

DEVELOPMENT OF AN IMPROVED PADDY PARBOILER FOR SMALL AND MEDIUM-SCALE PROCESSORS

Shittu, S.K., Dangora, N.D., Attanda, M.L., Muhammad, A.I., Abubakar, M.S., Lawan, I., Falalu, R.J., Nasidi, N.M. and Mohammed, M.

Department of Agricultural and Environmental Engineering, Bayero University Kano, Kano State, Nigeria

*Corresponding email: skshittu.age@buk.edu.ng

ABSTRACT

Rice is a staple diet of more than half of the world's population. It is an important food and can potentially become a major export commodity for Nigeria in the near future. Paddy parboiling is a crucial process done to reduce excessive rice breakage and loss of nutrients. Most small-scale rice processors in Nigeria, specifically in Kano clusters, depend on the traditional paddy parboiling method, which uses pots or open drums to cook the paddy using firewood on a tripod. This method produces poor-quality rice; it is not efficient and time-consuming. This research is aimed at developing an improved paddy parboiler for small/medium-scale rice processors and also to carry out the performance tests of the parboiler. The improved paddy parboiler consists mainly of a boiler, a stove, steam pipes, steam pipe support, and a parboiler tank. The results of the performance tests carried out show that the steaming period and temperature have a significant effect on the moisture uptake and head rice yield at 1% probability level. The mean moisture uptake and the head rice yield increase with increased steaming period and temperature, and their values are significantly different at 5% probability level. The mean paddy moisture uptake ranged from 7.34 to 12.57%, and the mean head rice yield ranged from 59.79 to 92.13%. It is recommended that detailed performance evaluation of the improved paddy parboiler be done to investigate the effects of other parboiling parameters on moisture uptake and milling quality of rice for both direct and portion-size filling of paddy grains into the parboiling tank and also optimize the performance process using RSM.

Keywords: Development, improved, paddy, parboiler, processors

1 INTRODUCTION

Rice (*Oryza Sativa*) belongs to the family of Gramineae. The crop is a staple diet for more than half of the world's population [1]. It is estimated that 80% of the world's population uses rice as a major source of calories [2]. It is among Nigeria's most important crops which occupy a fundamental portion of the government's strategic efforts in tackling food shortages through various national programs and agencies in the country. It is an essential food and can potentially become a major export commodity of the country in the near future. It is eaten as whole grain and can be converted to rice flour and subsequently reconstituted in hot water into a paste and eaten with soup known as *tuwo shinkafa* in Northern Nigeria. Paddy production in Nigeria has been on the increase in recent years [3]. In West Africa, Nigeria is the largest rice producer. Nigeria produced 8.5 million tonnes of rice in 2022, which makes Nigeria occupy the 13th position in the world's top 20 countries in rice production in the year 2022 as presented in Figure 1 [4].

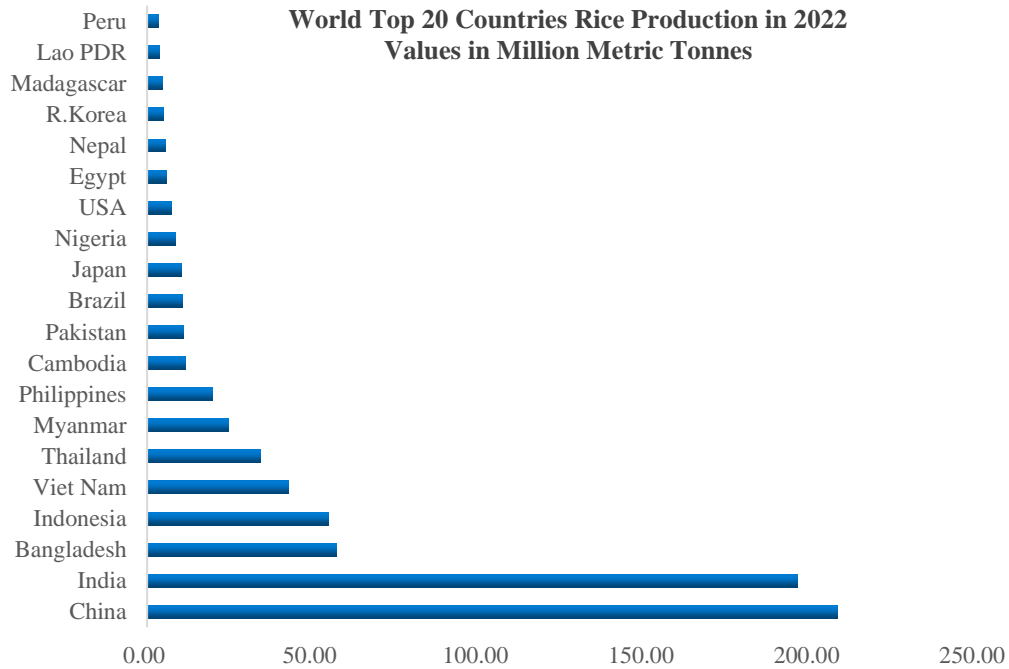


Figure 1. World Top 20 Countries Rice Production in 2022 [4]

Paddy is an unprocessed rice crop consisting mainly of white rice (70%), rice husk (20%), rice bran (8%) and rice germ (2%) [5]. Paddy can be processed into parboiled rice or regular rice. Regular rice is produced by direct milling of the paddy into without parboiling while traditionally parboiled rice is produced following the steps as given in Figure 2.

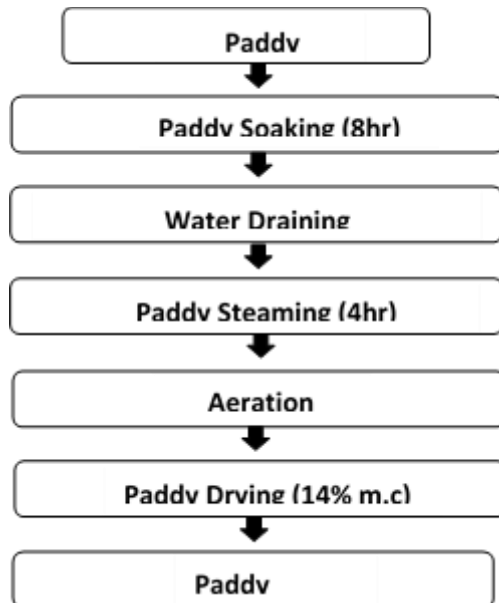


Figure 2. Traditional parboiled rice processing

Parboiling is a hydrothermal process that means partial boiling. Parboiling is done because of its soft structure, rice if milled raw may suffer excessive breakage along with loss of vitamins and minerals.

The white rice kernel inside a paddy consists mainly of starch (Amylose (20%) and Amylopectin (80%)). The theory of parboiling is presented in Figure 3.

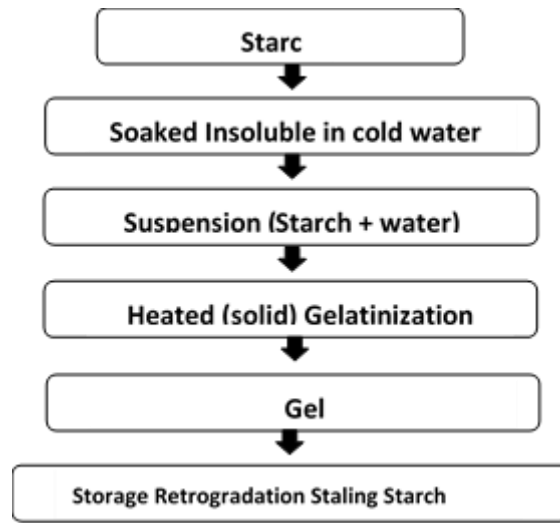


Figure 3. Theory of Parboiling

During parboiling, there is irreversible swelling and fusion of starch granules. The starch changes from crystalline to amorphous form and partial gelatinization of starch occurs [6]. Parboiled rice is consumed in every part of Nigeria, and the government policy of disbanding rice importation in recent times has made rice to have wider spread cultivation across the nation. This has also led to an increase in the number of small-scale rice processing industries in the country, and the majority of the small-scale processors have upgraded their plants from the olden-days rice dehulling machine to a modern rice milling machine that is faster, more efficient and produce a better quality rice heads. Some of them have also gone the extra mile of acquiring rice destonner in their efforts to meet the consumer demand for quality rice, but the majority of them yet depend on the traditional paddy parboiling method which uses pots or open drums to cook paddy using firewood on a tripod. This method results in overcooking the paddy closer to the heat source instead of steaming the entire paddy uniformly. The method produces poor-quality rice (coloured); it is not efficient and is time-consuming. It is therefore necessary to develop an improved paddy parboiler that will have a steam tank separate from the parboiling tank so that steam under pressure can be channeled through pipes into different parts of the parboiling tank uniformly. This research aimed at developing a sustainable paddy parboiler that can be adopted by small/medium scale rice processors in Nigeria and also carry out its performance test of the parboiler.

2 MATERIALS AND METHODS

As shown in Figure 4, the improved paddy parboiler consists of (1) Stove (2) Boiler (3) Temperature gauge (4) Pressure gauge (5) Steam pipe (6) Steam pipe support (7) Valves (8) Parboiler tank (containing perforated steam distribution pipes) (9) Parboiler stand and material outlet. To prevent corrosion, stainless steel materials were used for the boiler, pipes and fittings and the parboiler tank. Table 1 presents the specifications of the various components of the improved rice parboiler.

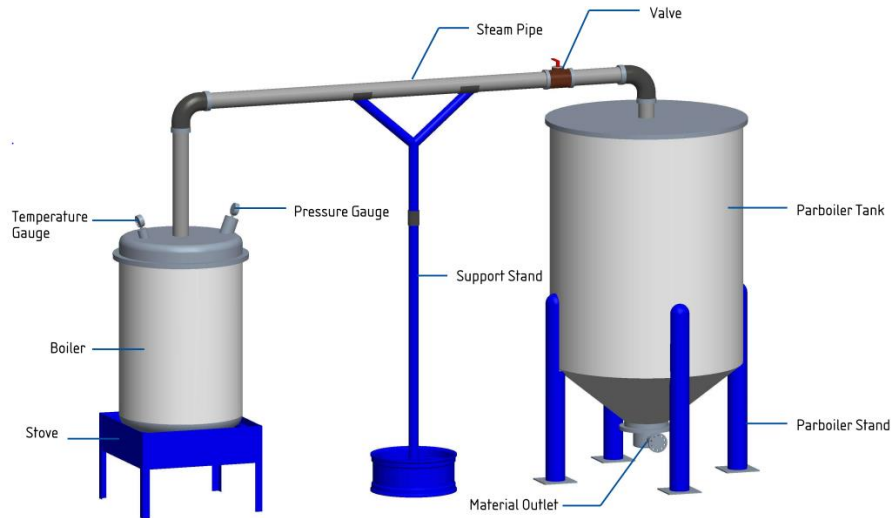


Figure 4. Isometric view of the Rice Parboiler

Table 1. Specifications of the Improved Rice Parboiler

S/N	Parameters	Specifications
1	Parboiler capacity	300 kg
2	Stainless steel thickness	2 mm
3	Density of Stainless steel	7.93 kg/m ³
4	Parboiler volume	0.528 m ³
5	Parboiler height	1060 mm
6	Parboiler diameter	779 mm
6	Boiler capacity	0.1 m ³ (100 litre)
7	Boiler thickness	3 mm
8	Boiler height	700 mm
9	Steam pipes dimensions	1 and 2 inches pipes
10	Stove dimension	490 x 470 x 300 mm
11	Gas cylinder capacity	12 kg
12	Unimeter digital moisture meter	

2.1 Development of the Boiler (pressure steam pot) and the Stove

The boiler is a 100 litre capacity vessel made from 4 mm thick stainless steel. The boiler generates the required steam which is conveyed by 2-inch steam pipes to the paddy in the parboiler tank. On the steam, a 2-inch stainless steel valve is installed to control stem supply into the paddy parboiler tank. A hollow inverted cylinder is concentrically welded to the inner part of the boiler to increase the surface area of the boiler receiving the heat and therefore reduce the water boiling time. A smaller size boiler was adopted to reduce the time of producing highly pressurized steam, and a water replenishing point was provided so that the volume of water required for parboiling paddy of 1 to 1.5 L/kg of paddy processed as recommended [7]. The stove was designed for different kinds of fuels, such as liquefied petroleum gas (LPG), firewood, rice husk, or sawdust to fire the boiler. In this study, the LPG was used for the performance evaluation of the parboiler.

2.2 Development of the Paddy Parboiler Tank and Steam Distribution Pipes

Using the relation, $\text{Density} = \frac{\text{Mass}}{\text{Volume}}$ with a paddy parboiler tank of 300 kg paddy capacity, take the bulk density of paddy as 568 kg/m³ [8]. The required volume of the parboiler was calculated as 0.528 m³. The parboiler tank is a cylindrical container in which the steaming of the paddy takes place. The steam pipe conveys the high-pressure steam from the boiler to a distribution box inside the parboiler tank. Five (5) blind perforated pipes (1 inch Ø) are connected to a distribution box inside the parboiler tank. The pipes are arranged vertically in the parboiler tank to discharge steam under pressure to the paddy at different strategic positions. An air-tight lid was provided to prevent heat and steam losses from the paddy parboiler tank. The parboiler tank was mounted and supported on a sturdy stand. The paddy parboiler tank was designed taken into consideration structural strength to withstand the various forces acting on it. It has a circular cross-section having its lateral pressure, total lateral wall load per perimeter and vertical wall load per perimeter are determined using the Jassen equation as given [9].

$$L = (wR/\mu) + (1 - e^{-k\mu h/R}) \quad (1)$$

Where, L = Lateral pressure (kg/m²); w = Density of paddy (568 kg/m³); R = Hydraulic radius (m) = cross-sectional area of tank divided by its perimeter.

$$\text{Therefore, } R = D/4$$

The diameter of the parboiler tank = 0.779 m. Hence, $R = 0.195$ m; μ = Coefficient of friction between grain and wall ($\mu = 0.314$) [10]. k = ratio of lateral to vertical pressure in grains.

$$k = \frac{1 - \sin\vartheta}{1 + \sin\vartheta} \quad (2)$$

Taking ϑ as 32.69° for paddy [11], $k = 0.299$. h = depth of paddy to the point under consideration = 1.06 m, $L = 1409.55$ kg/m², $L = 13827.69$ N/m².

$$P = Lh \quad (3)$$

Where, P = Total lateral wall load per perimeter (kg/m). Therefore, $P = 1494.12$ kg/m.

$$F_V = \mu Lh \quad (4)$$

Where, F_V = Vertical wall load per perimeter (kg/m). Therefore, $F_V = 469.15$ kg/m.

2.3 Energy Required to Steam the Paddy

Energy required to steam the paddy was estimated using equation 5.

$$E = E_1 + E_2 \quad (5)$$

Where: E = Total energy required to steam paddy (kJ); E_1 = Sensible heat added to paddy (kJ); E_2 = Sensible heat added to paddy (kJ).

$$E = W_p C_p (T_1 - T_2) + IW_g \quad (6)$$

Where, W_p = Weight of the paddy to be steamed is 300 kg. C_p = Specific heat capacity of paddy is taken as 4.34kJ/kg-K. [12]. T_1 = Minimum ambient temperature of Kano 100°C [13]. T_2 = Temperature inside the parboiler tank 21°C. I = Heat of vaporization of water at 100°C = 2256 kJ/kg [12]. W_g = Mass of water gained by steaming (kg).

$$W_g = \frac{W_p(M_f - M_i)}{100 - M_f} \quad (7)$$

Where M_i = Paddy initial moisture content 13%; M_f = Paddy final moisture content 38%. As given by [14].

2.4 Performance Evaluation of the Improved Paddy Parboiler

The paddy parboiler was evaluated using *Jamila* a local variety of paddy. The experiment was carried out using completely randomized design (CRD) with three levels of steaming period of 25, 30, and 35 minutes and three temperature levels of 100, 105 and 110°C respectively in three replications. Two performance indicators used for the evaluation of the parboiler were paddy moisture uptake and head rice yield percentage determined using equations 8 and 9 respectively. Paddy moisture uptake: the percentage of moisture uptake for the samples was determined using direct measure with a Unimeter digital moisture meter by calculating the difference between the initial moisture content of paddy before steaming and the final moisture content of paddy as given in equation (8) [15].

$$U_m = M_i - M_f \quad (8)$$

Where U_m = Percentage moisture uptake of paddy samples (%); M_f = Final moisture content of paddy (%); M_i = Initial moisture content of paddy (%). Head rice yield (HRY) percentage: After steaming, the paddy then was dried to reach a moisture content of 14%, and was milled using husker and polisher to produce parboiled rice and head rice yield was determined using the relationship given by [16] in equation (9).

$$\text{Head rice yield \%} = \frac{\text{Mass of whole grain}}{\text{Total mass of milled rice}} \times 100 \quad (9)$$

3 RESULTS AND DISCUSSION

3.1 The Developed Improved Paddy Parboiler

Plate 1 presents the pictorial view of the assembly of developed paddy parboiler for small and medium-scale processors.



Plate 1. Pictorial View of the Developed Paddy Parboiler

3.2 Performance Results

The results of the performance evaluation of the improved parboiler using paddy moisture uptake and head rice yield percentage of the parboiler at different temperature levels and steaming period are

presented in the following sections. This method is similar to the method applied [16]. Table 2 shows the Analyses of variance results for moisture uptake and head rice yield percentage. Table 3 presents the mean separation results of performance tests for factors that have significant effects.

Table 2. Analyses of variance on the result of performance tests

Source of variation	Paddy moisture uptake (F-values)	Head rice yield % (F-values)
Steaming period (P)	104.52*	446.57*
Temperature (T)	659.78*	325.17*
P*T	2.30 ^{NS}	74.14*

*Significant at 1% level; ^{NS} No Significant difference

Table 3. Mean separation results of performance tests

Treatments	Paddy moisture uptake	Head rice yield (%)
Steaming period (mins)		
35	11.11 ^A	92.13 ^A
30	10.16 ^B	73.27 ^B
25	9.02 ^C	59.79 ^C
Temperature (^o C)		
110	12.57 ^A	87.90 ^A
105	10.37 ^B	76.92 ^B
100	7.34 ^C	60.37 ^C

3.2.1 Paddy Moisture Uptake

The results from Table 2 show that the steaming period and temperature have significant effect on the moisture uptake at 1% probability level, while the interaction effect between the steaming period and temperature is not statistically significant on the paddy moisture uptake. Mean paddy moisture uptake ranged from 9.02-11.11% and 7.34-12.57% for the steaming period and temperature levels under consideration respectively. The results for further analyses using Least Significant Difference (LSD) as presented in Table 3 show that the mean moisture uptake increases with an increase steaming period and the values are significantly different at 5% probability level. This is because as the steaming period increases, there is more time for the paddy to be exposed to water thereby increasing its moisture uptake. These results corroborate with the findings of [15, 17]. From Table 3, it is evident that paddy moisture uptake also increases with an increase in temperature, and mean values of moisture uptake for the three levels of temperature under consideration are significantly different at 5% probability level. This trend can be associated with the energy level of water at higher temperature makes it available for absorption by paddy than at low temperature probably because water molecules are more free when the temperature rises. The results agreed with the findings of [15].

3.2.2 Head Rice Yield Percentage

Table 2 revealed that the steaming period, temperature and the interaction between the steaming period and temperature have significant effect on the head rice yield at 1% probability level. Mean head rice yield ranged from 59.79 - 92.13% and 60.37 - 87.90% for the steaming period and temperature levels under consideration respectively. The results for further analyses using LSD (Table 3) show that the mean

values of head rice yield increase with increased steaming period and the values are significantly different at 5% probability level. This is probably because when the steaming period increases, a larger portion of the paddy is well steamed thereby reducing the portion of the paddy that is not well steamed and therefore increasing the head rice yield percentage. This result is in accord with the findings [18]. From Table 3, it is evident that head rice yield also increases with an increase in temperature, and mean values of head rice yield for the three levels of temperature studied are significantly different at 5% probability level. This phenomenon can be associated with the higher energy acquired by the steam when the temperature increases which could aid the splitting of the paddy bran. The results agreed with the findings of [18, 19].

4 CONCLUSIONS

The following conclusions can be drawn from the study: An improved paddy parboiler for small and medium-scale processors was developed and its performance evaluation was carried out. The results show that the steaming period and temperature have a significant effect on the moisture uptake at 1% probability level. Mean paddy moisture uptake ranged from 9.02-11.11% and 7.34-12.57% for the steaming period and temperature levels under consideration respectively. The results showed that the steaming period, temperature and the interaction between the steaming period and temperature have a significant effect on the head rice yield at 1% probability level. Mean head rice yield ranged from 59.79 - 92.13% and 60.37 - 87.90% for the steaming period and temperature levels under consideration respectively.

REFERENCES

1. Fukagawa, N.K. and Ziska, L.H. (2019). Rice: Importance for Global. *Journal of Nutritional Science and Vitaminology*, vol. 65, S2-S3.
2. Asati, A.R. 2013. Treatment of Waste Water From Parboiled Rice Mill Unit by Coagulation / Flocculation. *Int. J. Life Sc. Bt & Pharm. Res.*, vol. 2, pp. 264-277.
3. Shittu, S.K. and Eze, N.M. (2021). Performance Evaluation of a Rice (*Oryza sativa*) Thresher. *FUOYE Journal of Engineering and Technology*, vol. 6, issue 3, ISSN: 2579-0617 (Paper), 2579-0625 (Online). <http://journal.engineering.fuoye.edu.ng/>.
4. FAOSTAT (2024). Food and Agricultural Organization of the United Nations Statistics. https://www.fao.org/faostat/en/#rankings/countries_by_commodity. Retrieved 1st October, 2024.
5. Zou, Y. and Yang, T. (2019). Rice Husk, Rice Husk Ash and Their Applications. *Rice Bran and Rice Bran Oil*, AOCs Press, pp. 207-246.
6. Taghinezhad, E., Khoshtaghaza, M. H., Minaei, S., Suzuki, T., and Brenner, T. (2016). Relationship Between Degree of Starch Gelatinization and Quality Attributes of Parboiled Rice During Steaming. *Rice Science*, vol. 23, issue 6, pp. 339-344.
7. Sayanthan, S. and Thusyanthy, Y. (2018). Rice Parboiling and Effluent Treatment Models; a Review. *International Journal of Research Studies in Agricultural Sciences*, vol. 4, issue 5, pp. 17-23.
8. Ravi, P. and Venkatachalam, T. (2014). Important Engineering Properties of Paddy. *University of Belgrade Faculty of Agricultural Engineering Scientific Journal*, vol. 4, pp. 73-83.
9. Dyck, G., Rogers, A. and Paliwal, J. (2023). A Review of Analytical Methods for Calculating Static Pressures in Bulk Solids Storage Structures. *KONA Powder and Particle Journal*, pp. 1-15. [/https://doi.org/10.14356/kona.2024013](https://doi.org/10.14356/kona.2024013)
10. Asli-Ardeh, E.A., Abbaspour-Gilandeh, Y. and Shojaei, S. (2010). Determination of dynamic friction coefficient of paddy grains on different Surfaces. *Int. Agrophysics*, vol. 24, pp. 101-105. <https://www.researchgate.net/publication/286854901>.

11. Sahul, B., Khokhar, D., Patel, S., Mishra, N.K. and Chandel, G. (2018). Some Engineering Properties of Selected Paddy Varieties. *Int. J. Pure App. Biosci.*, vol. 6, no. 2, pp. 1337-1342. <http://dx.doi.org/10.18782/2320-7051.6513>.
12. Mohapatra, D. and Bal, S. (2003). Determination of specific heat and gelatinization temperature of rice using differential scanning calorimetry. *Published by the American Society of Agricultural and Biological Engineers, St. Joseph, Michigan* www.asabe.org. No 036113, ASAE Annual Meeting, doi: 10.13031/2013.15335.
13. Shittu, S.K., Ibrahim, B., Nalado, D.D. Lawan, I. and Jibril, A.N. (2021). Modification of an Existing NSPRI Fish Smoking Kiln. *Bayero Journal of Engineering and Technology*, vol.16, no. 1, pp. 148-156.
14. Muhammad, A.I., Ahmad, R.K. and Lawan, I. (2017). Effect of moisture content on some engineering properties of groundnut pods and kernels. *Agric Eng Int: CIGR Journal*, vol. 19, no. 4.
15. Gbabo, A., Abdullahi, L. and Kuku, A.M. (2014). Design, Fabrication and Testing of Improved Traditional Rice Parboiler. *International Journal of Engineering and Technical Research*, vol. 2, issue-9, pp. 331-338.
16. Agidi, G., Dauda, S.M. and Igbeka, J.C. (2008). Effect of variety, pressure and specific volume of steam on the head rice yield of milled parboiled rice. *Jour. Food Sci Technol*, vol. 45, no. 3, pp. 282-283.
17. Rezaei, F., Corleto, R., Giudice, V.L., Bak, M., Németh, R. and Niemz, P. (2024). Water uptake and permeability in sapwood and heartwood of hydro-thermally proceed Turkey oak. *Wood Material Science and Engineering*, vol. 19, issue 3, pp. 803-810. <https://doi.org/10.1080/17480272.2024.2337151>.
18. Hasbullah, R., Pujantoro, L., Koswara, S., Fadhallah, E.G. and Surahman, M. (2017). Steaming process of paddy to improve quality and reduce glycemic index of parboiled rice. *Proc. III International Conference on Agricultural and Food Engineering. Acta Hort.* 1152. ISHS 2017. DOI 10.17660/ActaHortic. 1152.50 <https://www.researchgate.net/publication/315466417>.
19. Kumar, V., Singh, J., Chauhan, N., Chandra, S., Kumar, V. and Yadav. M.K. (2018). Process of paddy parboiling and their effects on rice-A Review. *Journal of Pharmacognosy and Phytochemistry*, SP1, pp. 1727-1734.