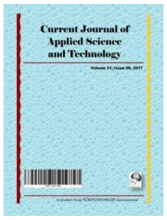

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Threshing Methods, Dryers and Dehuskers Suitable for Brown Rice Production - A Review

Mukesh Jain[1*], Santosh Satya[2] and Kanchan K. Singh[3]

[1]Department of Farm Machinery and Power Engineering, College of Agricultural Engineering and Technology, CCS Haryana Agricultural University, Hisar, India.
[2]Centre for Rural Development and Technology, Indian Institute of Technology, Delhi, India.
[3]Engineering Division, Indian Council of Agricultural Research, Delhi, India.

Authors' contributions

All the authors collaboratively conducted the review study. Author MJ reviewed the available literature on threshing methods and dryers and prepared the first draft of manuscript. Authors SS and KKS reviewed the available literature on brown rice and dehuskers, respectively. All the authors read and approved the final manuscript.

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ABSTRACT

The importance of choosing whole grains such as brown rice rather than refined grain, i.e., white rice, to maintain a healthy body weight, prevention of cardiovascular diseases, phyto-nutrient qualities associated with health promoting activity equal to or even higher than that of vegetables and fruits, etc is well established. In India, generally after harvesting of paddy crop, it is left in the field for drying and the crop is threshed for removal of grains from the panicles. The paddy grains are again dried and milled for the production of brown rice. During this process, lots of middle men are involved by which the cost of brown rice becomes very high and thus, unaffordable to common people. Hence, it was thought that if equipment like thresher cum drier cum dehusker is made available, then brown rice can be produced in the farm itself which will be very cheap. Thus, to fabricate a paddy thresher cum drier cum dehusker, a review was conducted to identify the most

**Corresponding author: E-mail: mukeshjainhisar@rediffmail.com;*

suitable threshing method, a drying method which can instantly dry the grains after threshing and the most appropriate dehusker which can remove the husk of the paddy grain efficiently. From the review, it is concluded that a paddy thresher cum drier cum dehusker can be fabricated by having axial-flow threshing mechanism with co-axial split-rotor threshing drum (suitable for high moisture paddy crop), a drier with infrared emitters for instant drying of paddy grains and rubber roll dehusker for removal of husks with high milling efficiency.

Keywords: Brown rice; threshing; drying; dehusking; axial-flow; co-axial split-rotor.

1. INTRODUCTION

Rice (*Oryza sativa L.)* is one of the most important food crops of Indians in terms of area, production and people's preference. Paddy is harvested as a covered grain, which is also referred to as rough rice. It consists of a white, starchy endosperm surrounded by tightly adhering bran and germ within a hull. The hull which constitutes about 20–25% of the rough rice mass surrounds the grain and it is not bound to it [1,2]. Dehulling of rough rice separates the hull from the brown rice. The most common dehuller makes use of rubber rolls. Most brown rice is converted into white or milled rice in a process which is referred to as milling. Milling of brown rice kernels involves removing the bran and germ from the underlying endosperm by applying friction and/or abrasion forces. As a result, bran is removed by frictional forces created between individual rice grains on one hand and between rice grains and the metal screen surface on the other [3,4,5].

Brown rice is a rich source of the trace mineral manganese, and a good source of selenium, phosphorus, copper, magnesium, and niacin (vitamin B_3). The process that produces brown rice removes only the outermost layer, the hull, of the rice kernel and is the least damaging to its nutritional value. However, the complete milling and polishing that converts brown rice into white rice destroys 67% of the vitamin B_3, 80% of the vitamin B_1, 90% of the vitamin B_6, 50% of the manganese, half of the phosphorus, 60% of the iron, and all of the dietary fiber and essential fatty acids [6]. Functional role of minerals and vitamins in food is well known.

In India, the paddy crop is usually harvested at 20 to 25% moisture content (wet basis) either manually or with the help of power operated equipments. Small farmers generally prefer to harvest manually and leave the crop in the field for drying. When the moisture content is about 15%, threshing of paddy crop is done at the farmers field itself. Threshing is the process of separating the paddy grain from the rest of the cut crop and it is generally performed by specially available power operated paddy threshers. Further processing of paddy grain is done at rice mills with the help of hullers/shellers/dehuskers to remove the husk, whiteners/polishers to remove the bran layer (for white rice) etc. Generally farmers thresh the paddy crop in the field itself with the help of tractor operated paddy threshers and sell the paddy grain in the market and the whole exercise of crop production to selling, fetches them very meagre amount. Further processing of paddy crop to brown rice by removing the husk is done by rice mills and the major profit is earned by them or retailers. Thus, a machine is needed which can thresh the paddy crop, dry and dehusk it at farm level so that the farmers can reap better benefits.

For the production of brown rice in the farm itself, mainly three operations are involved. Firstly, threshing of paddy grains from the panicles of paddy crop; secondly, drying of paddy grains so that it is suitable for dehusking (milling); and thirdly, dehusking for removing the outer layer i.e., hull or husk so that brown rice is recovered. Hence, literature survey was done to identify the most appropriate method of threshing, drying and dehusking of paddy crop for maximized brown rice recovery which is discussed in this paper.

2. THRESHING METHOD ADOPTED

Threshing of cereal grains by machine is an important part of mechanized agriculture. The separation of grains from the panicles of the stalks of crop is termed threshing. The separation of grain from the panicles occurs due to rubbing action, impact and stripping. The term thresher is a general name for all machines that are involved in the process of detaching grains from the panicles of cereal crops.

Prior to agricultural mechanization, the paddy threshing was done by beating paddy bundles against clay molds or logs and by treading them under animal feet or tractor tires. Miah et al. [7] has also confirmed that the percentage of grain damage, unthreshed grains, germination rate and storage life of grains depends on the method of threshing.

Traditionally, paddy was harvested and threshed manually in Pakistan. To mechanize the process, a Power Take Off (PTO) shaft based tractor operated high capacity (throw-in type) paddy thresher was tested at Rice Research Institute, Daharki, Sindh [8]. It had an axial-flow threshing mechanism. An axial flow was generated along the threshing drum with the horizontal loading of feed at one end and consequent straw removal at the other. Grains were separated upon oscillating sieves while blasted by air stream. Un-threshed material was recycled through the threshing drum with the help of a screw conveyor. Grain output capacity of the thresher ranged between 1.5 t h^{-1} to 2 t h^{-1} and with a cleaning efficiency of 99%, with negligible grain loss. The system was commercialized and performed to the satisfaction of users.

A study conducted long ago by Toquero et al. [9] in Philippines concluded that the percentage of losses in tractor, manual, axial-flow and portable IRRI threshers were 8.11, 6.82, 2.07 and 1.97, respectively. Two combines with axial-flow and cross-flow threshers were compared for their performance by Ichikawa and Sujiyama [10]. It was reported that the threshing losses in European combine with radial flow thresher was approximately 10% and concluded that axial-flow thresher had better efficiency. On the same line, Gummert et al. [11] concluded that the axial-flow thresher (IRRI model) with a peripheral speed of 14 to 15 m s^{-1} was useful for threshing wet crop i.e., threshing immediately after harvesting.

Similarly, Alizadeh and Bagheri [12] evaluated the field performance of different rice threshing methods i.e., power tiller operated, axial-flow thresher, tractor type thresher and combine harvester as a thresher. It was found that threshing method had significant role in quantitative and qualitative losses irrespective of paddy varieties. When combine harvester was used as a thresher, highest percentage of losses which includes broken, hulled and fissures grain was reported. Least percentage of losses was reported in power tiller operated thresher. However, its threshing capacity was low (0.18 t/h). Thus, the researchers have recommended to use axial-flow thresher so as to achieve optimum threshing capacity and minimum losses.

A co-axial split-rotor thresher was designed by Chimchana et al. [13] for threshing high moisture paddy which had unequal speed co-axial split-rotor. First rotor serves mainly the threshing operation, whereas, rotating at relatively higher speed, the second rotor does mainly the separation of rice grains from husk. Faster rotation of second rotor increases separation performance by increasing centrifugal force. The optimum speed of threshing rotor and separation rotor was found to be 600 and 720 rpm, respectively with 0.8 m diameter rotor. With the material feeding rate of 0.6-1.8 kg s^{-1}, the separation losses reduced to 0.7-1.3%. By increasing the rotor speed above 800 rpm the grain damage was increased.

From the above review, it is very evident that the adoption of axial-flow thresher for the threshing of paddy crop will help in achieving optimum threshing capacity and minimum losses. Furthermore, the choice of co-axial split-rotor thresher will result in better separation performance particularly under high moisture paddy crop.

3. DRYING

Generally paddy is harvested at higher moisture content than what is required for its safe storage i.e. 12 to 14%. To reduce the moisture content of paddy after its harvest, normally convective driers are used for its drying. But it is a slow process, as low temperature is used in the driers for maintaining the rice milling quality. When high drying temperature is used for drying the grains, then more moisture at the surface is removed as compared to its centre, thus creating a moisture gradient in the rice kernel. The moisture gradient can create tensile and compressive stress resulting in cracks after cooling, which ultimately lowers head rice yield and milling quality [14,15,16]. In order to tackle this issue, it had been a common practice to adopt multiple drying passes at a relatively low temperature (upto 54°C for 15-20 minutes), and in each pass only 2 to 3% moisture is removed to minimize the generation of moisture gradient [17].

It has also been revealed that the recovery of head rice is affected by the amount of moisture that has been removed within a time interval, rather than temperature of the drying air. Thus, it was indicated that some amount of moisture can be removed using high temperature without sacrificing the head rice yield [18].

Glass transition hypothesis which has been proposed and investigated for paddy drying [19, 20] have shown that paddy can be dried at a higher air temperature (60°C) in a rubbery state, or above the glass transition temperature, to remove a large amount of moisture in a single pass without reducing the head rice yield [21, 22].

Amongst different methods used for drying of paddy grains, solar drying is one of the methods which has been tried by different researchers.

3.1 Solar Drying

Zomorodian et al. [23] used a novel method of using solar radiation for dying paddy. The prototype consisted of six ordinary solar heaters supported with an auxiliary electric heating channel, drying chamber and air distribution system. The paddy solar dryer employed cross flow and active mixed-mode type with timer assisted semi-continuous discharging system. On evaluation it was found that the maximum capacity of the dryer was about 132 kg of rough rice and the moisture content of 27% db was reduced from 27 to 13 % db in 3 hours.

The performance of the oscillating bed solar dryer has been investigated by Kumar et al. [24] for the drying of non-parboiled paddy grains with and without bed cover and reflecting mirrors. The dryer can dry 36 kg of non-parboiled paddy grains in just a single day, from the initial moisture content of 18% to the required level of moisture content (12-14%). The drying performance of the dryer was the best with bed cover and reflecting mirrors in comparison with the other combinations of the bed cover and reflecting mirrors.

Ashfaq S et al. [25] designed, developed and evaluated a new solar assisted paddy dryer with central air distribution model (along the length of drying chamber). Solar assisted paddy dryer took 8 hours for drying the 100 kg paddy up to 14% moisture content, while sun drying method dried paddy up to 13.9% moisture in 19 hrs.

The reviews of solar drying clearly indicate that it is very difficult to reduce the moisture content instantly by solar drying. The main challenge involved in the success of thresher cum drier cum dehusker is the ability of the drier to dry the grains within very short duration (may be within 5 to 10 minutes). Hence some other method of drying like Infrared (IR) radiation needs to be studied thoroughly for its possible adoption.

3.2 Infrared (IR) Radiation

Infrared (IR) radiation can be used as an alternative option for achieving fast and uniform heating of the grains for quick removal of moisture. As the penetration of heat is uniform throughout the profile of grain, there will be no moisture gradient issue. Thus, there will be no fissures in the kernels and will also result in improved milling quality. High heating rate and energy efficiency are the added benefits of IR radiation over conventional drying methods [26-34].

IR radiation was used for drying paddy during 1960s [35,36]. It was reported that 2 to 3% removal of moisture content in a single pass was possible by spreading the paddy in a single layer. Rao [37] has concluded that to reduce the moisture content from 20 % to 14.8 % (db), the time required was only 7 minutes as compared to 30 min for hot air drying.

Arinze et al. [38] and Nindo et al. [39] have investigated drying of agricultural products using wavelengths of 2 to 100 µm and concluded that maximum absorption of IR radiation by the paddy grains happened at 2.9 µm [40].

The finding of many researchers supports the idea that the IR radiation can also help in disinfestations and increase the shelf life of grains [41,42]. Simultaneous drying and disinfestations with high rice milling quality was achieved by Zhongli Pan et al. [43] by using a catalytic infrared emitters. They further concluded during the year 2011 that high heating rate, fast drying and good rice quality was achieved by infrared radiation heating of rough rice to about 60^0 C followed by tempering and natural cooling when the sample was tested on a bed of 10 mm thickness.

High rate of drying of rough rice using infrared radiation was reflected by the findings of Ragab Khir et al. [44]. The study concluded that the moisture diffusivity coefficients during heating and cooling of infrared radiation dried rice with tempering were much higher than those of convective drying.

Thus, the work done by the Researchers' motivates that the infrared (IR) heating technology can be used as an instant and efficient drying method to dry the freshly threshed paddy grains without losing the milling quality.

4. DEHUSKERS

Paddy has to be dehusked to get brown rice. In the past, dehusking of the paddy was done manually by pounding the paddy in a receptacle with a wooden stump. This was later replaced by mechanical dehusking with the use of rubber rollers, which gave a greater dehusking efficiency and less grain breakage. Now-a-days, two types of mills are engaged in rice processing i.e. conventional and modern rice mills. Conventional rice mills are the units, in which the paddy processing is carried out by using steel hullers, an age old technology which is inefficient. Different activities like cleaning, drying, grading, polishing etc. are carried out manually. Modern rice mills are the units, in which the paddy processing is carried out by using rubber roll dehuskers, a modern technology which is more efficient [45].

Initially, the rollers produced were based on silica-filled styrene-butadiene rubber (SBR) compounds because of their longer service life and better thermal stability compared to natural rubber (NR) rollers. However, lately many alternative materials such as acrylonitrile rubber especially the carboxylated grades, polychloroprene rubbers, EPDM, etc. were being used to give even longer service life than the SBR rollers [46].

In a modern rice mill, a pair of rubber-lined rollers are mounted in an enclosed chamber and driven at different rpm, with the faster roller revolving at 900 rpm. The paddy in passing through the rollers nip is subjected to both compressive and shearing forces. When these forces are correctly predetermined for a particular grade of paddy (by rubber hardness, resilience, rollers nip, speed and friction ratio) the paddy will remain substantially intact after going through, while the husk is broken off. In practice, the dehusking efficiency can be as high as 90% per pass.

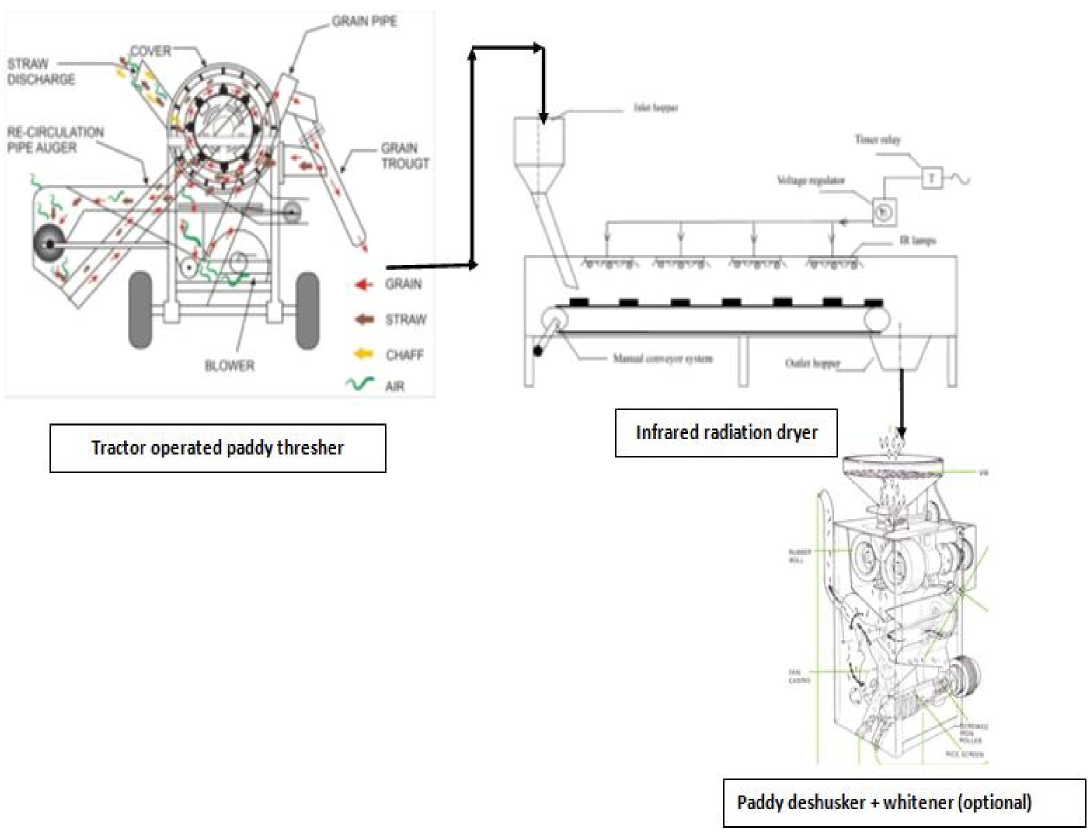

Fig. 1. Schematic diagram of proposed thresher cum drier cum dehusker for brown rice production

Ancheta and Andales [47] revealed that the higher values of head rice yield were obtained at moisture content of 12% w.b. Firouzi et al. [48] carried out a study at the Rice Research Institute of Iran (RRII) to investigate the effect of rollers differential peripheral speed of commercial rubber roll husker and paddy moisture content on the husking index and percentage of broken rice. The experiment was conducted at six levels of rollers differential speed (1.5, 2.2, 2.9, 3.6, 4.3 and 5 m/s) and three levels of paddy moisture content (8-9, 10-11 and 12-13% w.b.). Two common paddy varieties namely, Binam and Khazer, were selected for this study. It was concluded that rollers differential speed of 2.9 m/s and moisture content of 8-9% was the most appropriate combination for paddy husking of Binam and Khazar varieties in rubber roll husker.

The findings of Ancheta and Andales [47] was endorsed by Gbabo and Ndagi [49] who conducted performance evaluation of a rice mill developed at National Cereal Research Institute, Badeggi and reported that the machine performed well at all levels of moisture contents, however, 12-13% moisture content was found to be optimum for all grain types. Feed rate of 0.033 kg/s was recommended for optimal performance of machine.

The literature review lucidly indicates that by adopting rubber roll dehuskers, dehusking efficiency as high as 90% per pass can be achieved. However, dehusking efficiency is largely affected by rollers differential speed and moisture content of paddy grains.

5. CONCLUSION

An exhaustive review of literature reveals that no work on the development of thresher cum drier cum dehusker for brown rice production on the farm itself has been reported. Reason may be the challenge involved in the drying of the high moisture paddy to a level at which milling can be done efficiently. Convective type of drying methods used earlier, utilize low temperature system for the moisture removal so that the generation of moisture gradient is avoided. But it has been reported that IR radiation can be used effectively for reducing the moisture instantaneously at a very short period without sacrificing the milling quality. Keeping in view the health benefits of brown rice, there is an urgent need to design and develop thresher cum drier cum dehusker so that brown rice is available at a cheaper cost to the common people. For the development of paddy thresher cum drier cum dehusker, axial-flow threshing mechanism with co-axial split-rotor threshing drum (suitable for high moisture paddy crop), a drier with infrared emitters for instant drying of paddy grains and rubber roll dehusker for removal of husks with high milling efficiency would prove to be a viable option (Schematic flow diagram is given in Fig. 1).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Champagne ET, Wood DF, Juliano BO, Bechtel DB. The rice grains and its gross composition. In: Champagne, E.T. (Ed.), Rice: Chemistry and Technology, third ed. American Association of Cereal Chemists, St. Paul, MN, USA. 2004;77-107.
2. Delcour JA, Hoseney RC. Structure of cereals. Principles of Cereal Science and Technology, third ed. AACC International, St. Paul, MN, USA. 2010;1-22.
3. Bond N. Rice milling. In: Champagne, E.T. (Ed.), Rice: Chemistry and Technology, Third ed. American Association of Cereal Chemists, St. Paul, MN, USA. 2004;283-300.
4. Delcour JA, Hoseney RC. Rice and oat processing. Principles of Cereal Science and Technology, third ed. AACC International, St. Paul, MN, USA. 2010; 149-160.
5. Kohlwey DE. The quest for the whole grain in rice milling. Cereal Foods World. 1992;37(8):633-634.
6. The George Mateljan Foundation for the World's Healthiest Foods. Available:http://www.whfoods.com/genpage.php?tname=foodspice&dbid=128

7. Miah AK, Roy AK, Hafiz MA, Haroon M, Seddique SS. A comparative study on the effect of rice threshing methods on grain quality. Agril. Mechanization in Asia, Africa and Latin America. 1994;25(3):63-66.
8. Anonymous; 2006.
DAWN. Returns on paddy threshing 14th Aug, 2006.
Available:https://www.dawn.com/news/205917
(Accessed on April 21, 2017)
9. Toquero Z, Maranan C, Ebron L, Duff B. Assessing quantitative and qualitative losses in rice post production systems. International Rice Research Institute, Paper No. 77-01, Manila, Philippines; 1977.
10. Ichikawa T, Sujiyama T. Development of a new combine equipped with screw type threshing and separating mechanism. Japan Agril. Research Quarterly. 1986; 20(1):31-37.
11. Gummert M, Muhlbuer M, Kutzlaoch W, Wacker P, Quik GR. Performance evaluation of IRRI axial-flow paddy thresher. Agril. Mechanization in Asia, Africa and Latin America. 1992;23:47-54.
12. Alizadeh M. Reza and Bagheri Iraj. Field performance evaluation of different rice threshing methods. International J. of Natural and Engg. Sci. 2009;3(3):155-159.
13. Chimchana D, Salokhe VM, Soni P. Development of an unequal speed co-axial split-rotor thresher for Rice. Agril. Engg. International: The CIGR Ejournal. Manuscript PM 08 017. 2008;X.
14. Ban T. Rice cracking in high rate drying. Japan Agril. Research Quarterly. 1971; 6(2):113-116
15. Kunze OR, Choudhury MSU. Moisture adsorption related to the tensile strength of rice. Cereal Chemistry. 1972;49(6):684-696.
16. Kunze OR. Fissuring of the rice grain after heated air drying. Transactions of ASAE. 1979;22(5):1197-1202, 1207.
17. Kunze OR, Calderwood DL. Rough rice drying. In Rice: Chemistry and technology. St. Paul, Minn.: American Association of Cereal Chemists. 1985;233–263.
18. Stipe DR, Wratten FT, Miller MF. Effects of various methods of handling brown rice on milling and other quality parameters. Louisiana Agricultural Experiment Station Annual Program Rep., Rice Exp. Stn. 1972;113.
19. Perdon A, Siebenmorgan TJ, Mauromoustakos A. Glassystate transition and rice drying: Development of a brown rice state diagram. Cereal Chemistry. 2000;77(6):708-713.
20. Siebenmorgan TJ, Yang W, Sun Z. Glass transition temperature of rice kernels determined by dynamic mechanical thermal analysis. Transactions of ASAE. 2004;47(3):835-839.
21. Cnossen AG, Siebenmorgen TJ, Yang W, Bautista RC. The glass transition temperature concept in rice drying and tempering: Effect on milling quality. Transactions of ASAE. 2000;43(6):1661-1667.
22. Cnossen AG, Jimenez MJ, Siebenmorgen TJ. Rice fissuring response to high drying and tempering temperatures. J. of Food Engg. 2003;59:61-69.
23. Zomorodian A, Zare D, Ghasemkhani H. Optimization and evaluation of a semi-continuous solar dryer for cereals (Rice, etc.). Desalination. 2007;209(1–3):129–35.
24. Kumar P, Shanmugam S, Veerappan AR. An experimental study on drying of non-parboiled paddy grains using an oscillating bed solar dryer. Energy Engineering. 2011; 108(2):69-80.
25. Ashfaq S, Ahmad M, Anjum, Munir and Wajid A. Design, development and performance evaluation of a small-scale solar assisted paddy dryer for on farm processing. J Food Process Tech. 2015;6: 480.
DOI: 10.4172/2157-7110.1000480
26. Abe T, Afzal TM. Heat and mass transfer characteristics of barley during far infrared radiation drying. Proceedings of 2nd international workshop on ''Control applications in post-harvest and processing technology" (CAPPT'98), Budapest, Hungary; 1998
27. Afzal TM, Abe T. Combined convection and far-infrared radiation drying of rough rice. *ASAE* Paper No. 9760972. St. Joseph MI; 1997.
28. Bilowicka E. Research concerning the drying of small seeds by infrared radiation. International drying conference. Warsaw, Poland: Institute of Mechanization and Electrification of Agriculture; 1960.
29. Das I, Das SK, Bal S. Determination of mixing index of paddy grains under vibrating conditions. J. of Food Process Engg. 2004;26(1):121-133.

30. Das I, Das SK, Bal S. Specific energy and quality aspects of infrared (IR) dried parboiled rice. J. of Food Engg. 2004; 62(1):129-133
31. Ginzburg AS. Application of infrared radiation in food processing. London: Leonard Hill. 1969;174-254.
32. Masamure A, Sado H, Hoda T, Shimizu M, Nabetani H, Nakajima M, et al. Drying of potato by far infrared radiation. Nippon Shokuhin Kogyo Gakkaishi. 1998;35(5): 309–314.
33. Sharma GP, Verma RC, Pathare PB. Thin-layer infrared radiation drying of onion slices. J. of Food Engg. 2005;67(3):361-366.
34. Zhu K, Zou J, Chu Z, Li X. Heat and mass transfer of seed drying in a two pass infrared radiation vibrated bed. Heat Transfer-Asian Research. 2002;31(2):141-147.
35. Faulkner MD, Wratten FT. The Louisiana State University infrared-preheat rice dryer. 41. In Proceedings of the 13th Rice Technical Working Group Mtg. Beaumont, TX: Texas A& M Univ., College Station; 1970.
36. Hall CW. Theory of infrared drying. Transactions of ASAE. 1962;5(1):14-16.
37. Rao ON. Effectiveness of infrared radiation as a source of energy for paddy drying. J. of Agril. Engg. 1983;20(2):71-76.
38. Arinze A, Schoenau J, Bigsby W. Determination of solar energy absorption and thermal radiative properties of some agricultural products. Transactions of ASAE. 1987;30(1):259-265.
39. Nindo CI, Kudo Y, Bekki E. Test model for studying sun drying of rough rice using far-infrared radiation. Drying Technology. 1995;13(1-2):225-238.
40. Bekki E. Rough rice drying with a far-infrared panel heater. J. of the Japanese Society of Agril. Machinery. 1991;53(1): 55-63.
41. Kirkpatrick RL, Tilton EW. Infrared radiation to control adult stored-product Coleoptera. J. of the Georgia Entomology Society. 1972;7:73-75.
42. Kirkpatrick RL. Infrared radiation for control of lesser grain borers and rice weevils in bulk wheat. J. of Kansas Entomological Society. 1975;48(1):100-104.
43. Zhongli Pan, Khir Ragab, Godfrey D. Larry, Lewis Richard, Thompson F. James and Salim Adel. Feasibility of simultaneous rough rice drying and disinfestations by infrared radiation heating and rice milling quality. Journal of Food Engineering. 2008; 84:469-79.
44. Khir Ragab, Pan Zhongli, Salim Adel, Hartsough R. Bruce and Mohamed Sherief. Moisture diffusivity of rough rice under infrared radiation drying. LWT- Food Science and Technology. 2011;44:1126-32.
45. Goyal SK, Jogdad SV, Agrawal AK. Energy use pattern in rice milling industries-a critical appraisal. J. Food Sci. Technol. 2014;51(11):2907-16.
46. Anonymous. International rubber products exhibition centre: Paddy dehusking roller; 2002.
Available:http://www3.lgm.gov.my/irpec/prd_paddydehusk.html
(Accessed on 21th April 2017)
47. Ancheta CJ, Andales SC. Total milled and head rice recoveries of paddy as influenced by its physio-varietal characteristics. Agricultural Mechanization in Asia, Africa and Latin America. 1990; 21(1):50-54.
48. Firouzi S, Alizadeh MR, Minaei S. Effect of rollers differential speed and paddy moisture content on performance of rubber roll husker. International Scholarly and Scientific Research & Innovation. 2010; 4(11): 607-10.
49. Gbabo A, Ndagi B. Performance Evaluation of a Ricemill Developed in NCRI. Intenational Journal of Engineering Research. 2014;3(8):482-87.

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