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Influence of Oscillatory Motion of a Rice Dehydrator on Energy Consumption and Milling Quality of Rice

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Abstract: This study aimed to evaluate the influence of the oscillatory motion of a rice dehydrator on drying time, drying rate, electrical energy consumption, specific energy consumption, milling quality (broken milled rice, head milled rice and milling recovery) of rice varieties of FARO 62, FARO 15, and FARO 60. The dehydrator was designed to operate either in a stationary or oscillatory motion. The dehydrator motion influences the drying time, drying rate, electrical energy and specific energy consumption and milling quality regardless of the rice variety. The drying time of the rice varieties ranged from 125 to 290 mins, drying rate (2.897 to 6.72 kgH_2O/kg solids h), electrical energy consumption (15.43 to 35.46 MJ), specific energy consumption (5.25 to 11.20 MJ/kg), milling recovery (67.58 to 73.97%), head milled rice (60.47 to 69.10%) and broken milled rice (1.62 to 9.46%), respectively. The oscillatory motion of the dehydrator aided a shorter drying time, faster drying rate, less electrical energy consumption and specific energy consumption, and desirable milling quality. The study concluded that the adoption of oscillatory motion during drying would aid in energy conservation and in the production of quality milled rice.

Keywords: Energy consumption; dehydrator; milling quality; oscillatory motion; rice varieties

I. Introduction

Rice (*Oryza sativa*) is a critical staple food for approximately three billion people worldwide [1]. Globally, about 480 million metric tons of milled rice is being produced annually, with Asian countries such as India, Thailand, China etc., accounting for over 50% of rice grown and consumed [2]. In Nigeria, rice consumption increased by 4.7% in the last decade, with total consumption of 6.4 million tons in 2017 compared to the yearly 3.7 million tons produced [3]. Nigeria is the largest producer and consumer of rice in the West Africa sub-region. However, production lags consumption, necessitating more rice importation for consumption [4]. Rice is grown almost in all Nigeria's agro-ecological zones, varying from the mangrove forest and mouldy ecologies of the Niger delta in the coastal areas to the deserted zone of the Sahel in the North [5].

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Paddy rice, sometimes referred to as rough rice, is the individual rice kernels in their natural and unprocessed state. The drying of paddy rice is an essential step in the postharvest processing of rice because inappropriate drying could lead to quality and quantity losses during milling and storage. Drying is the third stage of the rice parboiling process and requires gently lowering the moisture content to attain optimum milling and storage conditions. Milling is the next stage after paddy rice drying, and it involves the remover of husk and bran layer, thus, resulting in saleable rice products [1, 6]. Different types of rice dryers have been developed, among which are; Solar bubble dryer [7], Circular bin dryer [8], Solar assisted grain dryer [9], Flatbed dryer [10], Reversible Air Flatbed Dryer [11] etc.

Despite the enormous work on the dryers, there is insufficient information on the influence of dehydrator motion on drying time, drying rate, energy consumption, and rice milling quality. Energy analysis plays a crucial role in energy conservation and improving processing efficiency. Paddy rice drying is a primary concern in rice producing countries because it is an energy-intensive process that significantly affects milled rice quality, particularly head rice yield [12]. The authors [13] and [14] reported that drying of paddy rice required high specific energy consumption with energy value to evaporate water ranging from 4630 to 5260 $kJkg^{-1}$ and 6800 to 43200 $kJ\ kg^{-1}$. Drying operations could consume more than 25% of national energy use [14, 15]. Therefore, there is a need to study the influence of the motion of rice dehydrator on drying rate, drying time, energy consumption and milling quality. The evaluation of the motion of the dehydrator could aid in providing more insight into how drying time, drying rate, specific energy consumption and milling quality could be influenced. This study aimed to evaluate the influence of dehydrator motion on the drying time, drying rate, electrical energy consumption, milling quality and specific energy consumption of rice varieties.

II. Materials and Methods

A. Description of the Dehydrator

Figure 1 shows the isometric view (a), exploded view (b), and pictorial view (c) of the developed dehydrator. The dehydrator comprises stainless steel screen, oscillatory electric motor, drying chamber, temperature controller, temperature sensor, electric heating element, electric blower, removable dehydrator cover, cover handle, chimney and standing frame. The stainless-steel screen has a mesh size of 1.5 mm, and it is meant to hold paddy rice. The screen mesh was designed to aid a faster rate of hot air penetration into the paddy rice, and thus, it is expected to increase the drying rate. The oscillatory electric motor (0.5 hp) is the driving mechanism of the dehydrator that aids the oscillatory motion of the dehydrator. The electric motor transfers oscillatory energy to the arm-like mechanism that causes oscillatory motion to the dehydrator and moves to and fro at 50 rev/min. The rice dehydrator is designed to operate either in oscillatory motion or stationary state. The drying chamber houses the electric heating element, temperature sensor, screen and blower (0.5 hp). The temperature controller (REX C-700) was used to set and keep the temperature of the rice dehydrator to the desired drying temperature. The temperature sensor senses the temperature within the drying chamber and sends it to the temperature controller. The electric heating element of 2000 watts was the heating source that generated heat for the dehydrator while the blower blows and circulates the hot air within the drying chamber.

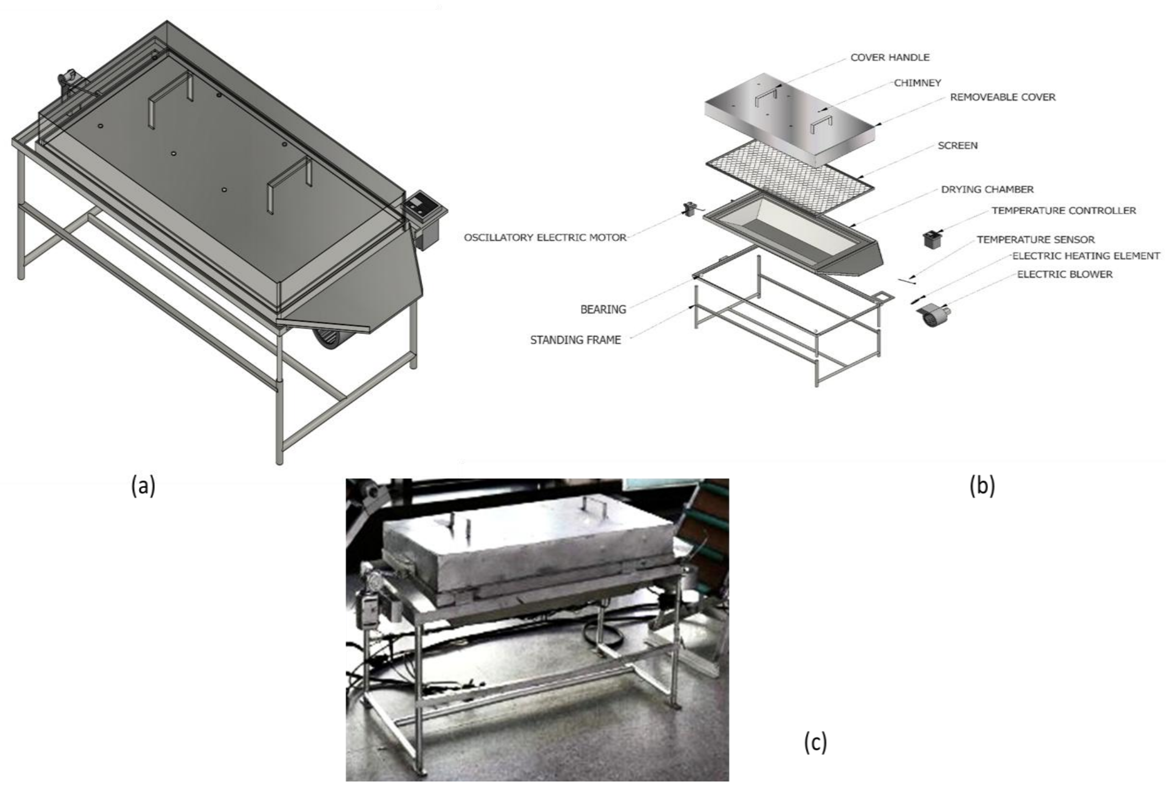

Figure 1: Developed dehydrator (a) Isometric view (b) Exploded view (c) Pictorial view

The removable dehydrator cover was made up of galvanized steel. The cover has a handle and chimney and provides a close condition for paddy rice drying to minimize heat loss and enhance a better drying process. The cover handles easily aid the remover of the cover to load paddy rice on the screen while the chimney allows the easy escape of the vapour during drying.

B. Estimation of Drying, Energy and Milling Parameters of the Dehydrator based on Motion

The paddy rice of 4 kg each of FARO 15, FARO 60 and FARO 62 were procured from the grain quality laboratory of NCRI, Baddeggi, Niger State, Nigeria. The paddy rice of the varieties was cleaned to remove stones and chaff. The washed paddy rice was steeped in a fabricated rice parboiler at 80°C till moisture content reached 28% wet basis (wb). After soaking, the paddy rice was steamed at a temperature above 100 °C for 40 mins. The mass of the steamed paddy rice was recorded and divided into two equal portions. The first portion of the paddy rice was dried in the dryer using the stationary state at a drying temperature of 45°C, and the drying was terminated when 14% wb was achieved. The second portion was dried using the oscillatory motion of the dehydrator at the same temperature of 45 °C till the moisture content reached 14% wet basis. The drying time required for the paddy rice to reach 14% wb in a static state and oscillatory state of the drier was recorded. The amount of moisture removed was evaluated using Eq. 1. The air mass flow rate, volumetric airflow rate, and drying rate of the rice varieties under stationary and oscillatory states were evaluated using Eqs. 2 to 4. The electrical energy consumption, the electrical energy consumed by the blower, electrical energy consumed by the electric heating element and oscillatory electric motor and specific energy consumption during the static and oscillatory state of drying of the rice varieties were determined using Eq. 5 and 8, respectively. The dried samples were later milled using a rice milling machine (Model MLNJ-15-13, India). The milling recovery (MR), head milled rice (HMR) and broken milled rice (BMR) of the rice varieties obtained in stationary and oscillatory drying states were determined using Eq. 10 and 12.

i. Amount of moisture removed

The amount of moisture removed from paddy rice to bring the moisture content to 14% moisture content in a specified time was calculated using the following Eq. 1 as described by [16].

$$M_w = \frac{M_p(M_i - M_f)}{(100 - M_f)} \quad (1)$$

Where M_w is the mass of the moisture removed (kg), M_p is the mass of the paddy rice (kg), M_i is the initial moisture content (%) and M_f is the final moisture content (%).

ii. Mass flow rate of air

The mass flow rate of air needed in drying the paddy rice was determined using Eq. 2 as described by [17].

$$M_{ar} = \frac{m_a}{t_d} \quad (2)$$

Where M_{ar} is the mass flowrate of air, Ma is the mass of air flow and t_d is the drying time for each rice variety at a specific dehydrator motion.

Mass of airflow (Ma) during drying was determined from energy requirement during drying as indicated in Eq. 3 as described by [17].

$$M_a = \frac{M_w L}{C_{pa}(\Delta T)} \quad (3)$$

Where L is the specific latent heat of

vaporization of water at 45°C is 2394 kJ/kg, C_{pa} is the specific heat capacity of air (1.005 kJ/kgK) ΔT is the change in temperature of the drying chamber from 28°C to 45°C.

iii. Volumetric flowrate of air

The volumetric flow rate of air (V_a) was evaluated using Eq. 4 as reported by Hussein *et al.* [17].

$$V_a = \frac{M_{ar}}{\rho_a} \quad (4)$$

where ρ_a is the density of the air at 45°C (1.2754 kg/m^3)

iv. Drying rate (DR)

$$DR = \frac{dM}{dt} = \frac{Pi - Pf}{\Delta t} \quad (5)$$

Where dM is the change in moisture content, dt is the change in drying time, Pi is the initial moisture content of the rice paddy and P_f is the final moisture content of the paddy rice.

iv. Electrical energy consumption (EEC)

The electrical energy consumption during the drying of the paddy rice and rice dehydrator operating mode was estimated using Eq. 6 as described by [18].

$$EEC = EEC_b + EEC_h \quad (6)$$

where EEC_b is electrical energy consumed by the blower and EEC_h is electrical energy consumed by electric heating element and oscillatory electric motor. EEC_b was estimated using Eq. 7 while EEC_h was estimated using Eq. 8.

$$EEC_b = \sqrt{(3VIcos\emptyset) \times t} \quad (7)$$

V is the line voltage, I is the line current, Cos Ø is the power factor, t is the operating time (h)

$$EEC_h = P_{osm\times}P_b \times t \quad (8)$$

Where, P_b is the electric heating element rated power, P_{osm} is the power rating of the electric motor and t is the operating time (h).

Specific energy consumption (SEC)

The specific energy consumption (SEC) was estimated using Eq. 9 based on the electrical energy consumption and the mass of paddy rice that undergo the drying process.

$$SEC = \sum \frac{EEC}{m_p} \quad (9)$$

where EEC is the total electrical energy and m_p is the paddy rice mass.

v. Milling quality

The milling recovery (MR) and head milled rice (HMR) of the rice varieties was determined using Eq. 10 and 12 as described by [1] and [19].

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

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

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

where mmr is the mass of the milled rice, mp is mass of the rice paddy, mr is the milling recovery, MHMR is the mass of head milled rice and MBMR is the mass of broken milled rice.

III Results and Discussion

A. Influence of Dehydrator Motion on the Drying Time

Figure 2 depicted the influence of dehydrator motion on the drying time of three rice varieties. The drying time for the three rice varieties varies from 125 mins to 290 mins. It was observed that the drying time of the rice varieties during oscillatory motion was lower than in stationary state. FARO 62 had the longest drying time in the stationary state, while FARO 15 was observed to have the shortest drying time when the dehydrator was operated in oscillatory motion.

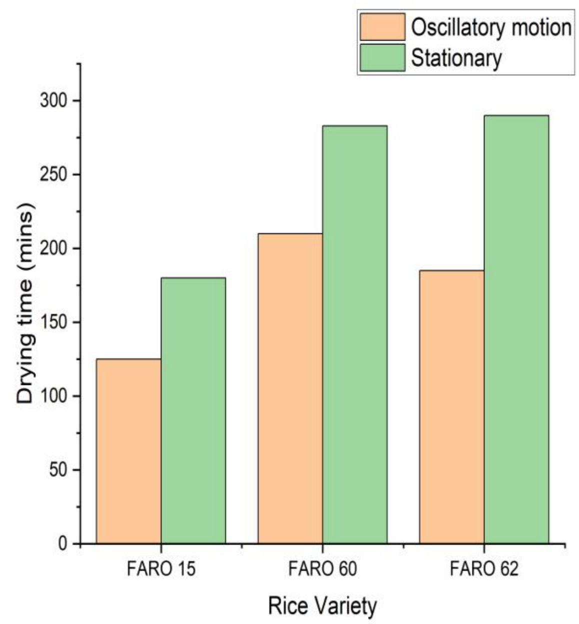

Figure 2: Influence of dehydrator motion on the drying time of three rice varieties

Therefore, it can be inferred from the findings that the motion of the rice dehydrator influences the drying time. This could be because the to and fro movement of oscillatory motion allows easy penetration of hot into the screen that holds the paddy rice in the drying chamber, thus hastening the drying process of the paddy rice as against when it is in a motionless state which was observed when the rice dehydrator was in a stationary state. In addition, it was observed that the drying time of the rice varieties differs from one type to the other. This could be due to the difference in the rate at which rice varieties reach their equilibrium moisture content. The authors [20] also noted that the drying time of FARO 44 and FARO 52 differs.

B. Influence of Dehydrator Motion on the Drying Rate

Figure 3 shows the effect of dehydrator motion on the drying rate of three rice varieties. The drying rate varies from 2.89 kg$H_2$0/kg solids h. to 6.72 kg$H_2$0/kg solids h. It was observed that the drying rate of the oscillatory motion was higher than the stationary state. This could be due to the sifting of the paddy rice that occurs on the screen of the drying chamber during the oscillatory motion and thus facilitates a faster drying rate. It was observed that FARO 15 had the highest drying rate when the dehydrator was in oscillatory motion, while FARO 62 had the lowest drying rate when the dehydrator was in a stationary state. Therefore, it can be inferred from the findings that the motion of the rice dryer influences the drying rate. In addition, it was observed that the drying rate for the rice varieties differs from one variety to another, which could be due to differences in the shape and size of the rice varieties.

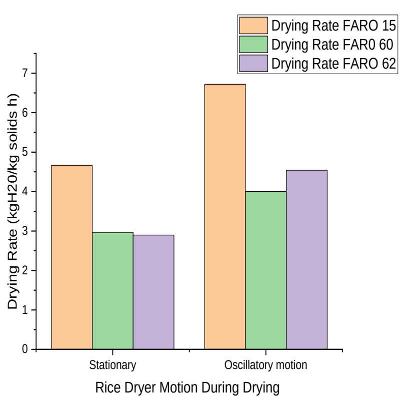

Figure 3: Influence of dehydrator motion on the drying rate of three rice varieties

C. Influence of Dehydrator Motion on Electrical Energy Consumption (EEC)

The electrical energy consumption is the total energy consumed during the drying operation. That is, from of the blower, the heater and the electric motor that aids the oscillation. Figure 4 shows the effect of dehydrator motion on the electrical energy consumption of three rice varieties. The electrical energy consumption for the rice varieties ranged from 15.43 MJ to 35.46 MJ. The electrical energy consumption of the dehydrator at a stationary state is higher than the oscillatory motion for all the rice varieties. It was observed that FARO 15 had the lowest electrical energy consumption when the rice dehydrator was in oscillatory motion. In contract, FARO 62 had the highest electrical energy consumption when the dehydrator was in a stationary motion. The motion of the dehydrator influences the electrical energy consumption of the rice varieties, and this could be traced to the short drying time observed when the dehydrator operates under oscillatory motion than in a stationary state. These findings corroborate with [21] and [22] that processing time influences energy consumption. The difference in the electrical energy consumption of the rice varieties could be due to the difference in the behaviour of the rice varieties during drying. Author [23] reported that the type of rice variety influences energy consumption.

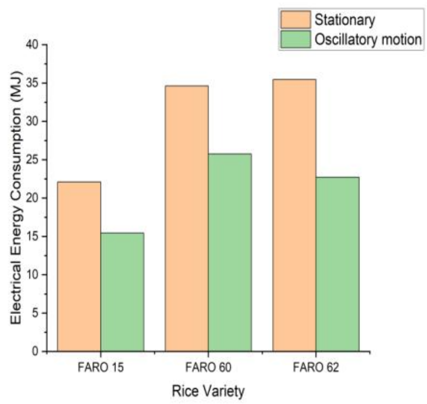

Figure 4: Influence of dehydrator motion on electrical energy consumption of three rice varieties.

D. Influence of Dehydrator Motion on Specific Energy Consumption (SEC)

Specific energy consumption is the energy consumed by each variety based on the mass of paddy rice that was processed. Figure 5 shows the influence of dehydrator motion on the specific energy consumption of three rice varieties. The specific energy consumption ranged from 5.25 MJ/kg to 11.20 MJ/kg. When the dehydrator operates under a stationary state, the specific energy consumption is higher than in oscillatory motion. It was observed that FARO 15 had the lowest specific energy consumption when the rice dehydrator was in oscillatory motion. In contrast, FARO 62 had the highest specific energy consumption when the dehydrator was in a stationary state. The difference in the specific energy consumption of FARO 15, FARO 60 and FARO 62 could be due to the difference in the drying time at the same drying temperature.

The dissimilarity in the drying time of the rice varieties could be influenced by the physiological properties of the rice varieties. Therefore, it can be inferred from the findings that the motion of the rice dehydrator and the rice varieties influences the specific energy consumption.

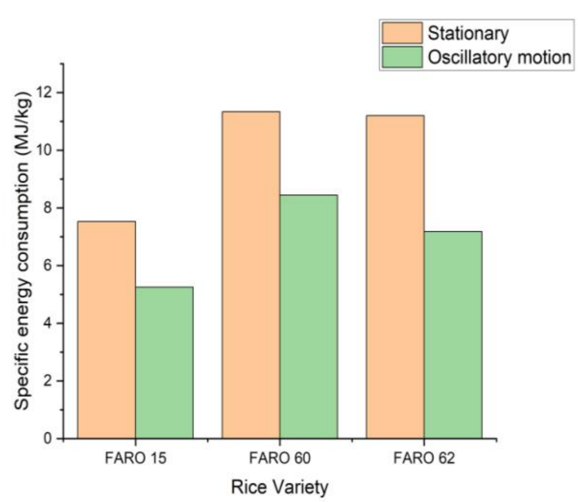

Figure 5: Influence of dehydrator motion on specific energy consumption of three rice varieties

E. Influence of Dehydrator Motion on Milling Quality

Figure 6 shows the effect of dehydrator motion on the milling quality of the three rice varieties. Milling recovery, head milled rice and broken milled rice are essential quality indicators in the rice industry [19]. The milling recovery ranged from 67.58% to 73.97%, head rice yield (60.46% to 69.10%) and broken rice yield ranged from 1.62% to 9.46%. It was observed that milling recovery and head milled rice of paddy rice dried under the oscillatory motion were higher than the stationary state. In contrast, broken milled rice was higher in the stationary state than in oscillatory motion. The difference in the milling quality could be due to the separate approaches used in drying the paddy rice. This result agrees with the findings of [24], that the drying method gives different milling yields and head milled rice. It was observed that FARO 15 had the highest milling recovery, head milled rice when the rice dehydrator was in an oscillatory state, while FARO 62 had the lowest milling recovery and head milled rice when the dehydrator was in an oscillatory state, while FARO 62 had the lowest milling recovery and head milled rice when the dehydrator was in a stationary state. However, FARO 15 had the highest broken rice when the rice dehydrator was in a stationary state for the broken milled rice, while FARO 62 had the lowest broken rice when the dehydrator was in oscillatory motion. The difference in the milling quality can be associated with the different behaviours of the varieties during milling.

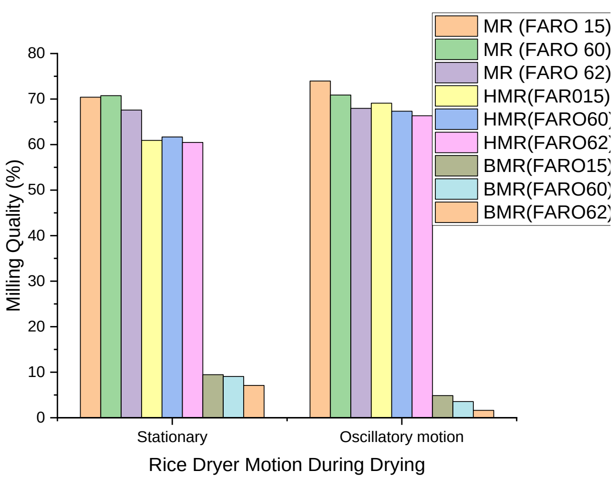

Figure 6: Influence of dehydrator motion on the milling quality of rice varieties (where MR is milling recovery, HMR is head milled rice and BMR is broken milled rice).

The grain size, presence of fissures and porosity of starch granules could influence the differences in the milling quality of the three rice varieties. Authors [19] and [23] reported similar findings. Therefore, it can be inferred from the results that the motion of the rice dehydrator influences the milling quality.

IV Conclusions

The dehydrator motion influenced the drying time, drying rate, electrical energy consumption, specific energy consumption and milling quality of the three rice varieties. The oscillatory motion of the dehydrator reduces the drying time and increases the drying rate of the rice varieties. The dehydrator's oscillatory motion consumes less energy than when it is in a stationary state. The drying time, drying rate, electrical energy consumption, specific energy consumption, broken-milled, head-milled rice and milling recovery rice differ. This information would be helpful for rice processors in the area of rice dehydrator design, energy conservation and the production of quality milled rice.

References

[1] Sanusi, M.S. and Akinoso, R. "Multiobjective optimization of parboiled rice quality attributes and total energy consumption". Nigerian Journal of Technological Research. Vol. 15, 2020, pp. 24-33.

[2] Muhammed, Y., Ojo, M. A., Abdullahi, A., Ajayi, O. J., Jibrin, S. and Loko, A. I. "Evaluation of resource-use efficiency among rice farmers in Katcha Local Government Area of Niger State, Nigeria." Journal of Agricultural Research and Development, Vol. 18 No 1, 2019, pp.9-19.

[3] Adejo, E. G., Saliu, O. J. and Adejo, P. E. "Perspective of Policy Interventions in Rice and Cassava Value Chain Among Women in

Nigeria". In Developing Sustainable Food Systems, Policies, and Securities, 2020, pp. 127-150. IGI Global.

[4] Sanusi, M.S. and Akinoso, R. "Modelling and optimising the impact of process variables on brown rice quality and overall energy consumption". International Journal of Postharvest Technology and Innovation, Vol. 8, No. 1, 2021, pp.70–88.

[5] Daudu, C.K., Yakubu, A.A., Sambo, I.J., Okworie, E., Adeosun, J.O and Onyibe, J.E. "Rice production, processing, utilization and marketing in Nigeria. Extension bulleting" National Agricultural Extension and Research Liaison Service ABU Zaria, No. 230, 2014.

[6] Hunt, M. "Impact of parboiling processing conditions on rice characteristics". Kansas State University, 2019.

[7] Agrawal, R.M. "Small Scale Batch Dryers for Developing and Underdeveloped Countries. ADM Institute for the Prevention of Postharvest Loss." University of Illinois at Urbana Champaign, 2020.

[8] Regalado, M. J. C., Bekki, E. and Madamba, P. S. "Dehumidification drying of high-moisture rough rice in a radial-flow, circular bin". Drying Technology, 18(10), 2307-2326.

[9] Sidrah, A. Ahmad M. and Wajid A. "Design, development and performance evaluation of a small-scale solar assisted paddy dryer for on farm processing." Journal of Food Processing and Technology Vol. 6, 2015, pp. 217-228.

[10] Bautista, E. U., and Evelyn F. J. "The evolution of rice production practices". PIDS Discussion Paper Series, No. 2005- 14.

[11] Vinh, L. Q. and Gavino, H. F. "Adaptability of Vietnamese Reversible Airflow Flatbed Dryer In The Philippines". International Workshop on Agricultural and Bio-systems Engineering (IWABE), 2011, December 2nd-3rd

[12] Jittanit, W., Saeteaw, N. and Charoenchaisri, A. "Industrial paddy drying and energy saving options". Journal of stored products research, Vol.46, No 4, 2010, pp. 209-213.

[13] Sarker, Md., Abdur R., Khorshed A., and Jeff Gow. "Exploring the relationship between climate change and rice yield in Bangladesh: An analysis of time series data." Agricultural Systems, Vol. 112, 2012, pp. 11-16.

[14] Defraeye, T. "Advanced computational modelling for drying processes–A review". Applied Energy, Vol. 131, 2014, pp.323-344.

[15] Panda, D., Mishra, S. S., and Behera, P. K. "Drought tolerance in rice: focus on recent mechanisms and approaches". Rice Science, Vol. 28, No. 2, 2021, pp.119-132.

[16] Ehiem, J. C., Irtwange, S. V., and Obetta, S. E. "Design and development of an industrial fruit and vegetable dryer". Research Journal of Applied Sciences, Engineering and Technology, Vol.1, No. 2, 2009, pp. 44–53.

[17] Hussein, J.B., Hassan, M.A., Kareem, S.A. and Filli, K.B. "Design, construction and testing of a hybrid photovoltaic (PV) solar dryer". International Journal of Engineering Research and Science, Vol. 3, No. 5, 2017, pp. 1-14.

[18] Billiris, M. A., Siebenmorgen, T. J. and Baltz, G. L. "Energy use and efficiency of rice-drying systemsi. on-farm cross-flow dryer measurements". Applied Engineering in Agriculture, Vol. 30, No. 2, 2014, pp. 205-215.

[19] Sanusi, M. S., Akinoso, R., and Danbaba, N. "Evaluation of physical, milling and cooking properties of four new rice (*Oryza sativa* L.)

varieties in Nigeria)". International Journal of Food Studies, Vol. 6, No. 2 ,2017, pp. 245–256.

[20] Maijalo, A. I., Idakwo, P. Y., Aviara, N. A. and Badau, M. H. "Drying Characteristics of Two Improved Parboiled Rice Varieties". Saudi Journal of Engineering and Technology, Vol. 5, No. 12, 2020, pp. 491-500.

[21] Wang, L. "Energy efficiency and management in food processing facilities". CRC press, 2008.

[22] Sanusi, M.S. and Akinoso, R. "Evaluation of Energy Consumption Pattern in Rice Processing Using Taguchi and Artificial Neural Network Models". Agricultural Engineering International: CIGR Journal 24 (2), 2022.

[23] Kwofie, E. and Ngadi, M. "A review of rice parboiling systems, energy supply, and consumption". Renewable and Sustainable Energy Reviews 72, 2017, 465-472.

[24] Adesina, B. S., Akinyemi, D.O., Samuel, D. O., Olayanju, T. M. A. and Dairo, O. U. "Effect of Drying Methods on the Milling Qualities of Funaabor- 1 and Funaabor- 2 Rice Paddy". Journal of Scientific, Engineering and Technology Research Vol-1, Issue-1, 2017 13 - 33, January ISSN: 2616 - 1249. https://postharvestinstitute.illinois.edu/wp-content/uploads/2020/04/ADMI-dryer-report.pdf.