maybe due to proper gelatinization, which made the paddy rice become hardened and thus, could withstand milling pressure. Chavan *et al.* [6] reported a decrease in the broken rice milled and had a similar reason as obtained in this study. Meresa *et al.* [5] reported that an increase in soaking and steaming time caused a decrease in the broken milled rice after milling. A similar result was also observed in the study reported by Ayamdoo *et al.* [11].

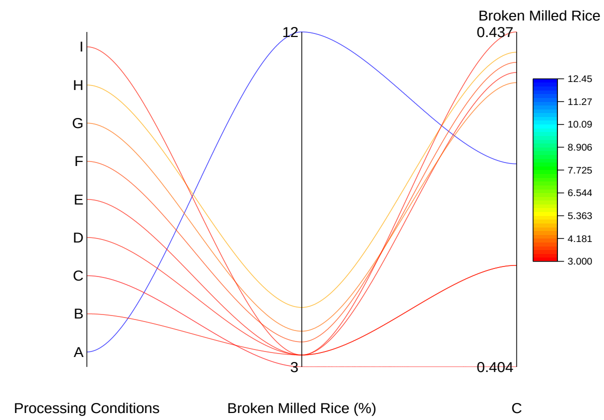

Fig 6. Effect of processing conditions on broken milled rice

3.5 Effect of processing conditions on energy requirement

It is crucial to determine the energy required to execute the grading process in most energy-consuming processes. Figure 7 shows the effect of processing conditions on the energy requirement of the rice samples. It was observed that the energy required for grading the nine rice samples varied from 2.632 MJ to 2.649 MJ. FARO 15 ranged from 2.632 MJ to 2.649 MJ, FARO 60 (2.633 MJ to 2.645 MJ) and 2.634 to 2.644 MJ in FARO 62. Rice that was processed with conditions of 4 h soaking time and 30 mins steaming time had the least energy requirement for grading, while rice that was processed by soaking for 6 h and steaming for 40 mins required the highest energy for grading. The lowest and highest energy requirements were obtained from FARO 15, which were similar to the milling recovery and grading time. However, since the milling recovery and grading time increased due to the processing conditions, energy requirement was also expected to increase, as observed in sample C. Sanusi and Akinoso [7] reported an increase in energy consumption of parboiled paddy rice as the soaking and steaming time were increased.

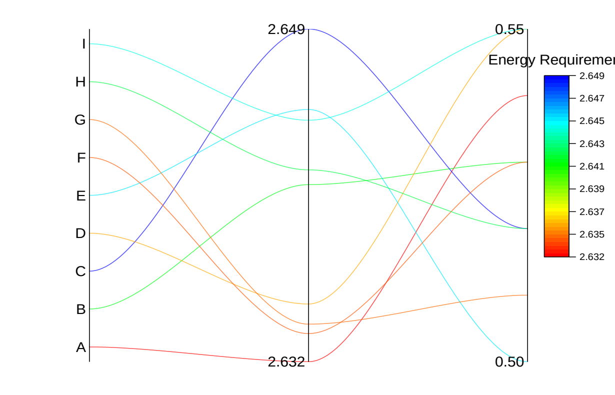

Fig 7. Effect of processing conditions on energy requirement

3.6 Effect of processing conditions on the energy intensity

Figure 8 shows the effect of processing conditions on the energy intensity of the graded rice samples. The energy intensity of the graded rice samples ranged from 1.20 MJ/kg to 1.58 MJ/kg. FARO 15 was observed to have both the lowest and highest energy intensity for grading but at different processing conditions. It was observed that 4 h soaking time for 30 min steaming time gave the lowest energy intensity while 6 h soaking time and 40 mins steaming time gave the highest energy intensity. Since energy intensity is the energy per mass of paddy rice, high milling recovery of rice required high energy, and hence, high energy intensity. Kapur *et al.* [27] reported an increase in energy intensity due to processing conditions.

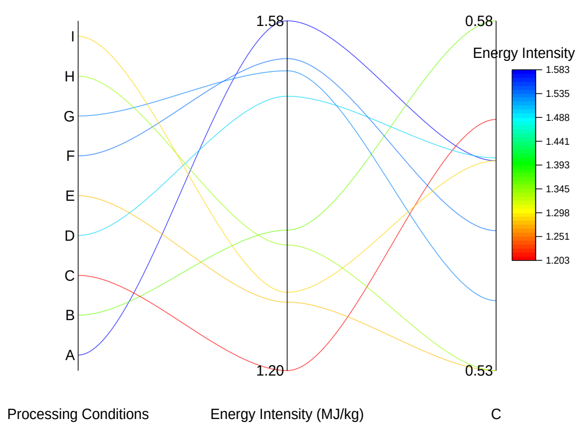

Fig 8. Effect of processing conditions on energy intensity

4. Conclusions

A vibratory rice grader for grading rice into the head and broken rice was developed. The rice grader showed that grading time varies based on the type of rice variety used, soaking time and steaming time. Soaking time and steaming time influence the milling recovery, head milled rice and broken milled rice. Long soaking and steaming time increase the milling recovery and head milled rice but reduce the broken milled rice. The energy requirement and energy intensity required to grade the milled rice under different processing conditions were also differs. An increase in soaking time and steaming time increased the energy requirement and energy intensity. The estimated cost of the developed vibratory rice grader was $151 and could be adopted by rice processors for grading rice that is processed under different conditions.

Conflict of Interest

The authors declare that they have no conflict of interest

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Recommended Citation

Sanusi MS, Sunmonu MO, Hussein JB, Olaleye SA, Adedeji IB, Hamzat GO, Popoola IT. Evaluation of rice milling quality and energy requirement via a developed vibratory rice grader. *Alger. J. Eng. Technol. 2022*;7:19-26.