Journal of Engineering Research and Reports

13(1): 1-11, 2020; Article no.JERR.57403
ISSN: 2582-2926

A Review on Performance of Rice De-stoning Machines

O. A. Adetola[1*] and D. L. Akindahunsi[1]

[1]*Department of Agricultural Engineering, Federal University of Technology Akure, Ondo State, Nigeria.*

Authors' contributions

This work was carried out in collaboration between both authors. Author OAA designed the study, performed the statistical analysis and wrote the protocol. Authors OAA and DLA managed the literature searches, managed the analyses of the study and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2020/v13i117090
Editor(s):
(1) Dr. Djordje Cica, University of Banja Luka, Bosnia and Herzegovina.
Reviewers:
(1) Chanchal Dass, India.
(2) P. D. Sharma, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/57403

Review Article

Received 10 March 2020
Accepted 17 May 2020
Published 29 May 2020

ABSTRACT

The major challenge in Nigerian rice industry is poor processing which allows contaminants such as stone pebbles to be introduced during harvesting and post-harvest handling. Despite the several efforts of various researchers in Nigeria, no commercial rice de-stoning machine is available because the machines have not been optimized and tested for various machine parameters. This review showed the highlights, prospects, performance evaluations, and limitations of some rice de-stoning machines, de-stoning machine modified, and motorized rice de-stoning machine. Their unique advantages and operational parameters, for example, de-stoning efficiency, capacity, and operating speed were assessed. The de-stoning efficiency, capacity, and operating speed ranged from 40.8 - 99.75%, 1.8 – 7500 kg/h, and 200 – 2980 rpm respectively. Mechanization of the de-stoning process will ensure the quality and hygiene of products, thus increasing the commercial value of the final exported or consumed products.

Keywords: De-stoning; efficiency; evaluation; output capacity; rice.

**Corresponding author: Email: oaadetola@futa.edu.ng;*

1. INTRODUCTION

The utmost common cereal crops of the world include wheat, barley, oats, rice, maize, sorghum and millets, but in developing countries, the major cereal crops are rice, maize, sorghum and millets [1]. "Reference [2]" reported that rice production and consumption has been on a significant increase due to its adaptability in various traditional food recipe, bread and alcoholic drinks. Hence, rice is a universal food grown and eaten in all part of the world. The rate of rice consumption differs in countries and continents [3]. Rice, which is primarily grown for human consumption, has been imported into West Africa by more than 40 percent (2.75 million per year) [4]. However, over 90 percent of global rice production, particularly in Asia, comes from tropical and semi-tropical arid climates. An estimated 120 million Nigerians rely on rice as a primary food where it is eaten in various forms throughout the localities and most commonly as boiled grains [5]. Likewise, Nigeria is the major manufacturer of rice in West Africa, with an annual production of 3.2 million tons of paddy rice culminating in approximately 2 million tons of refined rice. In Nigeria, rice consumption has risen to more than 10 per cent per year, triggering shifts in consumer preferences [6]. Nonetheless, development is mostly carried out by small-scale farmers farming on an estimate of 1 to 2 hectares of land whereby production per hectare is comparatively low due to numerous factors including weak production systems, lack of proper training, older farming population, low level of competition between indigenous and imported rice, etc. [7].

The importance of rice as a staple food in Nigeria has risen dramatically in the last four decades. Today rice is made and sold in the streets of all the country's cities and villages and for many families; it's a regular item on the menu. Hence, any research on the improvement of the locally produced rice is not misdirected [8]. Nigeria therefore has huge likely to rise her domestic rice production and marketing with the high hopes of becoming a self-sufficient rice producer as this will equally impact positively on the nation's economy by affecting all the stakeholders and key players (Paddy farmers, rice millers, processors, traders, citizens, transporters, government and exporters). The key problem in the Nigerian rice industry, however, is inadequate processing that allows for the introduction of pollutants such as stone pebbles, sticks and chaff during harvesting and post-harvest processing [5,9].

To avert this development, farmers were trained on how to handle paddy rice right from the field but not accomplished due to the nature of the field where this rice is grown 100% free-stone-rice. The pneumatic winnowers used for cleaning the threshed paddy only could extract light impurities and rough textured sand but do not extract rice-like sand texture. The method of wet cleaning (submersion of rice into water) practiced by some small-scale rice processing industries also separates only light impurities (unfilled or partially field grains) and very dense impurities since separation is accomplished by difference in the basic gravity of paddy and impurities. Nevertheless, impurities which remain and parboiled (in the case of parboiled rice) are of the same size and density as the paddy. Upon milling, these stones escaped with the milled rice making the rice produced locally unacceptable to Nigerians. Nigeria's demand for foreign rice had been due to the prevalence of pollutants once produced locally [5].

Rice de-stoning requires extracting stones combined with milled rice. Agricultural products can be isolated using either one or the combination of the following methods: sampling, fluidization, pneumatics and floatation. Previously there have been work attempts to solve this problem with varying rates of success. The production and adoption of locally produced rice de-stoning machines for farmers' use will enhance the quality of locally produced rice that will go a long way in creating employment for the teaming of young graduates as well as creating wealth for the country.

1.1 Rice Grain Structure and Compositions

Rice grain (rough rice or paddy) comprises of an external hull defensive and rice caryopsis or fruit (brown, container, dehulled or dehusked rice) [10]. Brown rice comprises of the pericarp, seed-coat, and nucellus outer layers; the germ or embryo; and endosperm. The endosperm consisting of the normal aleurone layer and endosperm, which is the subaleurone layer and the starchy or inner endosperm [11].

Embryo is surrounded by the aleurone coat. The pericarp is limited to pigment (Juliano and Bechtel, 1985). The hull (husk) is around 20 per cent of the weight of rough rice, but values vary from 16 per cent to 28 per cent. Brown rice weight distribution is 1 to 2 per cent pericarp, aleurone plus nucellus and seed-coat 4 to 6 per cent, germ 1 per cent, scutellum 2 per cent, and endosperm 90 to 91 per cent [12]. The aleurone layer ranges from one to five layers of cells; on the dorsal side it is thicker than on the ventral side, and in short grain it is thicker than in long grain rice.

The aleurone and embryo cells are abundant in protein bodies, including globoids or phytate bodies, and lipid bodies [13,14]. The endosperm cells are thin-walled and lined with amyloplasty granules comprising starch compounds. The two outermost layers of cells (the subaleurone layer) are rich in protein and lipid and have smaller amyloplasts and starch granules compound than the inner endosperm. The starch granules are polyhedral and have a scale of generally 3 to 9 μm, with unimodal distribution.

Protein exists predominantly in endosperm in the form of spherical protein bodies 0.5 to 4 μm throughout size [15], although crystalline protein bodies and small spherical protein bodies are found throughout the subaleuron layer. Non-waxy rice (containing amylose besides amylopectin) has a translucent endosperm, while waxy rice (0 to 2 percent amylose) has an opaque endosperm due to the presence of pores between and within the starch granules. Thus, waxy grain has the grain weight of non-waxy grain between 95 to 98 per cent.

1.2 Economic Importance of Rice

Rice has shaped the culture, diets and economic of thousands of millions of peoples. For over half of mankind "rice is life" The significance of rice is:

Rice is an important staple food crop for over 60 per cent of people around the world. According to USDA, over 430 million metric tons of rice were eaten worldwide in 2008.

i. Things ready to eat are produced iii, e.g. popped and puffed rice, instant or rice flakes, canned rice and fermented produce.
ii. Rice husk is used as feed for animals, for paper making and as a source of fuel.
iii. Rice bran is used in feed for cattle and poultry, defatted bran, which is high in protein, can be used in biscuit preparation and as feed for cattle.

Rice bran oil is used in soap industry. Refined oil can be used as a cooling medium like cotton seed oil/ corn oil. Rice bran wax, a byproduct of rice bran oil is used in industries [9].

1.3 Techniques for Rice Paddy Processing

1.3.1 Traditional technique for rice paddy processing

Traditional methods of processing rice paddy include soaking the paddy in water for 2 to 3 days to soften the kernel, followed by steaming the soaked paddy for 5-10 minutes and drying in the sun, followed by pounding the dried paddy into a mortar and pestle tool. However, the conventional rice processing technique is simple but repetitive, it has very low performance and results in rice kernel breakages and unfinished husk removal. More so, because the fat in the bran generates rancidity it has a limited storage life [16].

1.3.2 Modern techniques for rice paddy processing

The processing of rice in Nigeria has increased relative to the 1990's. In modern techniques, the rough rice or paddy is first washed to eliminate contaminants, and the husks are then separated by the so-called shellers; these are most usually horizontally spaced rotating abrasive stones, but rubber roll or rubber belt shaped shellers are increasingly being used. Rice and hulls are removed by aspiration, and any remaining paddy with rice is removed in a separator for padding. Nigerian rice's biggest issue is the presence of stone in rice grains, it is discovered. The survey investigated shows that de-stoner was produced locally, made in Nigeria. The drying process is another development of the rice processing in Nigeria. The conventional drying of the sun was replaced by mechanical dryer or improved form of sun drying. This form of dryer can process approximately 3000 kg and in 6hrs remove 50 percent rice moisture. Other dryers have been developed as well as this mechanical dryer which uses diesel or electricity, such as solar dryer for drying rice paddy. This development is the result of an incessant power outage throughout the region. This form of solar dryer is fitted with a ventilator to increase the distribution of hot air over the rice paddy [6].

2. SOME RICE PROCESSING ENGINEERING PROPERTIES

The growing economic value of food materials and the sophistication of modern technology for their manufacturing, handling, storage, preservation, quality evaluation, distribution and marketing and use need detailed knowledge on the physical properties of these materials. Scale, distance, surface area, a thousand grain weights, density, porosity, resting angle, friction coefficient are of prime importance for this reason. These properties affect rice processing design and evaluation namely drying, husking, whitening and polishing, and grading machines, storage and grain moving equipment. For instance, knowledge of the paddy friction coefficient on the wall of the equipment and on the surfaces of the silo wall is necessary and fundamental for a rational and safe design of grain-moving handling equipment, processing and storage [17-20]. To design conveying equipment, knowledge of the friction coefficients of grain is necessary. For example, friction between an unconsolidated material and a conveyor belt affects the maximum angle with the horizontal that can be assumed by the conveyor when conveying the solid. Husking features of paddy depend on its shape and size [21]. Some of the rice's physical characteristics such as grain thickness have a significant influence on the volume expansion ratio of the cooked rice, followed by degree of milling and then the grain's apparent amylase content [22]. Knowledge of the physical properties of paddy grain is important for modeling dynamic abrasion in a rice milling process and for the design of suitable polishing systems in order to obtain better quality-milled rice [23]. Awareness of physical properties such as dimensional characteristics and the determination by image processing techniques of milled rice quality parameters will enable daily monitoring of the milling activity in an objective manner and thus allow the operator to respond quickly to changes in material properties within a few minutes [24].

Frictional and gravitational properties of grain can be used for analysis of the efficiency of harvesting operations. Based on the research conducted by [25], grain bulk density and rest angle are related to separator efficiency, while grain harvesting enhances the separator power, while raising the grain angle of repose has the opposite result. Information pertaining to porosity and basic gravity is known to be of utmost importance for studies involving heat and mass transfer and air movement through the bulk grain among certain physical characteristics of the agricultural products. In addition, along with moisture content, length, specific gravity, and porosity are the basic criteria for studying the drying and storage of agricultural products and for predicting the material's quality loss before its time for marketing [26]. One may describe the real gravity as the ratio between a body's mass and its volume. This definition applied to the individual grain which determines the actual specific gravity of each grain. Once applied to bulk grain this definition defines the bulk density. Porosity is described as the ratio of the volume of the intergranular void space and the volume of the bulk grain. Using an air comparison picnometer, the porosity can be measured by the direct method by calculating the added liquid to satisfy the void space of bulk grain or by the indirect method [18].

Through the years, many scholars emphasized the need for knowledge of certain physical properties. External friction coefficients, such as grains on the wall of the equipment and on the surfaces of the silo wall, are important and fundamental for a fair and secure design of grain-moving equipment, processing and storage. This property plays a significant role in the conduct of silo wall pressure and grain flow. The coefficient of friction is described as the ratio between both the force of friction (force due to motion resistance) and the normal force on the surface of the material used for the wall [17-20]. For biological products, two types of friction coefficients are considered according to Mohsenin [19], the static coefficient determined by the force capable of initiating the movement and the dynamic coefficient determined by the force required to sustain the movement of the grains in contact with the surface of the wall depending on the form and existence of the material in contact.

The system that calculates the shear stress is allocated for the calculation of the physical properties and the flow of the stored products [27], where the actual static and dynamic friction coefficients are within those properties. "Reference [28]" developed a technique for evaluating these properties and a tool for evaluating shear stress on stored goods. Jenike's load cell is widely recognised as the Jenike shear cell tester, used by many researchers worldwide, has been adopted and approved by many international standards [27], [19]. Via the parameters calculated by this apparatus it is possible to determine the pressure on the structure and particularly the type of flow which is very useful information about the processing and the unloading of products stored in bulk. "Reference [29]" investigated that the Jenike shear cell tester is the most commonly used device for the determination of shear stress. Through this tool, the product properties are calculated in compliance with a well-described operating manual, usually resulting in accurate silos design performance. This tester and its related procedures are cited by the American Society for Testing and Materials (ASTM) Std in standard or draft versions. D6128-00, European Chemical Engineering Federation (EFCE) and British Material Handling Board (BMHB).

The processing and milling of rice involve several unitary operations, according to Satake and Yamashita stated by [21]. During these operations the grains are exposed as effects, shearing and friction to different forces mainly during husking and milling [21]. "Reference [30]" have been found to depend on the physical and mechanical properties of the grains for the extent of the damage caused during the processing. Knowledge of the mechanical properties of rice grain, mainly the compression resistance of grain, is important for the determination of analysis and breakage or its cracking during processing [31,32].

3. REVIEW OF MECHANIZED RICE DE-STONING MACHINES IN NIGERIA

Many investigators have designed and constructed machines for the removal of stones and other impurities from processed rice to meet consumers' demand for a clean product [33-37]. This has contributed to many technological advancements and method of removing impurities from rice. "Reference [34]", for example, created a rice de-stoning machine using a vibrating sieve and recorded high de-stoning effectiveness. "Reference [37]" produced a cereal purifier that is especially suitable for use in processed rice cleaning impurities. "Reference [33]" developed a gravity-based and floating separator. However, the difficulty of using a separator in rice cleaning is that adequate drying is necessary after separating and there is the likelihood of storage growth of mold or fungi [38]. The technical specifications of the mentioned designs, however, are very complicated and difficult to locate [39,35,36,40]. This is possibly the reason why rice processing is still, in some ways, a big challenge given the amount of work accomplished.

The machine in (Fig. 1) developed by [41] rotating at 700 rpm had an output capacity of 7.50 t/hr and 80% de-stoning efficiency. It uses two inclined meshes which are each held by six springs. The meshes are rectangular in form, with guides along the lengths to prevent dropping off the mixture of sand and stone. The hopper is at the left end of the upper mesh / screen, the means by which the mixture is poured into the separating chamber, while a collector for the broad stones is located at the right end of the separating chamber.

"Reference [34]" used vibrating sieves to develop a rice de-stoner as shown in Fig. 2. The machine's output was evaluated, and the results obtained showed that the opening of the feed regulator has significant impacts on the de-stoning rate, de-stoning efficiency and loss of rice.

The best output was achieved at 20 mm opening of feed regulator. The higher the feed regulator, the higher the de-stoning rate and grain losses, and the lower the de-stoning capacity, the greater the 20 mm opening. The machine's mean efficiency was found to be 31.84 g / sec. And thus, the average efficiency was also 98.3%.

A motorized rice de-stoner by [42] as presented in Fig. 3 requires vibrating sieves, eccentric shaft and blower for de-stoning. For the study three local rice varieties (Bukola, Alhaji Aba, and Kodogiche) were used. The assessment results show that the Alhaji Aba variety has the maximum rice separation efficiency (RSE) and stone separation efficiency (SSE) of 81.0 percent and 77.3 percent respectively with the minimum impurity after separation (IML) and 6.5 percent and 14.5 percent tray loss (TL), respectively. Although variety Bukola has the maximum IML of 7.8 percent with the minimum SSE of 72.6 percent and variety Kodogiche has the maximum TL of 14.8 percent with the lowest RSE of 79.0 percent. After the study, the machine is found capable of de-stoning various varieties of locally produced rice but performed much better with the long rice grain than with the short rice grain, which means that the machine's efficiency has been determined by the -size of rice grain. The work is a contribution to improving the quality of Nigerian rice.

"Reference [35]" developed a locally produced rice de-stoning machine operating on mechanical principles of reciprocating and vibrating sieves. The machine was tested for efficiency in rice separation, efficiency in stone separation, degree of impurity after separation and loss in tray. The result for rice separation efficiency, stone separation efficiency, tray loss and impurity after separation showed an average of 74.2 percent, 70 percent, 16 percent and 25.8 percent. The developed machine has the promise to solve the stone infestation problem normally experienced in rice produced locally.

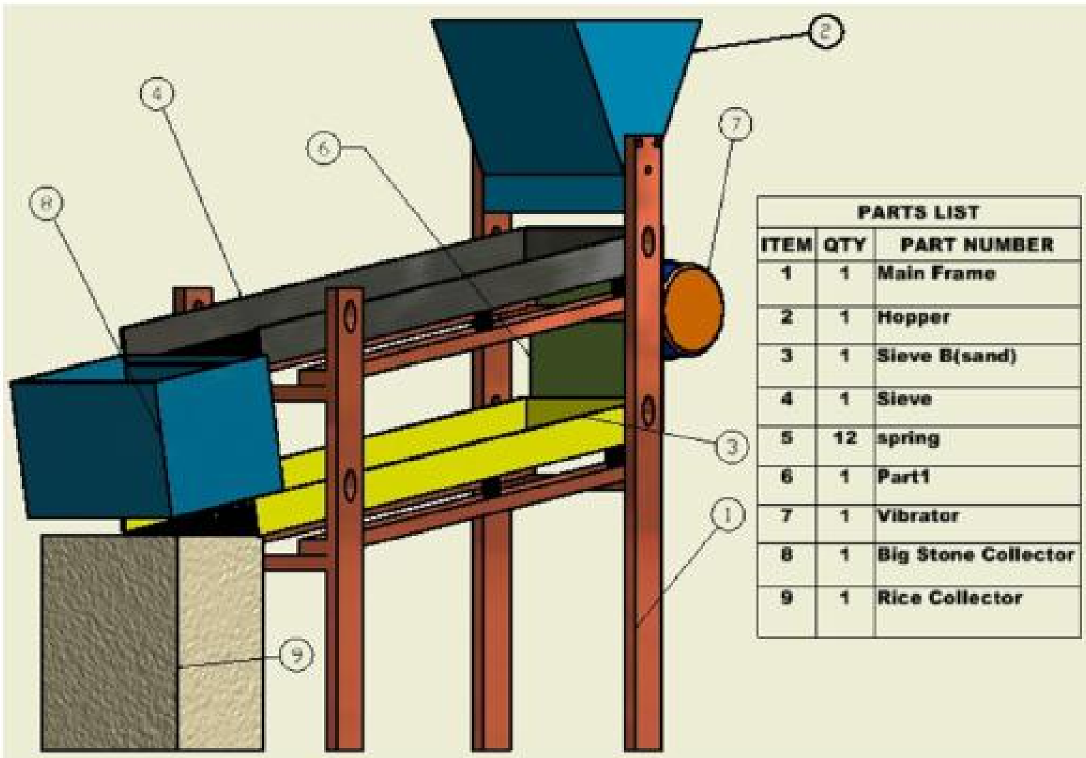
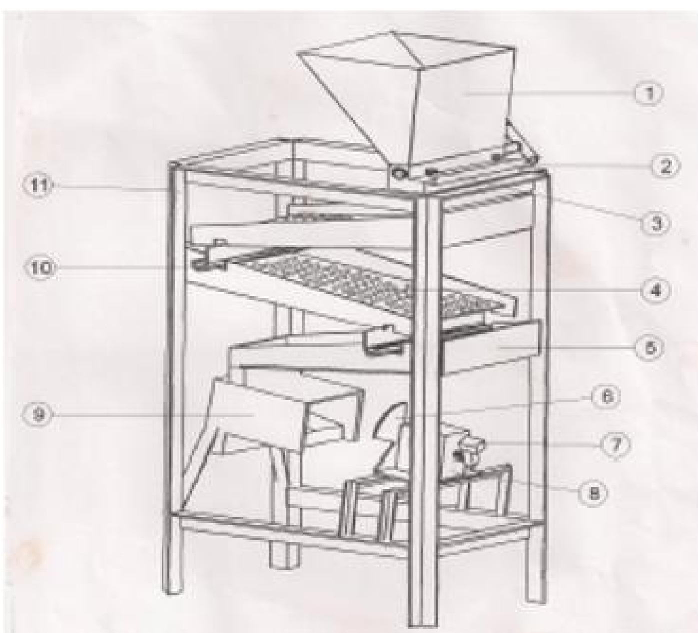
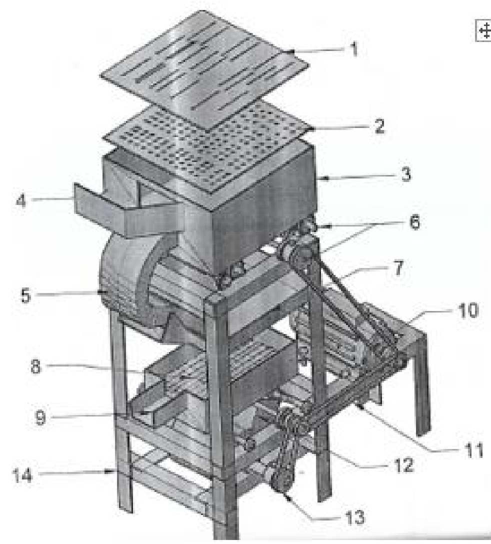


Fig. 1. Assembled isometric drawing of rice de-stoner [41]



PARTS LIST	
S/N	COMPONENTS
1.	Hopper
2.	Feed regulator
3.	Bolt
4.	Sieve
5.	Collecting tray
6.	Blower
7.	Vibrator
8.	Electric motor
9.	Outlet tray
10.	Stone passage
11.	Frame

Fig. 2. Schematic diagram of vibrating sieve rice de-stoning machine [34]



LEGENG OF RICE DE-STONING MACHINE			
S/N	COMPONENTS	MATERIAL	QTY
1.	First reciprocating screen	Mild steel	1
2.	Second reciprocating screen	Mild steel	1
3.	Vibrating sieve	Mild steel	1
4.	Stone outlet	Mild steel	1
5.	Rice channel	Mild steel	1
6.	Eccentric shaft	Mild steel	2
7.	Hopper	Mild steel	1
8.	Last reciprocating screen	Mild steel	1
9.	Last vibrating sieve	Mild steel	1
10.	Electric motor	Finished product	1
11.	Belt	Rubber	3
12.	Blower	Mild steel	1
13.	Pulley	--	4
14.	Machine frame	Mild steel	--

Fig. 3. A Developed Rice De-Stoning Machine [42]

4. CONTRIBUTORS TO THE DESIGN OF RICE DE-STONING MACHINE IN NIGERIA

Table 1 shows the brief contribution by various authors who have worked on the development of different kind's rice de-stoning machine in Nigeria. Most of this existing machine was analyzed with their peculiar advantages towards the end of this review work.

5. SUMMARY OF REVIEWED NIGERIA DE-STONING MACHINES

Table 2 summarizes various developed rice de-stoning machine in Nigeria with their authors based on their capacity, de-stoning efficiency and operating speed while Table 3 shows the merits and demerits of the existing rice de-stoners in terms of their performance.

Table 1. Authors and their contribution to rice de-stoning machine

S/No	Author(s)	Contribution(s)
1.	"Reference [35]"	Development of rice de-stoning machine operating on mechanical principles of reciprocating and vibrating sieves.
3.	"Reference [34]"	Evaluate the performance of a rice de-stoning machine at different feed regulator opening using vibrating sieves.
4.	"Reference [41]"	Developed a rice de-stoner with two separation chambers and collectors.
5.	"Reference [43]"	Developed a rice de-stoner made up of two sets of carriage each comprising of three screens.
6.	"Reference [5]"	Developed a rice de-stoner using reciprocating screen inclined at different angle.
7.	"Reference [44]"	Evaluate and modified an existing rice de-stoner with aerodynamic principle of lifting the rice grains.
8.	"Reference [42]"	Developed a motorized de-stoner via vibrating sieve.
9.	"Reference [45]"	Development of a rice motorized de-stoner.
10.	"Reference [46]"	Development of a rice de-stoning machine separating at two different stages.
11.	"Reference [47]"	Performance evaluation and modification of an existing rice de-stoner.
12.	"Reference [48]"	A low-cost rice cleaning and de-stoning machine.
13.	"Reference [49]"	Rice destoner machine/ stone impurities removing machine.
14.	"Reference [50]"	Rice destoner machine.

Table 2. Some developed Nigerian rice de-stoner with their output

S/No	Machine type	Author(s)	De-stoning efficiency (%)	Capacity (Kg/h)	Operating speed (rpm)
1.	Rice de-stoner	"Reference [35]"	70		1440
2.	Rice de-stoner	"Reference [34]"	98.3	114.6	250
3.	Rice de-stoner	"Reference [41]"	80	7500	700
4.	Rice de-stoner	"Reference [43]"	82.47	47.39	1440
5.	De-stoning machine Modified	"Reference [5]"	69.0		1440
6.	Rice de-stoner	"Reference [44]"	40.8	1.8	200
7.	Motorized rice de-stoner	"Reference [42]"	77.3		1400
8.	Motorized rice de-stoning machine	"Reference [35]"	99.75	104.4	2980

Table 3. Merits and demerits of some developed rice de-stoning machine in Nigeria

S/No	Machine type	Author(s)	Merits	Demerits
1.	Rice de-stoner	"Reference [35]"	Both reciprocating and vibrating sieves are involved in de-stoning process	It does not have speed adjustment mechanism and de-stoned rice is not properly clean.
2.	Rice de-stoner	"Reference [41]"	Ease of operation and convenient.	It cannot separate stones with relatively the size of rice.
3.	Rice de-stoning machine	"Reference [43]"	Required less power.	Complex working mechanism.
4.	Rice de-stoner	"Reference [5]"	It has a good and efficient operation.	De-stoning efficiency is low.
5.	Rice de-stoner	"Reference [42]"	Excellent function in operation	Required technical know-how and complex mechanism.
6.	Motorized rice de-stoning machine	"Reference [45]"	Effective and reliable in operation.	Required high operating speed.

For commercial purpose, the motorized rice de-stoning machine [46] with efficiency of 99.75% and operating at 2980 rpm and vibrating sieve rice de-stoner [34] with efficiency of 98.3% and operating speed of 250 rpm were recommended. Technical skill to operate the machine, inability to separate stones with relatively the size of rice, lack of speed adjustment mechanism and low efficiency are some of the many demerits of some rice de-stoning machines. It is important to note that not one machine has all the demerits.

6. CONCLUSIONS

The following conclusions can be made from this review of rice de-stoning machines in Nigeria.

i. The operating speed of the rice de-stoners ranged from 200 – 2980 rpm.
ii. The highest de-stoning efficiency and machine output capacity were 99.75% for motorized rice de-stoner and 7500 kg/h with two separation chambers and collectors. However, the de-stoning efficiency ranged from 40.8 to 99. 75% while output capacity from 1.8 to 7500 kg/h for the machines reviewed.
iii. The stone separation efficiency of the machines increased with decreasing angle of inclination.
iv. The more the feed regulator opening, the lower the de-stoning efficiency of the machines.

7. RECOMMENDATION

There should be proper selection of sieve size for any variety of rice to be de-stoned.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Olugboji OA. Development of a rice threshing machine. AU Journal of Technology. 2004;8(2):75-80.
2. Dagninet A, Negese Y, Asmamaw E. Development and evaluation of pedal thresher for threshing of rice. American Journal of Mechanics and Applications. 2015;3(4):27–32.
3. Cho B, Kang T, Won J, Kang S, Lee H, Han C. Effects of main shaft velocity on turbidity and quality of white rice in a rice processing system. Journal of Bio Systems Engineering. 2017;42(1):69–74.
4. Azouma OY, Porosi M, Yamaguchi K. Design of throw-in type rice thresher for small scale farmers. Indian Journal of Science and Technology. 2009;2(9):10–14.
5. Gbabo A, Ndagi B, Kuku AM, Abdullahi L. Development and testing of a rice de-stoning machine. International Journal of Engineering Research and Science and Technology. 2015;4(3):135–141.
6. Ajala AS, Gana A. Analysis of challenges facing rice processing in Nigeria. Journal of Food Processing. 2015;1–6. (Article ID893673).
   Available:https://doi.org/10.1155/2015/893673
7. Onu DO, Obike KC, Ebe FE, Okpara BO. Empirical assessment of the trend in rice production and imports in Nigeria (1980–2013). International Research Journal of Agricultural Science and Soil Science. 2015;5(6):150–158.
8. Adejuyigbe SB, Bolaji BO. Development and performance evaluation of a rice destoning machine using vibrating sieves. Journal of Natural Sciences, Engineering and Technology. 2012;11(2):94–105.
9. Mohammed DT. Introduction of Faro-52 (WITA-4) Rice variety as a measure of solving low yield problem among farmers in Yola-north local government area of Adamawa State, Nigeria. International Journal of Innovative Agriculture and Biology Research. 2016;4(2):1–7.
10. Juliano BO, Bechtel DB. The rice grain and its gross composition. Rice chemistry and technology. St Paul, MN, USA, American Association of Cereal Chemists. 1985;2: 17–57.
11. Juliano BO. Rice: Chemistry and technology. St Paul, MN, USA, American Association of Cereal Chemists, (2nd Edition). 1985;774.
12. Juliano BO. The rice caryopsis and its composition. Rice chemistry and technology. St Paul, MN, USA, American Association of Cereal Chemists. 1972;16-74.
13. Tanaka K, Yoshida T, Asada K, Kasai Z. Subcellular particles isolated from aleurone layer of rice seeds. Archives of Biochemistry and Biophysics. 1973;155: 136-143.
14. Tanaka K, Ogawa M, Kasai Z. The rice scutellum. II. A comparison of scutellar and aleurone electron-dense particles by transmission electron microscopy including energy-dispersive X-ray analysis. Cereal Chemists. 1977;54:684-689.
15. Bechtel BD, Pomeranz Y. Ultrastructure of the mature ungerminated rice (*Oryza sativa*) caryopsis. The starchy endosperm. American Journal of Botany. 1978;65: 684–691.
16. Srilakshmi B. Food science. New Age International Publisher, 3rd Edition; 2003.
17. Lawton PJ. Coefficients of friction between cereal grain and various silo wall materials. Journal of Agricultural Engineering Research. 1980;25:75–86.
18. Mohsenin NN. Physical properties of plant and animal materials. Gordon and Breach Science Publishers, New York. (2nd Edition). 1986;891.
19. Milani AP. Determination of the stored products properties for silo pressures and flow design. Ph.D. Dissertation, Dept. Civil. Eng., Sao Carlos University, Sao Carlos, SP, Brazil; 1993.
20. Suthar SH, Das SK. Some physical properties of karingda [*Citrullus lanatus* (Thumb) Mansf] seeds. Journal of Agricultural Engineering Research. 1996;65(1):15–22.
21. Shitanda DY, Nishiyama, Koide S. Compressive strength properties of rough rice considering variation of contact area. Journal of Food Engineering. 2002;53:53-58.
22. Mohapatra D, Bal S. Effect of degree of milling on specific energy consumption, optical measurements and cooking quality of rice. Journal of Food Engineering. 2007;80:119–125.
23. Mohapatra D, Bal S. Wear of rice in an abrasive milling operation, part 2: Prediction of bulk temperature rise. Bio Systems Engineering. 2004;89:101–108.
24. Yadav BK, Jindal VK. Monitoring milling quality of rice by image analysis. Computer

and Electronic in Agriculture. 2001;33:19–33.
25. Srivastava AK, Mahoney WT, West NL. The effect of crop properties on combine performance. Trans. ASAE. 1990;63–72.
26. Correa PC, Schwanz Da Silva F, Jaren C, Afonso Junior PC, Arana I. Physical and mechanical properties in rice processing. Journal of Food Engineering. 2007;79: 137–142.
27. Calil JRC. Flow and load recommendations in vertical silo design. Sao Carlos, Brazil: University of Sao Paulo. 1990;198.
28. Jenike AW. Storage and flow of solids. Salt Lake City, EE. UU: University of Utah. 1980;197.
29. Haaker GFJ. Progress in measuring bulk solid properties. Chisa Conference 115, Prague, Hungary. 1990;10.
30. Ojayi OA, Clark B. High velocity impact of maize kernels. Journal of Agricultural Engineering Research. 1997;67(2):97–104.
31. Pomeranz Y, Webb BD. Rice hardness and functional properties. Cereal Foods World. 1985;33(11):784–790.
32. Wouters A, Baerdemaeker J. Effect of moisture content on mechanical properties of rice kernel under quasi-static compressive loading. Journal of Food Engineering. 1988;7:83–111.
33. Henderson SM, Perry RL. Agricultural process engineering, 3rd Edition. The Avi Publishing Company, Incorporated, West – Port, Connecticut. 1976;170–189.
34. Adejuyigbe SB, Bolaji BO. Design, fabrication and performance evaluation of bean dehuller. Journal of Science and Technology. 2005;25(1):125–132.
35. Simonyan KS, Emordi IS, Adama JC. Development of a locally designed rice de-stoning machine. Journal of Agricultural Engineering and Technology (JAET). 2010;18(2).
36. Adegun IK, Adepoju SA, Aweda JA. A mini rice processing machine for Nigerian farmers. Journal of Agricultural Technology. 2012;8(4):1207–1216.
37. Okunola AA, Igbeka JC, Arisoyin AG. Development and evaluation of a cereal cleaner. Journal of Multidisciplinary Engineering Science and Technology. 2015;2(6):14-19.
38. Fadeyibi A, Osunde ZD, Ussaini MS, Idah PA, Balami AA. Evaluating monolayer moisture content of rubber seed using BET and GAB sorption equations. International Journal of Farming and Allied Sciences. 2012;1(3):72-76.
39. Ogunlowo AS, Adesuyi SA. A low-cost rice cleaning/de-stoning machine. European Centre for Research Training and Development UK. 2014;2(2):33-43.
40. Agidi G, Ndagi B, Kuku AM, Abdullahi L. Development and testing of a rice de-stoning machine. International Journal Engineering. Resources & Science & Technology. 2015;4(3). ISSN: 2319-5991 [Online].
Available:www.ijerst.com
41. Ismail SO, Ojolo SJ, Orisaleye JI, Okufo OS. Design of a rice de-stoner. International Journal of Mechanical Computational and Manufacturing Research. 2013;2(3):54–66.
42. Usman M, Balogun AL, Oyebanre OD. Design, fabrication and testing of a rice de-stoning machine. International Conference of Science, Engineering and Technology. 2018;3(1):1-12.
43. Olugboji OA, Jiya JY. Design and fabrication a rice de-stoning machine. Food Science and Technology. 2014;2(1): 1-5.
44. Yisa GA, Fadeyibi A, Katibi KK, Ucheoma OC. Performance evaluation and modification of an existing rice de-stoner. International Journal of Engineering Technologist (IJET). 2017;3.
45. Ojediran JO, Okonkwo CE, Okunola AA, Alake AS. Development of a motorized rice de-stoning machine. Department of Agricultural and Bio Systems Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria. CIGR Journal. 2019;20:4. Open Access [Online].
Available:http://www.cigrjournal.org
46. Tashiwa YF, Iya SA, Aliyu B, Kabril HU. Development and performance evaluation of a stationary rice grain destoner. Nigeria Journal of Engineering Science and Technology Research. 2019;5(1):84-94.
47. Mohammed GY, Adesina F, Kamil KK, Ucheoma OC. Performance evaluation and modification of an existing rice de-stoner. International Journal of Engineering Technologies. 2019;3(3):169–175.
48. Ogunlowo AS, Adesuyi SA. A low-cost rice cleaning and de-stoning machine. Agricultural Mechanization in Asia, Africa and Latin America. 1999;30(1):20-24.

49. Anonymous. Rice destoner machine/ stone impurities removing machine. 2020;28:4. (Accessed 7 May 2020) Available:https://www.agriculture-machine.com/rice-wheat-destoner-machine/

50. Anonymous. Rice destoner machine. 2018;9:4. (Accessed 7 May 2020) Available:http://www.rice-mill.org/PRODUCTS/Rice-Destoner-Machine/

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/57403