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A review of rice parboiling systems, energy supply, and consumption

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ABSTRACT

Parboiling is an energy and labour intensive pre-milling process aimed at improving the quality of paddy rice. Several parboiling processes along with different energy supply systems have been developed and reported to improve the overall grain quality, processing time and energy consumption. This paper reviews the parboiling process – concept, systems, energy supply and consumption, as well as the impact of energy use on product quality. Rice husk is most widely used energy source for parboiling and has been used primarily in direct combustion systems, as briquettes or through gasification systems. Parboiling energy consumption varies widely depending on the process conditions, parboiling system, processing capacity and the energy source.

1. Introduction

Parboiling is a hydrothermal pre-milling treatment to gelatinize starch component of rice in a three-stage process namely soaking, steaming and drying. This process leads to physical, chemical and organoleptic changes in the grain which greatly affects the milling, storage, cooking and eating qualities [1–7]. About 130 million tonnes of paddy is parboiled annually around the world with about 3–4 million tonnes high-value parboiled milled rice being moved in world trade [8]. Parboiling originated and is largely practiced in India [9–13] and in many Asian countries including Bangladesh [14] and Sri Lanka [15] as well as some Sub-Saharan Africa countries including Ghana [16,17], Benin [18,19], Senegal, Nigeria and Cameroon [20]. The quantities parboiled ranges from few tens of kilograms per batch [17] up to 1.2 t per hour [11,13,17,21]. The process as practiced in rural rice producing communities is time-consuming, laborious and energy intensive. For example, traditional soaking of paddy could take up to 48 h and while drying of steamed paddy to the required 14–16% (wb) moisture content require 6.9–9.7 MJ/kg more compared to non-parboiled rice [22,23]. As the demand for high quality and nutritious rice increases, improvement in the parboiling process is required to make locally processed rice competitive. Again, with the recent trend of global energy consumption increasing and expected to reach 630 quadrillion Btu by 2020 [24] due to industrialization and population growth, every effort ought to be made to supply energy in a more sustainable manner and also use efficiently. The task of achieving high-quality products and energy economy in rice processing has been pursued by several researchers through governmental and regional initiatives. For instance, the Canadian Department of foreign affairs, Trade, and Development in partnership with Africa Rice and McGill University have pursued energy supply and use improvements (improved stoves, briquetting, and gasification) towards a sustainable rice production in Sub-Saharan Africa [16,20]. These improvements have been primarily through tweaking of process conditions, development of new processes and equipment, and these have been reported in several literatures. The objective of this paper is to review the parboiling process, its impact on rice quality, recent advancement in process and equipment development as well as to review the supply and consumption of energy.

1.1. Concept of parboiling and its impact on rice quality

Rice grains are mainly composed of polygonal starch granules in their endosperm. The endosperm has intergranular spaces which are filled with air and moisture. During maturity of the grain, fissures and cracks are developed and that could cause breakage of the grain during subsequent milling. To reduce the breakage, the grains are parboiled during which starch is gelatinized filling the void and cementing the fissures and cracks [22,25]. During soaking, the first step, water penetrates into starch granules and forms hydrates through hydrogen bonding which causes swelling. This swelling is less pronounce when soaking is done in cold water due to the limited water absorbing capacity of starch granules. However, in hot soaking, heat energy disrupts hydrogen bonds and weakens the granule structure which gives more surfaces for water absorption and allows further hydration and swelling as temperature increases. The process of gelatinization is completed with heat from moist steam supplied during the steaming stage. Generally, soaking increases paddy moisture up to 45–50% (wb)

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Table 1
Characteristics of parboiled and non-parboiled rice [28].

Rice Variety	*Brown*	*Parboiled brown*	*Parboiled milled*	*Milled*
Chemical Composition (%)				
Moisture	12.60 ± 0.54	12.07 ± 0.74	10.83 ± 0.64	11.10 ± 1.16
Protein	6.85 ± 0.34	6.76 ± 0.20	6.36 ± 0.32	6.66 ± 0.34
Crude fat	2.65 ± 0.20	2.69 ± 0.13	0.38 ± 0.06	0.5 ± 0.07
Ash (%)	1.21 ± 0.06	1.18 ± 0.17	0.55 ± 0.04	0.47 ± 0.12
Mineral Composition mg/100				
K	181.71 ± 9.27	152.89 ± 8.77	143.21 ± 8.86	65.46 ± 5.57
P	61.27 ± 2.08	56.42 ± 1.84	58.85 ± 5.05	41.98 ± 5.40
Mg	16.88 ± 0.57	15.95 ± 0.28	15.43 ± 2.66	15.06 ± 2.34
Ca	6.85 ± 0.43	6.23 ± 0.41	4.61 ± 0.85	6.70 ± 0.42
Zn	1.98 ± 0.11	1.90 ± 0.10	1.15 ± 0.31	2.09 ± 0.09
Fe	0.57 ± 0.35	0.55 ± 0.47	0.43 ± 0.35	0.40 ± 0.29
Na	0.54 ± 0.20	0.44 ± 0.14	0.59 ± 0.07	0.53 ± 0.06
Mn	0.36 ± 0.05	0.42 ± 0.07	0.28 ± 0.02	0.45 ± 0.06
Cu	0.16 ± 0.07	0.15 ± 0.06	0.17 ± 0.03	0.18 ± 0.04
Se	0.04 ± 0.00	0.04 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
∑	270.35	235.02	224.75	132.88

hence the need for drying before milling [25].

Parboiling rectifies the problem of cracks and incomplete grain filling and lead to many favourable changes including easy shelling, higher head rice yield, fewer broken, increased resistance to insect and nutrient retention [26], and reduced disintegration and solubilisation of kernels on cooking [27]. A comparison of chemical and mineral composition of parboiled and non-parboiled rice is shown in Table 1.

Paddy (rough) rice is used as the feedstock for local rice processing whereas brown rice is mainly used in modern industrial parboiling process [29]. The choice of processing dehusked rice in modern processes is typically based on avoidance of husk associated natural contaminant [30], avoidance of colour and odour transport during soaking [5], reduction in processing time, energy consumption and handling cost [31]. Several studies regarding paddy quality have been done on the different stages of parboiling. Table 2 presents a summary of some research works on the influence of soaking and steaming conditions on quality.

Extensive qualitative changes such as colour and smell, and quantitative changes such as leachate loss, kernel bursting in the grain are observed during soaking [44]. The temperature of the soaking water is the most critical parameter. It determines the rate of water absorption which increases along rising water temperature and soaking time as a result of an upswing in diffusion coefficient [30,45]. Generally, soaking water temperature improves the moisture diffusion which is exponentially [46,47]. Nonetheless, it must be carefully chosen as higher temperature above the gelatinization temperature may result in a more yellow milled rice [48,49], downgrade the hydration and cooking characteristics and reduce tenderness [50], results in excess water uptake, husk splitting, cooking of paddy and may affect the quality of the parboiled rice due to soak water contamination [26]. Luh and Mickus [5] found that when the temperature exceeds 70 °C, paddy colour deepens after 5 h of soaking partly due to amylase activity and the variation in pH. Above pH of 5, colouration increases. The authors also claim that soaking water at 65 °C for more than 8 h develops an off-odour which is transferred to the parboiled rice.

After soaking, the paddy is steamed usually with saturated steam. The use of steam adds to the overall moisture content through condensation. This also helps the spread of water soluble substance. However, it has the potential of making the endosperm texture pasty. In commercial processes, steam could be used to produce power before its application to paddy. The conditions of steam have a considerable effect on the quality, but in the local steaming process usually at atmospheric pressure this change is not significant [22]. Steaming tends to increase the milling yield and improve the storage characteristics and the eating quality [5]. Excessive steaming time makes paddy loses it shape and increase in stickiness.

Steamed paddy is dried to reduce moisture to an appreciable level preferably 14.5%. The effect of drying on the quality is largely dependent on the drying temperature and time [51]. As drying temperature increases yellowness of milled rice increases, and hardness of cooked rice increases while its water absorption capacity decreases [52] which also affects the pasting properties of its flour [53]. Serious cracking may be observed when the temperature difference between drying air and paddy exceed 43 °C [54]. These cracks in the rice kernel are mainly due to the high drying temperature and long exposure time [55]. To minimize thermal stress on the kernel to a temperature gradient, Bonazzil, du Peuty [56] proposed temperature of drying air be kept below the transition temperature (53 °C). Nevertheless, they indicated that a similar high quality (> 94%) can be achieved at high temperature (e.g. 80 °C) and high relative humidity (e.g. 87%) without decreasing the head yield. The use of two-stage triangular spouted bed (TSB) has successfully been employed to achieve such high temperature drying [57]. Paddy of more than 25%

Table 2
Summary of research on impact of soaking and steaming on rice quality.

Author(s)	Year	Study domain	Reference
Hinton, J.J.	1948	Investigated the redistribution of vitamin b1 and retention of scutellum in rice grain during parboiling	[32]
Bhattacharya and Subba Roa	1966	Effect of Processing Conditions on Quality of Parboiled Rice	[3]
Padua and Juliano	1974	Studied the effect on parboiling on thiamin, protein and fat of rice	[33]
Chung et al.	1990	Soak temperature and equilibrium effect on parboiled rice quality	[34]
Igbeka et al.	1991	Developed a model for predicting selected quality attributes in parboiled rice	[35]
Farouk and Islam	1995	Effect of parboiling and milling parameters on breakage of rice grains	[36]
Guha and Ali	1998	Studied the effect of variety and parboiling conditions of brown rice	[37]
Gujral and Singh	2001	Established relationship between parboiling, degree of milling, ash distribution and conductivity in rice	[38]
Jagtap et al.	2008	Studied the influence of soaking time on the crushing strength of raw and parboiled rice and reported an inverse relationship	[39]
Agidi et al.	2008	Effect of variety, pressure and specific volume of steam on the head rice yield of milled parboiled rice	[40]
da Fonseca et al.	2011	Investigated the influence of soaking variables on parboiled rice quality	[4]
Ayamdoo et al.	2013	Studied the effect of varying parboiling conditions on physical qualities of Jasmine 85 and Nerica 14 rice varieties	[41]
Ballogou et al.	2013	Evaluated parboiling method, precooking and roasting on the physic-chemical and functional properties of two fonio (Digitaria exilis) landraces	[1]
Gunaratne et al.	2013	Studied the effect of parboiling on formation of resistant starch, digestibility and functional properties of rice flour and reported that parboiling reduces swelling volume, amylose leaching, and resistance starch	[42]
Ayamdoo et al.	2014	Studied the effect of varying parboiling conditions on the cooking and eating/sensory characteristics of Jasmine 85 and Nerica 14 rice varieties	[43]