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Optimizing parboiling parameters: Investigating the impact of microwave heating duration on the milling quality of soaked paddy

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Abstract
Rice, or *Oryza sativa*, constitutes a fundamental dietary staple for approximately half of the global population. However, minimizing losses during the postharvest processing of rice is imperative to meet the demand effectively. To address these losses, a crucial step involves parboiling, an essential process conducted prior to rice milling. Parboiling, synonymous with the milling treatment of paddy, plays a pivotal role in enhancing the overall quality of rice. This research delves into the investigation of the impact of varying durations of microwave heating on soaked paddy, specifically focusing on its milling quality. Furthermore, the study encompasses the optimization of soaking and microwave heating parameters employed in the parboiling of paddy, aiming to contribute to the reduction of postharvest losses and enhance the efficiency of rice processing. the Husking Efficiency (%) increases with increase in exposure time. The Husking Efficiency (%) was found to be highest for 6 min followed by 4 min & 2 min. The Husking Efficiency (%) was found to be highest for moisture content (wb) 33% followed by 30% & 27%. Polishing Bran (%) decreases with increase in exposure time. The Bran (%) was found to be lowest for 6 min followed by 4 min & 2 min. The Bran % was found to be lowest for moisture content (wb) 30% followed by 33% & 27%. The total yield (%) increases with increase in exposure time. The total yield (%) was found to be highest for 6 min at 450 W followed by 4 min & 2 min. The Total yield (%) was found to be highest for moisture content (wb) 33% followed by 30% & 27%. the Head Rice Yield (%) of paddy increased with the increase in time for exposure at various power levels. the broken (%) was found to be highest at power level of 180 W. The Percentage of broken was found to decrease with increase in time of exposure. Optimization parameters was observed that maximum value of Husking Efficiency (%), Total yield (%), Head yield (%), and minimum value of Polish (%), Broken (%) in a combination of 450 W, 6 min exposure time for 33% Moisture content (WB).

Keywords: Optimization, parboiling, milling quality, microwave heating duration, soaked paddy

1. Introduction

Paddy, also known as *Oryza sativa*, holds significant agricultural importance in Asia, particularly in India, where it stands as one of the foremost crops. India ranks among the world's leading rice producers, contributing to 20% of global rice production and ranking as the fourth largest rice exporter globally. The kharif season of the 2021-22 crop year (July-June) witnessed an estimated rice production of 121 million tons, compared to 112.9 million tons in the previous year (Indian rice market update, 2022). Rice plays a crucial role in the nutritional intake of a majority of Indians, as economic constraints often limit access to alternative food sources like fruits, vegetables, dairy, and animal products. Consequently, rice becomes the primary source meeting daily energy requirements (caloric intake) and fulfilling the essential need for vitamins, proteins, and other nutrients. The nutritive value of rice is particularly vital for the population of South East Asia and extends its significance globally. Typically, paddy is harvested with a relatively high moisture content ranging from 20% to 24% (wb). To safeguard against postharvest deterioration, it is crucial to dry harvested paddy to a moisture content of approximately 12 to 14% (wb) before storage, milling, and subsequent storage of milled rice. This moisture level is deemed safe for these processes. Typically, rice varieties comprise around 20% rice hull or husk, 11% bran layers, and 69% starchy endosperm, collectively referred to as total milled rice. During the milling process, the fractions obtained include 20% husk, 8 to 12% bran (depending on the milling degree), and 68 to 72% milled rice or white rice (varying with the selected variety). Total milled rice encompasses whole grains (head rice) and broken rice. By-products generated in the rice milling process include rice hull, rice germ, bran layers, and broken rice (IRRI, 2013).

Parboiling is a hydrothermal procedure wherein paddy absorbs water deliberately, followed by steaming to gelatinize the starch in the endosperm before drying and milling. This parboiling process seals internal fissures in the rice grain, resulting in a higher head rice yield (HRY) during milling (Manful *et al.*, 2009) [31]. Approximately one fifth of the world's total rice harvest undergoes parboiling. This transformative process alters the starch structure, making it more crystalline and hardening the endosperm, which becomes translucent. This hardness enhances the grain's toughness, reducing breakage during milling and improving head rice yield. Furthermore, parboiling increases the grain's resistance to insect infestation and enhances its overall nutritional quality. Parboiling, an age-old rice processing technique, is widely practiced in developing nations such as India, Sri Lanka, and Bangladesh, as well as in some other rice-exporting countries. Both traditional and modern high-end methods have been employed to produce parboiled rice (PBR), with various devices and techniques developed in recent years. However, modern methods, being energy and capital intensive, are not suitable for small-scale operations at the village level, where they are most needed (Roy *et al.*, 2011) [32]. The parboiling treatment brings about significant physicochemical changes in both paddy and rice, influencing subsequent storage, cooking, milling, and eating qualities. Despite its numerous advantages, PBR requires more energy, water, and time for processing and cooking compared to uncooked raw rice. The parboiling process involves starch gelatinization, enhancing the overall hardness of rice during the drying process, minimizing breakage and losses, and thereby increasing the milling yield of paddy. Excessive parboiling, however, can lead to husk components opening and endosperm bulging during milling, resulting in surface scouring and the loss of ground particles into the husk and bran. Incomplete or non-uniform parboiling, on the other hand, produces easily breakable white-bellied rice during milling, reducing the head rice yield. The parboiling process typically consists of three main steps: soaking the paddy in hot water for approximately 10 to 24 hours to saturate it with moisture, followed by heating to gelatinize the paddy and subsequent drying and milling. The overall advantages of parboiling include increased grain hardness, making it more resistant to insect infestation. Total kill after milling sees an enhancement of three to four percent compared to regular rice, as breakage is reduced due to the parboiling process. Parboiled rice boasts a rich mineral content, comprising 3% calcium, potassium, zinc, iron, and magnesium. Notably, it retains more starch during cooking, maintaining a firm texture for extended periods and a fluffy consistency. Additionally, parboiled rice is a good source of vitamins, particularly vitamin B and niacin, and it exhibits a low glycemic index. Microwave heating involves the use of specific electromagnetic wave frequencies to generate heat in a material, commonly utilized for defrosting and low-pressure drying. Frequencies of 915 MHz to 2450 MHz are employed, with 2450 MHz being typical for home ovens and both frequencies used in industrial applications (Pare and Madhya, 2011). The heating mechanism relies on the interaction between water molecules and the electromagnetic field, with higher moisture content areas absorbing more energy, resulting in faster drying and increased heating. The application of microwave heating in rice offers several benefits, including the improvement of physical and chemical characteristics, optimization of cooking conditions, preservation of sensory and nutritional properties, substitution of steam and conventional drying in the parboiling process through microwave heat treatment, and optimization of the processing of puffed rice products (Kaasova *et al.*, 2001) [33]. The parboiling process, a hydrothermal method that enhances the overall strength of rice grains through gelatinization, involves four primary unit operations: soaking, draining, heating, and drying. Each of these operations requires a well-designed setup for effective steaming and drying. To address the substantial heat losses encountered in the parboiling process and enhance energy efficiency, our study employed a microwave oven for the heating phase. Microwave ovens are known for their efficient, uniform, and time-saving heat application. The specific objectives of this study include:

1. To study the effect of different durations of microwave heating of soaked paddy on its milling quality.
2. To optimize the soaking and microwave heating parameters for parboiling of paddy.

2. Materials and Methods

The current investigation aimed to assess the impact of duration of microwave heating on paddy for parboiling and along with its effects on milling quality. This section outlines the materials, instruments, equipment, techniques, and experimental procedures employed to achieve the objectives of the study. The research was carried out at the Department of Post-Harvest Process and Food Engineering, College of Agricultural Engineering, JNKVV, Jabalpur (MP).

2.1 Sample Collection

A quantity of approximately 20 kg of the JR-81 paddy variety was obtained from the Department of Plant Breeding, College of Agriculture, JNKVV, Jabalpur. The paddy samples underwent a cleaning process, and their initial moisture content was determined. Subsequently, individual samples of 300 g each were precisely weighed and placed in microwaveable containers. These samples were then subjected to various power and time combinations according to the experimental plans outlined in Table 1. The study involved three distinct power levels for the microwave (180 W, 300 W, 450 W) and different time durations as per the experimental design.

The research methodology involved several sequential steps. Initially, the study focused on measuring moisture absorption during hot soaking. Subsequently, the milling qualities of the parboiled paddy were determined and compared with those of freshly harvested paddy samples (raw paddy) at a standardized moisture content of 13.6% (dry basis). Finally, the optimization of process parameters for parboiling was calculated.

Table 1: The dependent and independent parameters used in the study

Sr. No	Independent parameters	Levels	Dependent parameters
1.	Moisture content of soaked paddy	3 Moisture Content (wb): 27,30,33%	• Moisture absorption during hot soaking of paddy. • Milling quality of parboiled paddy.
2.	Microwave power levels	3	
3.	Microwave heating time	7	

2.2 Experimental procedures
As per the developed plan the experiments were conducted under following sub heading…

2.2.1 Moisture content determination by hot air oven method
Temperature controller and air oven was used for gravimetric method of moisture content determination. The temperature and time combination of 130 °C and 1 h. was used to find the moisture.
Procedure:
a) Sample in Petri dish
b) Placing in hot air oven
c) Setting time and temp.

The samples were weighed initially before placing in the hot air oven. Final weight was also recorded and the moisture content was calculated using the following equations.

$$\text{Moisture content (wb)} = \frac{\text{intial weight} - \text{final weight}}{\text{intial weight}} \times 100$$

$$\text{Moisture content (db)} = \frac{\text{intial weight} - \text{final weight}}{\text{final weight}} \times 100$$

It was found that 27%, 30% and 33% moisture content (db) were obtained in 10 hr, 24 hr and 36 hr respectively

2.2.2 Process of parboiling
The research work is based on parboiling which is a hydrothermal treatment and has steps of soaking, draining, heating and drying.

2.2.2.1 Soaking: The initial moisture content of 10 g paddy sample was 8% (db). The main aim of this process is to increase the moisture content so that all the voids and cracks of the rice grains can be filled by water. Due to hydrogen bonding, the intermolecular forces of attractions within the rice kernel are increased up to a great extent and the partial pre-gelatinization of starch in endosperm of rice kernel starts. For the processes of soaking; 11 samples each weighing 50 g each were soaked for the duration of 2 hr, 4 hr, 6 hr, 8 hr, 9 hr, 10 hr, 14 hr, 20 hr, 24 hr, 28 hr, 36 hr respectively.

2.2.2.2 Draining: The soaked samples contain a lot of surface moisture along with free gravitational water which can be easily drained out by gravity. The samples are left free into a sieve for draining out the free water with the effect of gravity. Then these drained samples were wrapped in blotting paper to remove hygroscopic water from their surface.

2.2.3 Sample Preparation
Then three samples (each weighing 6 kg) rice was soaked for 10 h, 24 h, 36 h for achieving the 27%, 30%, 33% mc (db) respectively. Each of these three soaked samples (6 kg) were used to form 22 samples each weighing 300 g constituting for 66 samples.

2.2.4 Microwave Heating Treatment
Drying was performed in a domestic digital Microwave oven (Samsung trio CE107 MDF). MW oven at three different microwave power levels (180, 300, 450 W) three energy levels were selected. Various parameters were used to compare the differences of these selected treatment combinations between the treated paddy sample and freshly harvested paddy sample. Each set of samples were subjected to different microwave heating as given in Table 2

Table 2: Microwave power level and heating time

Sr. No	Power level (W)	Heating time (min.)
1.	180	2, 4, 6, 8, 10, 12, 14
2.	300	1, 2, 3, 4, 5, 6, 7, 9
3.	450	1, 2, 3, 4, 4.3, 5, 5.30, 6

2.2.5 Drying and weighing
The samples are allowed to dry normally for 24 h and the samples were weighed and labelled accordingly. Each of the sample shown a varying degree of reduction in weight from 300 g due to removal of absorbed water. Hence, for the uniformity of the samples new samples of 200 g were formed and labelled accordingly.

2.2.6 Milling
2.2.6.1 Process of milling
The procured paddy was converted into brown rice through a laboratory model Rice Miller at Department of Food Science, College of Agriculture, JNKVV, Jabalpur. Milling refers to the size reduction and separation operations used for processing of food grains into edible from by removing the milling process. It includes both de-husking and polishing simultaneously in a rice processing lab McGill type rice miller which collectively operates both the operations of de-husking and polishing with a sample range up to 250 g. The rice miller removes the husk of paddy grain with the help of two rubber rolls rotating in opposite direction at different speeds. Broken from husked Rice were seprated using various openings of sieves size (3.5, 4.2, 4.6 and 4.8 mm). These separated components were weighed using a weighing machine of least count 0.01 g.
The milling action of 66 treated samples and 1 controlled sample of 200 g each gave us following products of milling:
a. Husk
b. Head rice
c. Broken
d. Unshelled paddy
e. Bran, with very little losses during operation.

2.2.6.2 Milling qualities of parboiled paddy
The qualities of parboiled paddy can be calculated by following formulas:

$$\text{Degree of milling} = \frac{\text{weight of milled rice}}{\text{total weight of sample regained after milling}} \times 100$$

$$\text{Degree of polishing} = \frac{\text{weight of bran}}{\text{weight of brown rice}} \times 100$$

$$\text{Head rice yield} = \frac{\text{Degree of polishing}}{\text{total weight of sample regained after milling}} \times 100$$

$$\text{Broken percentage} = \frac{\text{weight of brokens}}{\text{weight of sample(brokens + Head rice) after milling}} \times 100$$

3. Result and Discussion
The study outcomes have been organized and elucidated under relevant headers and subheadings, providing insights into various aspects of the research. Conclusions have been drawn based on the findings. One key focus was assessing the influence of microwave heating on moisture absorption in paddy during the hot soaking stage in preparation for parboiling. Subsequently, the next section delved into the examination of moisture absorption in paddy during hot soaking through microwave parboiling, considering different exposure times and energy levels.

Milling parameters for control paddy sample

1. Husking Efficiency of control sample was found to be 85.4%
2. Polish (%) of control sample was found to be 14.1%
3. Total yield (%) of control sample was found to be 56.2%
4. Head yield (%) of control sample was found to be 18.5%
5. Broken (%) of control sample was found to be 66.8%

3.1 To study the effect of different durations of microwave heating of soaked paddy on its milling quality.

The effects of microwave heating at different duration were discussed in the following sections.

3.1.1 Husking efficiency, (%) for parboiled paddy at different exposure time of microwave heating

As shown in figure 1, 2 & 3 the Husking Efficiency (%) increases with increase in exposure time. The Husking Efficiency (%) was found to be highest for 6 min followed by 4 min & 2 min. The Husking Efficiency (%) was found to be highest for moisture content (wb) 33% followed by 30% & 27%. The Husking Efficiency (%) increases due to hardening of rice and proper gelatinization of rice.

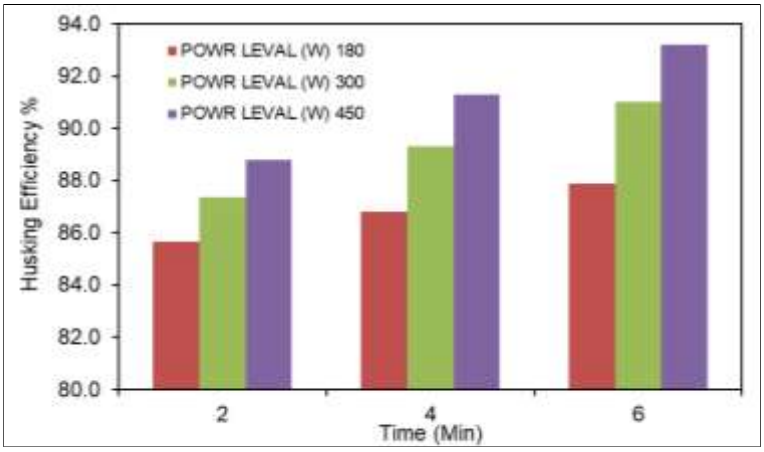

Fig 1: Observations on effect of heating power level and microwave heating time on husking efficiency (%) moisture content of soaked paddy 27% (wb)

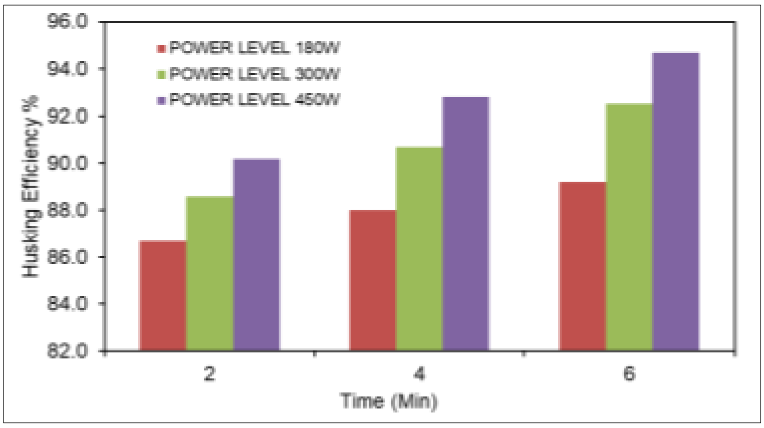

Fig 2: Observations on effect of heating power level and microwave heating time on husking efficiency (%) moisture content of soaked paddy 30% (wb)

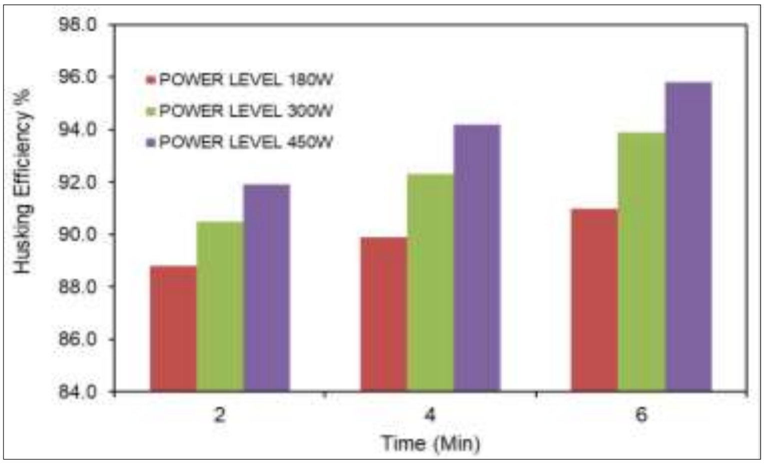

Fig 3: Observations on effect of heating power level and microwave heating time on husking efficiency (%) moisture content of soaked paddy 33% (wb)

3.1.2 Polishing (%) for parboiled paddy at different exposure time of microwave heating

As shown in figure 4, 5 & 6 the Polishing Bran (%) decreases with increase in exposure time. The Bran (%) was found to be lowest for 6 min followed by 4 min & 2 min. The Bran % was found to be lowest for moisture content (wb) 30% followed by 33% & 27%.

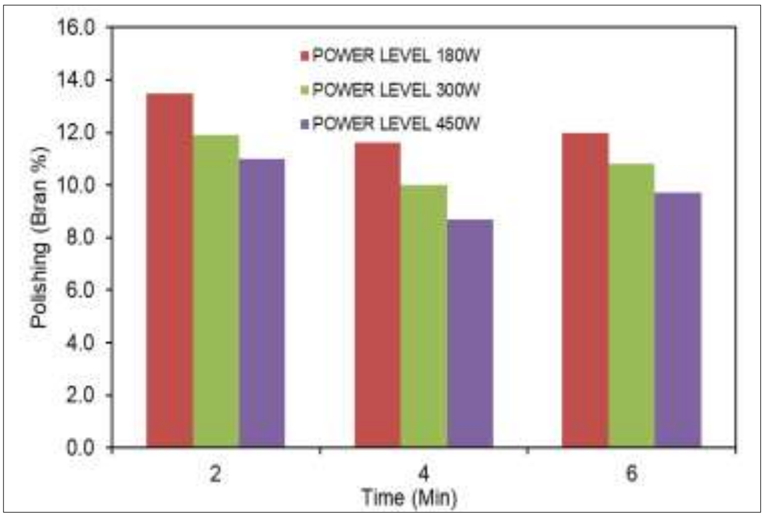

Fig 4: Observations on effect of heating power level and microwave heating time on polishing bran (%) moisture content of soaked paddy 27% (wb)

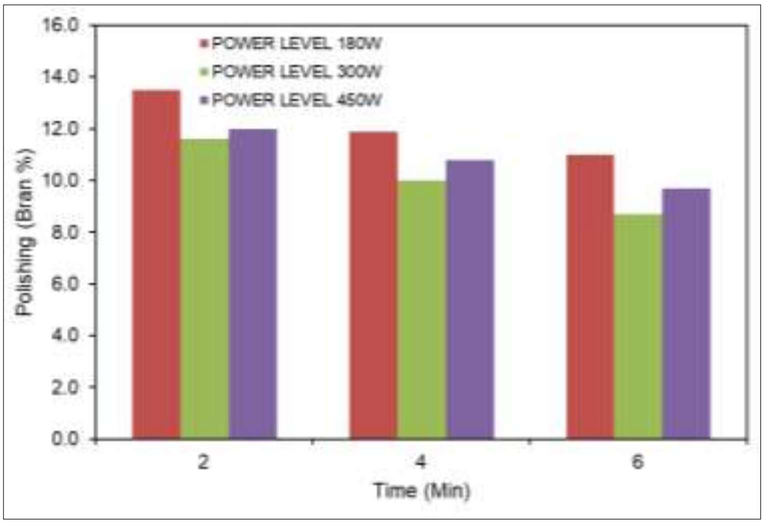

Fig 5: Observations on effect of heating power level and microwave heating time on polishing (bran%) moisture content of soaked paddy 30% (wb)

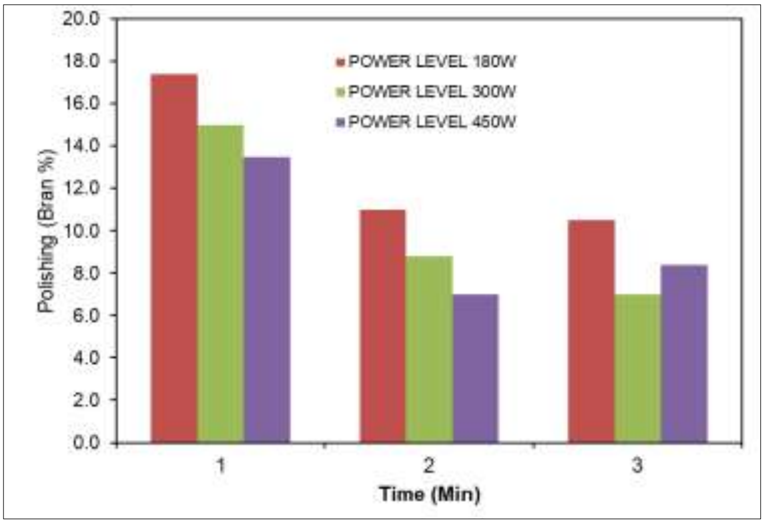

Fig 6: Observations on effect of heating power level and microwave heating time on polishing bran (%) moisture content of soaked paddy 33% (wb)

3.1.3 Total yield, % for parboiled paddy at different exposure time of microwave heating

As shown in figure 7, 8 & 9 The total yield (%) increases with increase in exposure time. The total yield (%) was found to be highest for 6 min at 450 W followed by 4 min & 2 min. The Total yield (%) was found to be highest for moisture content (wb) 33% followed by 30% & 27%.

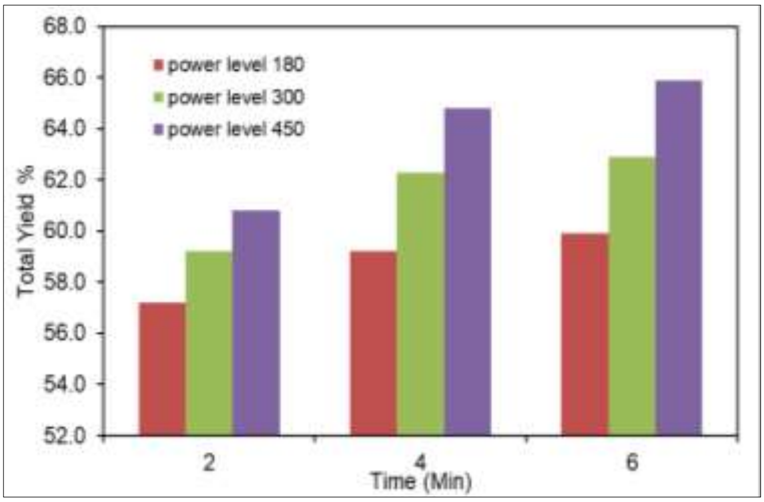

Fig 7: Observations on effect of heating power level and microwave heating time on total yield (%) moisture content of soaked paddy 27% (wb)

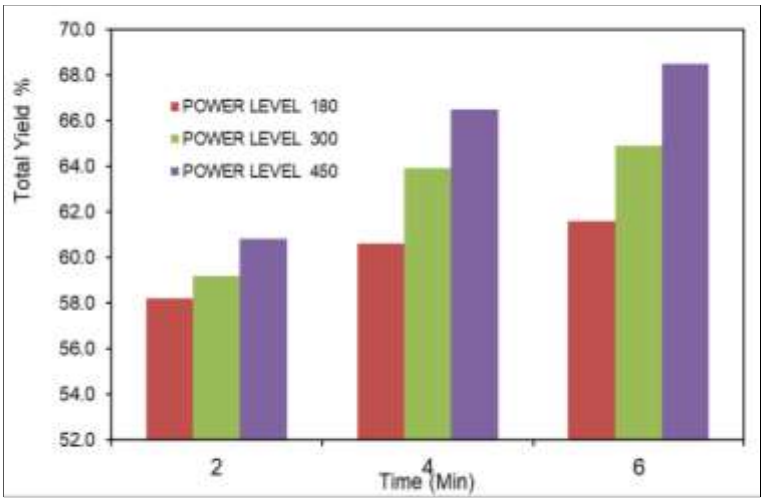

Fig 8: Observations on effect of heating power level and microwave heating time on total yield (%) moisture content of soaked paddy 30% (wb)

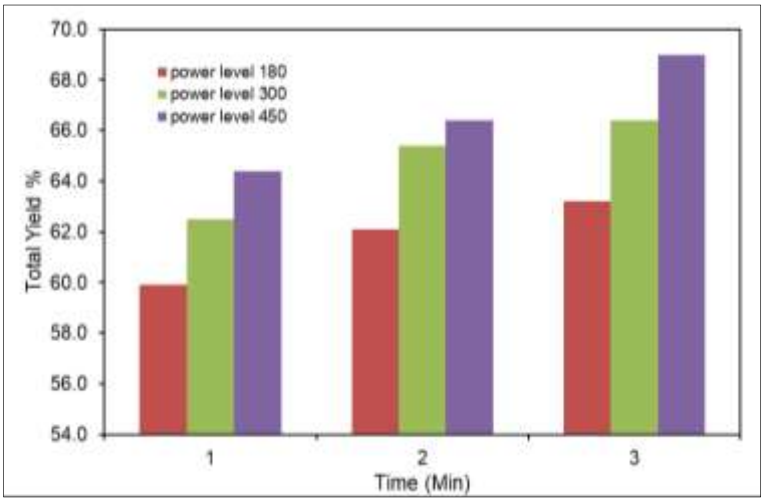

Fig 9: Observations on effect of heating power level and microwave heating time on total yield (%) moisture content of soaked paddy 33% (wb)

3.1.4 Head Rice Yield (%) for parboiled paddy at different exposure time of microwave heating

As shown in figure 10, 11 & 12 the Head Rice Yield (%) of paddy increased with the increase in time for exposure at various power levels (Fig 3). The head rice yield (%) was found to be higher for higher power level. For equal time interval the head rice yield (%) was found to be highest for 450 W followed by 300 W& 180 W. For the lowest power level more, exposure time was required in order to attain higher head rice yield (%). The higher moisture level in the higher power level facilitated proper gelatinization of the starch which resulted in hardening of rice which ultimately provided better head rice yield.

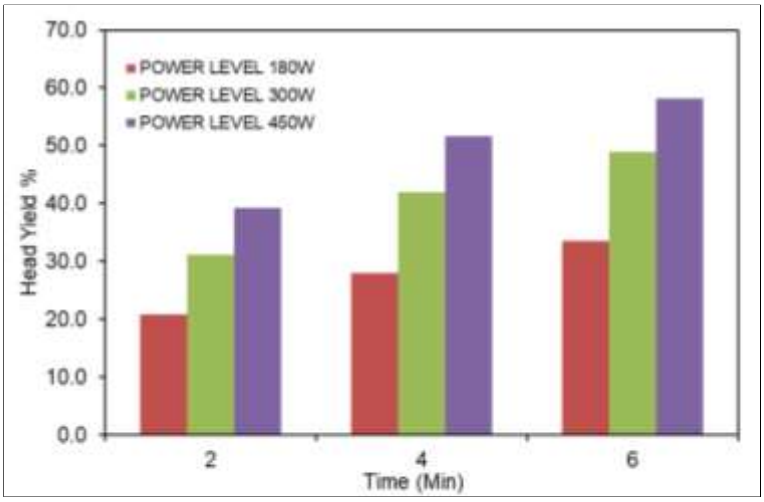

Fig 10: Observations on effect of heating power level h-4 and microwave heating time on head rice yield (%) moisture content of soaked paddy 27% (wb)

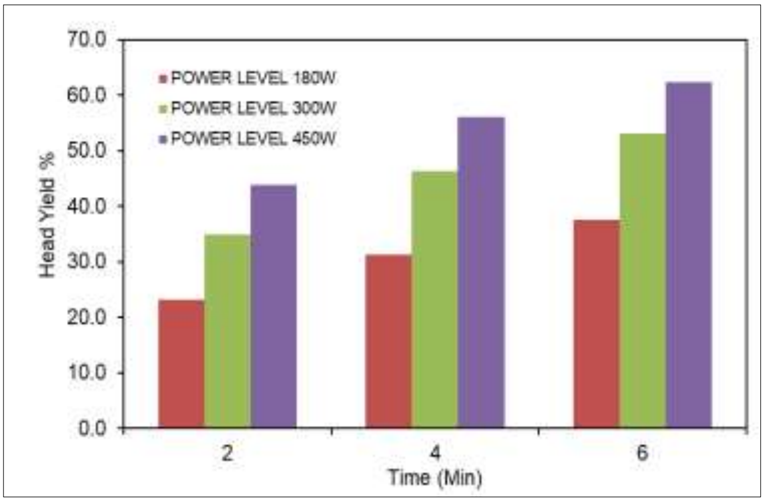

Fig 11: Observations on effect of heating power level h-4 and microwave heating time on head rice yield (%) moisture content of soaked paddy 30% (wb)

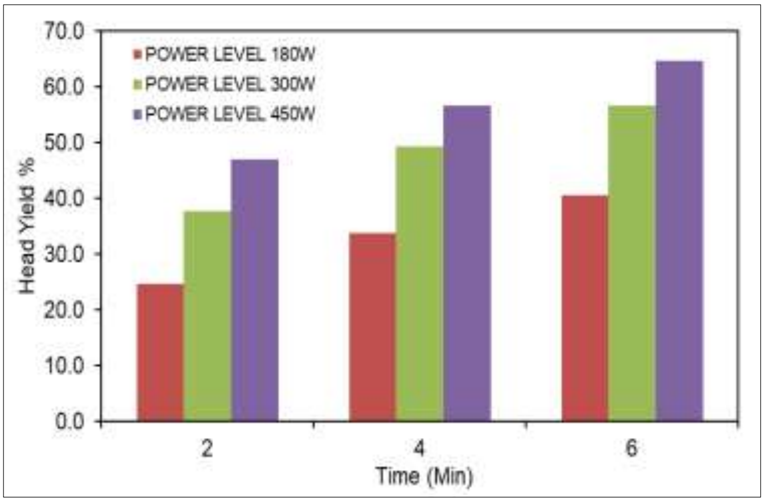

Fig 12: Observations on effect of heating power level h-4 and microwave heating time on head rice yield (%) moisture content of soaked paddy 33% (wb)

3.1.5 Broken (%) for parboiled paddy at different exposure time of microwave heating

As shown in figure 13, 14 & 15 the broken (%) was found to be highest at power level of 180 W. The Percentage of broken was found to decrease with increase in time of exposure. The lower power level at 14 min provided 67.7% broken. For The power level 450 W, we found only 6.67% broken in 5.50 min. The Major reason behind the decrease in broken with time is the high degree of gelatinization achieved with longer exposure time leading to increased hardness of the kernel. The lower power level has less moisture absorption and thus gelatinization is not proper compared to higher power level, this results in higher broken in the lowest power level compared to higher power levels. The lower power level longer exposure time allowed higher moisture absorption which resulted in complete gelatinization of starch and brittleness.

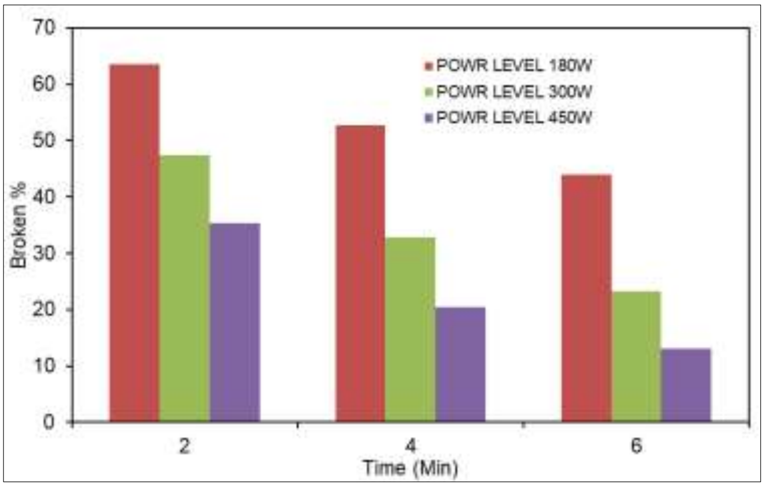

Fig 13: Observations on effect of heating power level and microwave heating time on broken (%) moisture content of soaked paddy 27% (wb)

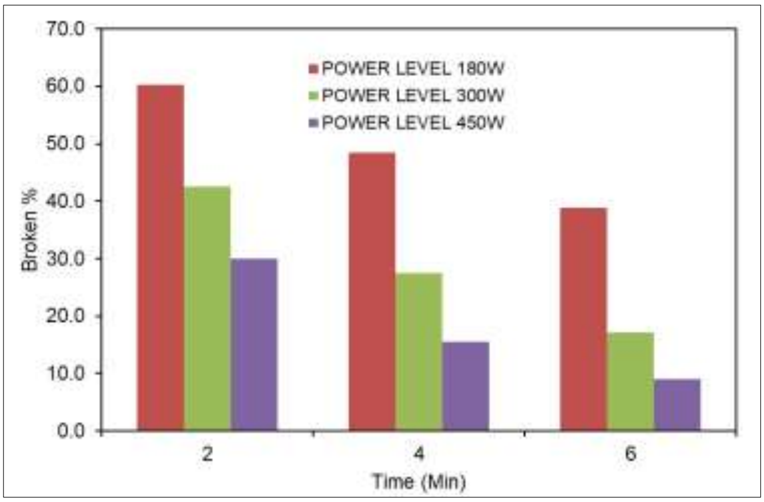

Fig 14: Observations on effect of heating power level and microwave heating time on broken (%) moisture content of soaked paddy 30% (wb)

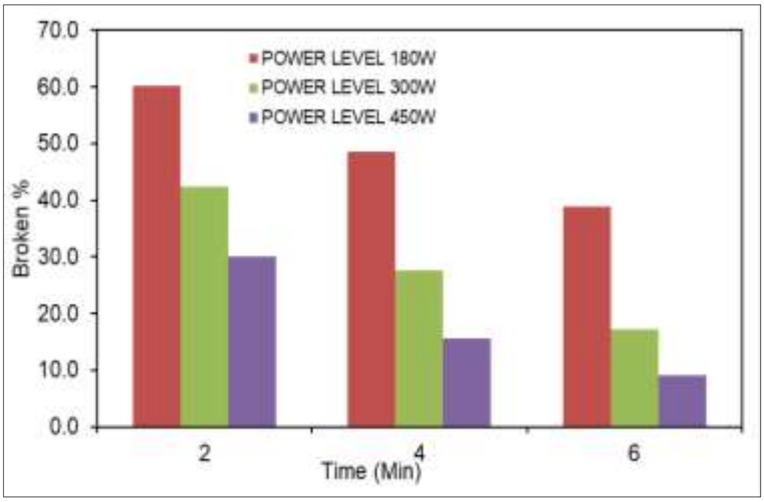

Fig 15: Observations on effect of heating power level and microwave heating time on broken (%) moisture content of soaked paddy 33% (wb)

3.2 To optimize the soaking and microwave heating parameters for parboiling of paddy

1. Husking Efficiency of 95.8% could be achieved at a combination of 450 W at 6 min exposure time for a sample of 33% moisture content (WB).
2. Polish (%) of 4.5% could be achieved at a combination of 450 W at 6 min exposure time for a sample of 30% moisture content (WB).
3. Total yield (%) of 69.5% could be achieved at a combination of 450 W at 6 min exposure time for a sample of 33% moisture content (WB).
4. Head yield (%) 64.7% could be achieved at a combination of 450 W at 6 min exposure time for a sample of 33% moisture content (WB).
5. Broken (%) of 7.2% could be achieved at a combination of 450 W at 6 min exposure time for a sample of 33% moisture content (WB).

It was observed that maximum value of Husking Efficiency (%), Total yield (%), Head yield (%) and minimum value of Polish (%), Broken (%) in a combination of 450 W, 6 min exposure time for 33% Moisture content (WB).

4. Conclusion

Parboiling is a hydrothermal process that enhances the strength of rice grains through gelatinization. The process involves four primary unit operations: soaking, draining, heating, and drying. Establishing a considerable setup for steaming and drying is essential, yet it results in significant energy losses, adding to production costs. To mitigate these energy losses, microwave ovens can be employed for heating during parboiling, offering efficiency, uniformity, and time savings. This research investigates the impact of varying durations of microwave heating on soaked paddy, with a specific focus on its milling quality. The study also includes the optimization of soaking and microwave heating parameters applied in paddy parboiling. The findings indicate that Husking Efficiency (%) is highest at 6 minutes, followed by 4 minutes and 2 minutes. The highest Husking Efficiency (%) is observed at a moisture content (wb) of 33%, followed by 30% and 27%. Polishing Bran (%) decreases with an increase in exposure time, being lowest at 6 minutes, followed by 4 minutes and 2 minutes. Similarly, Bran (%) is lowest at 6 minutes, followed by 4 minutes and 2 minutes, with the lowest value observed at a moisture content (wb) of 30%, followed by 33% and 27%. The total yield (%) increases with an increase in exposure time, being highest at 6 minutes at 450 W, followed by 4 minutes and 2 minutes. The highest total yield (%) is observed at a moisture content (wb) of 33%, followed by 30% and 27%. Head Rice Yield (%) increases with exposure time at various power levels. Broken (%) is highest at the power level of 180 W but decreases with an increase in exposure time. Optimization parameters reveal that the maximum values for Husking Efficiency (%), Total yield (%), Head yield (%), and the minimum values for Polish (%) and Broken (%) are achieved at a combination of 450 W, 6 minutes exposure time, and 33% moisture content (WB)

5. References

1. Abdul Hamid A, Sulaiman RR, Osman A, Saari N. preliminary study of the chemical composition of rice milling fractions stabilized by microwave heating. Journal of food composition and analysis. 2007;20(7):627-637.
2. Agu HO, Michael-Agwuoke A. Optimization of Soaking Duration and Temperature for Two Nigerian Rice Cultivars. Nigerian Food Journal. 2012;30(2):22-27.
3. Alizadeh MR. Effect of paddy husked ratio on rice breakage and whiteness during milling process. Australian Journal of crop science. 2011;5(5):562.
4. Andres M, Tuates Jr, Villota SMA, Ligisan AR, Caparino OA. Optimization of Parboiling Conditions of Local Rice Varieties in the Philippines. Asian Journal of Applied Sciences, 2016, (ISSN: 2321-0893.
5. Anonymous, Rice Knowledge Management Portal; c2019. http://www.rkmp.co.inicontent/advantages-of-parboiling.
6. Anonymous. Rice Knowledge Bank; c2010. https://www.knowled ebank.irri.org/training/fact-sheets/postharvest-management/rice-quality -fact-sheet-category /item/measuring fact-sheet.
7. Anonymous. Indian Rice Market Update; c2018. htt .//www.magships.com/rice market update/ Anonymous, 2010. Measuring Physical Quality of Paddy- IRRI Rice Knowledge Bank, www.knowledgebank.irri.org.
8. Anonymous, Milling and Parboilinghttp:// www.knowledgebank.irri.orq/ grain Qualit/module 4/06.htm
9. Bakshi AS, Singh RP. Kinetics of water diffusion and starch gelatinization during rice parboiling. Journal of Food Science. 1980;45(5):1387-1392.
10. Banu S. Studied on effect of soaking and steaming on parboiling, milling. cooking. and storage characterstics of some paddy varities of Chhattisgarh; c2006.
11. Bello MO, Loubes MA, Aguerre RJ, Tolaba MP. Hydrothermal treatment of rough rice: effect of processing conditions on product attributes. Journal of food science and technology. 2015;52(8):5156-5163.
12. Bello M, Baeza R, Tolaba MP. Quality characteristics of milled and cooked rice affected by hydrothermal treatment. Journal of Food Engineering. 2006;72(2):124-133.
13. Buffler CR. Microwave cooking and processing. New York: Nostrand Reinhold; c1992. p. 47-68.
14. Buggenhout J, Brijs K, Celus L, Delcour JA. The breakage susceptibility of raw and parboiled rice: A review. Journal of Food Engineering. 2013;117(3):304-315.
15. Chitra M, Singh V, Ali SZ. Effect of processing paddy on ability of rice starch by *in vitro* studies. Journal of food science and technology. 2010;47(4):414-419.
16. Danbaba N, Nkama I, Badau MH, Ukwungwu MN, Maji AT, Abo MEy, *et al*. Optimization of rice parboiling process for optimum head rice yield: a response surface methodology (RSM) approach. International Journal of Agriculture and Forestry. 2014;4(3):154-165.
17. Das 1, Das SK, Bal S. Specific energy and quality aspects of infrared (IR) dried parboiled rice. Journal of Food Engineering. 2004;62(1):9-14.
18. Demuyakor B, Dogbe W, Owusu R. Parboiling of paddy rice, the science and perceptions of it as practiced in Northern Ghana. International Journal of Scientific & Technology Research. 2013;2(4):13-18.
19. Doos HA, Rizk LF, EI-Shirbeeny M. Technological properties of microwave parboiled rice. Molecular Nutrition & Food Research. 1993;37(5):470-475.
20. Dumais S, Mayer S, 'Ian_ A. Improved Parboiling Practices in Benin. West Africa; c2010.

21. Dutta H, Mahanta CL. Traditional parboiled rice-based products revisited: Current status and future research challenges. Rice Science. 2014;21(4):187-200.
22. Graham-Acquaah S, Manful JT, Ndindeng SA, Tchatcha DA. Effects of soaking and steaming regimes on the quality of artisanal parboiled rice. Journal of food processing and preservation. 2015;39(6):2286-2296.
23. Guirai HS, Singh J, Sodhi NS, Singh N. Effect of milling variables on the degree of milling of unparboiled and parboiled rice. International Journal of Food Properties. 2002;5(1):193-204.
24. Taghinezhad E, Khoshtaghaza MH, Suzuki T, Minaei S, Brenner T. Quantifying the Relationship between rice starch gelatinization and moisture-electrical conductivity of paddy during soaking. Journal of Food Process Engineering. 2016;39(5):442-452.
25. Tirawanichakul S, Prachayawarakorn S, Varanyanond W, Tungtrakul P, Soponronnarit S. Effect of fluidized bed drying temperature on various quality attributes of paddy. Drying Technology. 2004;22(7):1731-1754.
26. Uyeh DD, Seung WM, Ha YS. Optimization of parboiling conditions for rice milling. In 2016 ASABE Annual International Meeting (p. 1). American Society of Agricultural and Biological Engineers; c2016.
27. Velupillai L, Verma LR. Parboiled rice quality as affected by the level and distribution of moisture after the soaking process. Transactions of the ASAE. 1982;25(5):1450-1456.
28. Wadsworth JIL, Verma LR. Microwave-vacuum drying of parboiled rice. Transactions of the ASAE. 1990;33(1):199-0211.
29. Yousaf K, Kunjie C, Cairong C, Abbas A, Huang Y, Arslan C, *et al*. The Optimization and Mathematical Modeling of Quality Attributes of Parboiled Rice Using a Response Surface Method. Journal of Food Quality; c2017.
30. Zhao S, Xiong S, Qiu C, Xu Y. Effect of microwaves on rice quality. Journal of Stored Products Research. 2007;43(4):496-502.
31. Manful JT, Abbey LD, Coker RD. Effect of artisanal parboiling methods on milling yield and cooked rice textural characteristics. Journal of food quality. 2009 Dec;32(6):725-734.
32. Roy P, Berger S, Schmuki P. TiO2 nanotubes: synthesis and applications. Angewandte Chemie International Edition. 2011 Mar 21;50(13):2904-2939.
33. Kaasova JI, Kadlec PA, Bubnik ZD, Pour VL. Microwave treatment of rice. Czech Journal of Food Sciences. 2001 Apr 30;19(2):62-66.