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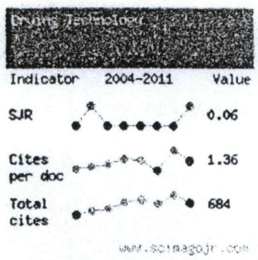

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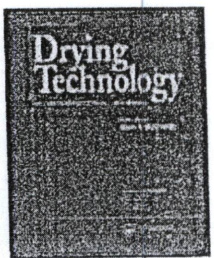

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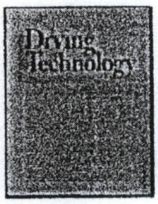

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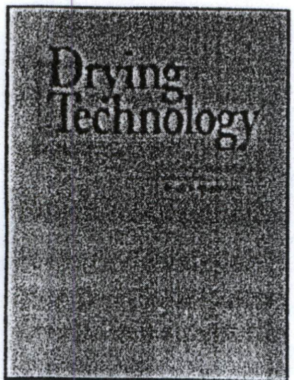

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Effects of Simultaneous Parboiling and Drying by Infrared Radiation Heating on Parboiled Rice Quality

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Effects of Simultaneous Parboiling and Drying by Infrared Radiation Heating on Parboiled Rice Quality

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Food Engineering and Bioprocess Technology, School of Environment, Resources and Development, Asian Institute of Technology, Klong Luang, Pathumthani, Thailand

An infrared (IR) radiation heating and vibrating apparatus was used to study a simultaneous parboiling and drying process. Physicochemical properties such as milling yield, color, and pasting properties of parboiled paddy were evaluated. Radiation intensity levels of 46.7 kW/m^2, variable exposure time, and rice samples at fixed initial moisture contents (IMC) of 30 and 32% wet basis (wb) were used. It was discovered that the radiation intensity of 46.7 kW/m^2 and 32% wb moisture content yielded a quality level similar to that of conventional steam-parboiled rice. The head rice yield (HRY) of IR paddy slightly decreased with increased exposure time. The HRY of IR heating was more than 60% compared to HRY values of 67.68 to 69.34% for conventional steam-parboiled rice. The b-values of 23 to 25 for IR samples showed lighter yellowness than the 29.7 b-value of conventional steam-parboiled rice. The pasting properties of all IR samples showed lower viscosity compared to the raw-milled rice samples but higher than conventional steam-parboiled rice. Initial moisture content of paddy affected the degree of starch gelatinization (SG) by differential scanning calorimetry (DSC). Under IR heating for 18 min of exposure time, the 32% wb IMC sample showed SG at 80.15% compared to SG at 59.02% with the 30% wb IMC sample. Hence, while employing simultaneous parboiling and drying with IR heating for an exposure time of 18 min, the sample retained more parboiled flavor as a result of a higher degree of starch gelatinization. The sample showed lower HRY, but yellowness was within the acceptable range. Energy requirement for producing 1 ton of parboiled paddy by the IR heating process is lower than the conventional steam-parboiled process but statistically nonsignificant ($P > 0.05$). However, the process time was reduced to one third of the conventional process, leading to improved quality. In addition, initial investment cost was minimal because a steam generator was not required.

Keywords IR heating; Parboiled rice; Simultaneous parboiling and drying

INTRODUCTION

The simultaneous drying and parboiling process is known as a non-steaming process. This is a quick process, meaning that soaked paddy is not only dried but its starch is simultaneously gelatinized.[1] This technique aims to eliminate the steaming process to reduce energy consumption and investment costs of a steam generator. It is subjected to quick conduction heating at high temperatures, which includes hot sand, a rotary drum drying, and thermic fluid. Electromagnetic waves, especially microwaves, can also be used for parboiled rice processing.[2] In addition, rapid moisture removal and improved milling yield under increasing degree of starch gelatinization for high-moisture paddy and parboiled rice drying can be obtained by hot air fluidization techniques.[3–8] During the drying process, starch is gelatinized and moisture in the grain is simultaneously lost. This technique contrasts with the conventional steaming process in which moisture content is added. The benefit of the non-steaming process is that the lower initial moisture content of paddy allows for faster drying, saving energy throughout the process. Pillaiyar[9] stated that 50% of total energy is consumed during the drying stage of the conventional parboiling rice process. Thus, decreasing the energy required for drying can save substantial energy. Dash[10] and Pillaiyar et al.[11] demonstrated a technique for saving energy using conduction heating and thermic fluid heating to improve the conventional parboiling rice process.

The conventional steam parboiling process of paddy is commonly divided into three underlying processes: soaking, steaming, and drying. Paddy is soaked in hot water to its saturation point and the grain is steamed to gelatinize the starch content. The grain is then dried before milling. The major advantages of parboiling rice are to improve milling yield, enhance nutrition, and increase resistance to spoilage due to insects and mold infestation.[12–14]

The yellow quality of parboiled rice and its aroma and taste have become widely accepted as a result of the conventional steam-parboiled rice process. At present only a relatively small group of consumers accept the appearance and flavor of conventional steam-parboiled rice in South Africa, Nigeria, and other African countries. Most modern rice consumers recognize the nutritional qualities of parboiled rice but are more familiar with white rice. Thus, consumer expectations regarding the qualities of parboiled rice substantially differ from its typical flavor and color.

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An increasingly popular alternative heating source, infrared (IR) radiation, is widely used in many industries as a heat source for drying products. In reviewing related literature, implementation of this technology in agricultural products has rarely been reported. IR heating is accepted as the most efficient method due to its significant advantages, such as versatility, simplicity, uniformity, heat transfer, and energy savings compared to conventional drying.[15–18] However, many researchers have indicated that IR heating is suitable for only the surface of objects. Increased depth of the grain bed causes a wide variation in moisture content, leading to fissuring of grain after drying.[19] To solve this problem, a deep-bed grain vibration system should be used to keep the grain in motion so that each piece receives radiation uniformly and dries more quickly.[20,21] Nowak and Lewicki[22] stated that final material temperature by IR heating affected the quality of apple slices, in particular mechanical properties. Some papers have indicated that a combination of IR heating and other drying techniques can accelerate moisture removal.[23–26] Furthermore, several models of IR drying were investigated to developing advanced process control.[27–31]

An IR heating and vibrating apparatus was designed and frabricated to study the simultaneous parboiling and drying of high moisture paddy under the hypothesis that the non-steam parboiling process could reduce energy costs and produce the desired quality parboiled rice. Effects of IR heating such as head rice yield, color, chalkiness, water absorption, solid loss, pasting property, and degree of gelatinization were investigated with respect to IR intensity, fixed grain bed depth, controlled vibrating amplitude, varying exposure times, and initial moisture content of paddy.

MATERIALS AND METHODS

Sample Preparation

The Pathumthani 60 variety of paddy, a long-grain type with intermediate amylase (26%), was used in this experiment. It was dried to 11% wb moisture content. The paddy samples were cleaned, kept in plastic bags, and refrigerated at 10°C. Before soaking, they were tempered at ambient temperature for at least 6 h. The paddy samples were soaked in hot water at 55°C until the moisture content reached 30 and 32% wb. They were then removed from the hot water and tempered for 1 h before exposure to the simultaneous parboiling and drying process with the IR heating and vibrating apparatus.

Two control samples were employed in the experiment. One was untreated paddy and the other was conventional steam-parboiled rice (steamed at 100 kPa for 10 min). Parboiled paddy was dried at 40°C in a hot air oven to 11% wb moisture content. Finally, the parboiled paddy was kept overnight before milling and other qualities were evaluated.

Adapted Infrared Radiation Heating and Vibrating Apparatus

The IR heating and vibrating apparatus consists of three parts: the heating source, sample tray, and vibrating table. The heating source utilized three carbon shield infrared radiation lamps (220 V, 700 W) that were installed in the 350 × 170 mm shiny aluminum reflector. It was hung on the heating source stand with adjusting level screws over the sample tray. The sample tray was rectangular (150 × 300 mm) and 50 mm high. It was divided into eight small compartments and clamped onto the vibrating table. The vibrating mechanism consisted of an eccentric joint with a speed-controlled motor and four helical springs. The vibration was transmitted to the sample tray through a 10-mm eccentric link and an adjustable-speed motor. The sample tray was enclosed in tempered glass, which increased the air temperature to 100°C during simultaneous parboiling and drying inside the tray. The infrared radiation heating and vibrating apparatus is shown in Fig. 1.

The parameters of the IR heating and vibrating apparatus were set as follows: height of IR heater (distance between IR lamp and sample) was 150 mm; IR power was 2100 W. The vibration of the sample tray was controlled at 25 Hz frequency and 7.1 mm amplitude. The sample size in this experiment was expressed in terms of the sample bed depth of 15 mm, producing 350 g of parboiled paddy, which was adequate to conduct quality evaluations.

Quality Determination of High Moisture Paddy Under IR Heating

The soaked paddy at 30% wb was heated using 2100 W IR heating for exposure times of 3, 5, 7, 9, 11, 12, 13, 14, 15, 16, 17, 19, 21, and 23 min. The paddy samples were then tempered at room temperature for 4 h. Next, they were dried under shade to 11% wb and finally kept overnight

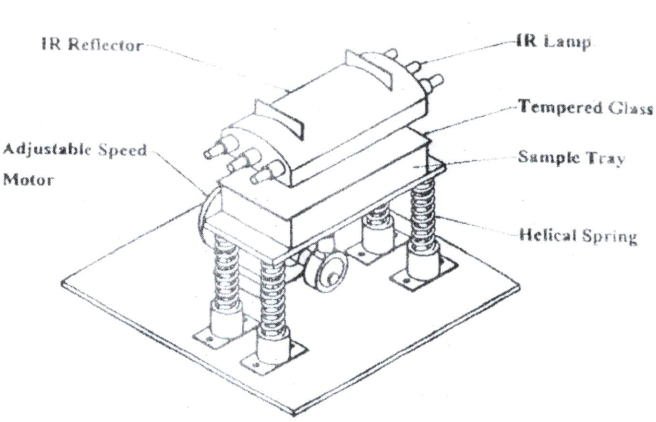

FIG. 1. Schematic drawing of the infrared radiation heating and vibrating apparatus.

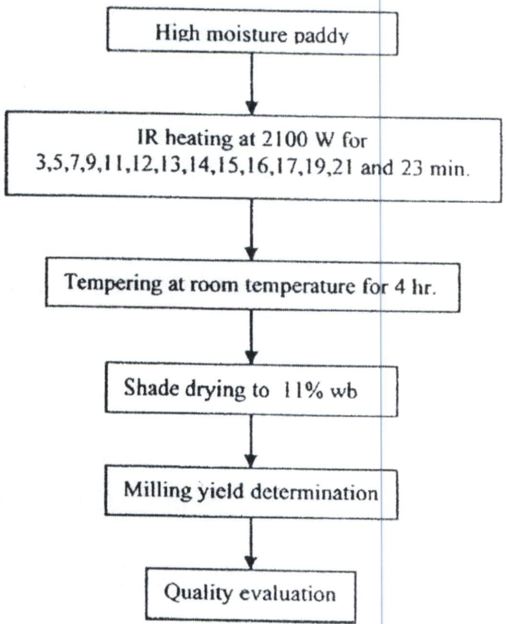

FIG. 2. Experimental design for quality evaluation of paddy parboiled using infrared radiation.

before milling, and other qualities were evaluated. The qualities of the paddy samples were compared with conventional steam-parboiled paddy and with untreated paddy. The experimental design is shown in Fig. 2.

Study of the Degree of Starch Gelatinization by DSC of High Moisture Paddy Under Simultaneous Parboiling and Drying with IR Heating

Initial moisture contents (IMC) of 30 and 32% wb were used in this experiment. The samples were simultaneously parboiled and dried using a 2,100-W IR heating for exposure times of 10, 13, 15, and 18 min. The paddy samples were then tempered at room temperature for 4 h. Next, they were dried under shade to 11% wb and finally kept overnight before milling, and other qualities were evaluated. The qualities of paddy samples were compared with conventional steam-parboiled paddy and with untreated paddy. The degree of gelatinization of rice samples by differential scanning calorimetry (DSC) was determined and compared. Figure 3 shows experimental design of simultaneous parboiling and drying with IR heating.

Quality Evaluation

Dried paddy samples were evaluated in terms of color, moisture content, milling evaluation, and chalkiness.

Moisture Content

The standard oven method was used for moisture content determination of paddy samples. The samples were dried at 105°C for 24 h.[32]

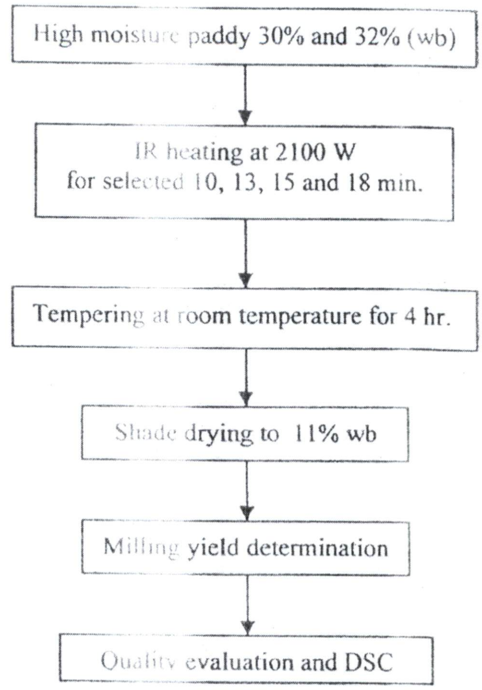

FIG. 3. Experimental design of simultaneous parboiling and drying with infrared radiation.

Milling Quality Evaluation

All paddy samples were dried under shade to obtain the same moisture level under 12% wb before the milling test. Milling quality test was based on a 250-g sample and was dehusked using a rubber roll husker (Satake, model THU-35A, Japan) and was polished by abrasive stone (Satake, model GTM, Hiroshima, Japan) and graded by 6.0 mm indented cylinder test rice grader (Satake, model TRG-05A). Milled rice, head rice yield, and broken grains were calculated by percentage and the results were compared using analysis of variance (ANOVA).

Color Evaluation

The color of parboiled rice was measured using a Hunter color meter (HunterLab, Colorflex, Reston, VA). The color was given values of L (light–dark), a (red), and b (yellow). Only yellowness (b-value) was considered a major quality of parboiled rice. The whiteness of paddy was evaluated using the KETT whiteness tester (model C-300, Tokyo, Japan).

White Belly/Chalkiness

One hundred sample grains from each treatment were evaluated. All types of chalkiness were measured as a percentage of chalkiness.

Water Absorption

The method developed by Sangnikornkiat,[33] with some modifications, was used to determine water absorption

Pasting Property

Pasting property of parboiled rice was determined using a Rapid Visco-Analyzer (model 4D, RVA, Newport Scientific Pty. Ltd., NSW, Australia). The viscograph was recorded and expressed in terms of peak viscosity (PV), breakdown viscosity (BKV), setback (SBK), and final viscosity (FV).

Degree of Gelatinization

Thermoanalysis of rice starch by DSC (model-3, Perkin Ltd., Norwalk, CT) was conducted to determine the degree of gelatinization of starch. Calculation of the thermal parameters for starch gelatinization is shown below[13]:

$$Starch\ Gelatinization\ (\%) = \left[1 - \frac{\Delta H_{parboiled...rice}}{\Delta H_{raw...rice}}\right]$$

Energy Consumption

The electrical power required to carry out various operations was measured in all tests. Energy consumption for soaking, steaming, and drying of high-moisture paddy could therefore be calculated separately.

Data Analysis

Results of all quality evaluations were analyzed for significant differences among the various IR heating exposure times and the control factors, untreated rice, and conventional steam-parboiled rice, using ANOVA and Fisher's least significant difference (LSD) at a significance level of 5%.

RESULTS AND DISCUSSION

Quality Determination of High-Moisture Paddy Under IR Heating

The soaked paddy at 30% wb was heated by IR at 2,100 W for exposure times of 3, 5, 7, 9, 11, 12, 13, 14, 15, 16, 17, 19, 21, and 23 min. The qualities of paddy samples compared to the untreated paddy and the conventional steam-parboiled paddy were as follows.

Moisture Removal

Moisture content of all IR-heated samples decreased with increased exposure time as shown in Fig. 4. Under IR heating, 10% of moisture content was removed within 14 min. Half of initial moisture content was removed in 19 min, whereas 23 min was required to remove two thirds of initial moisture content. In fact, the moisture removal occurred after IR heating due to sensible heat during tempering. This phenomenon took place due to enclosing the paddy sample tray with tempered glass; the vapor released from soaked paddy could not easily escape because moisture content was removed immediately when the tempered glass was opened. Vapor from paddy under high temperature continued to be released during tempering at room temperature, in contrast to the conventional steam-parboiled sample, whose moisture content increased more than 2% after the steaming process. The efficient IR heating shows a high rate of moisture removal. As expected, high IR heating of 2,100 W equivalent to 46.7 kW/m^2 IR intensity showed a faster drying rate and consequently a shorter drying time, consistent with previous research.[21,34,35]

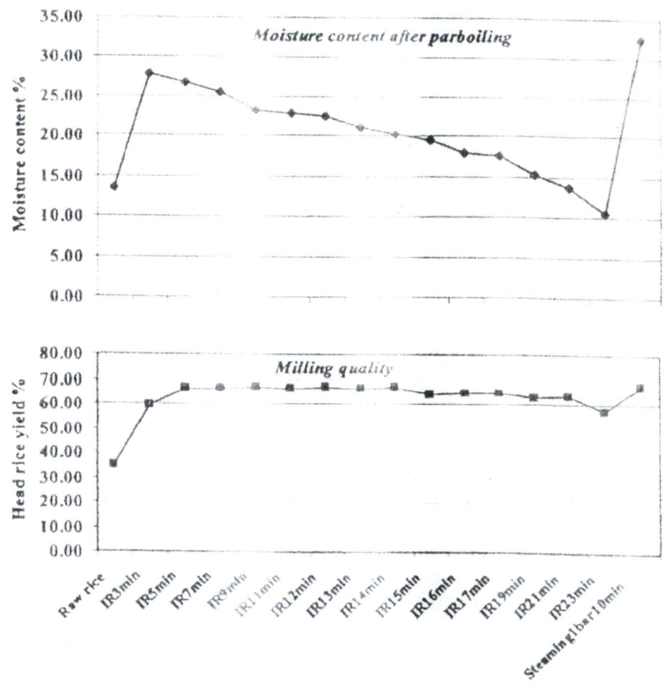

FIG. 4. Moisture content change after IR heating at various exposure times (above) and effect on head rice yield, HRY (below).

Milling Evaluation

All IR-heated samples gained high head rice yield compared to the raw rice (about 35% HRY) as shown in Fig. 4. The samples under IR heating at 5–14 min showed the highest level of HRY range at 66–67%, which was lower than the conventional steam-parboiled sample by about 1%. The samples for 15-, 16-, and 17-min IR heating decreased HRY about 2% (ranging from 64 to 65% HRY) and slightly dropped to 62–63% HRY for 19 and 21 min of IR heating. The minimum IR heating exposure time of 3 min gained 59.45% HRY and the lowest HRY was 56.90% for the sample undergoing 23-min IR heating. IR-heated samples showed an incresing milling yield caused by gelatinization of rice starch, which is similar to the hot air fluidization technique.[36,37] An stronger structure of the rice kernel was obtained during IR heating.

Chalkiness

One indicator of low-quality parboiled rice is the chalkiness or "white belly" caused by incomplete gelatinization.

The experimental samples showed no chalkiness in the grain, similar to conventional steam-parboiled rice. This occurred as a result of using maximum IR power of 2,100 W and covering the sample tray with tempered glass, which increased the temperature in the tray to 100°C. This was different from the results of the test unit without tempered glass in which the temperature was 70°C and yielded 2–10% white belly in all samples.

Color Evaluation

Color evaluation focused on the yellowness and whiteness of grain as shown in Fig. 5. The yellowness (b-value) of parboiled rice under 100 kPa steam for 10 min was the reference value, and raw rice was used for a whiteness reference. The results showed that samples under IR heating had a lower b-value than the control sample (steam-parboiled rice) at 29.7. Tests revealed that 3-min IR heating delivered the lowest b-value at 22.92. The b-value of samples ranged from 23 to 25 for heating times of 5–19 min. However, after 19 min of IR heating, the samples showed b-values that rapidly increased and approached levels of the control sample. This was especially true with the 21- and 23-min IR-heated samples that showed a mix of

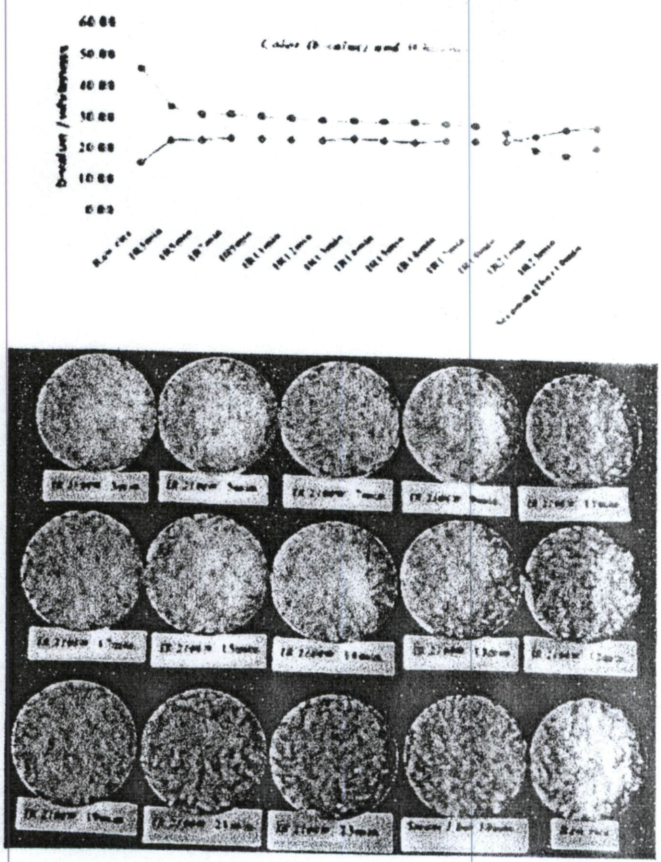

FIG. 5. Yellowness and whiteness of paddy samples under IR heating at various exposure times.

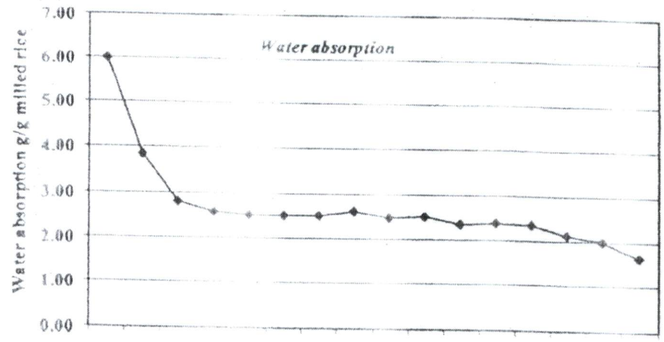

FIG. 6. Parboiled rice samples under IR heating at various exposure times compared to steam-parboiled rice and normal rice.

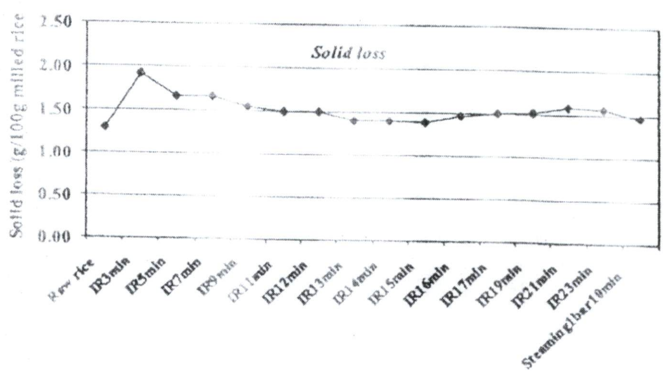

FIG. 7. Changes in water absorption and solids loss during cooking of IR-heated samples under various exposure times.

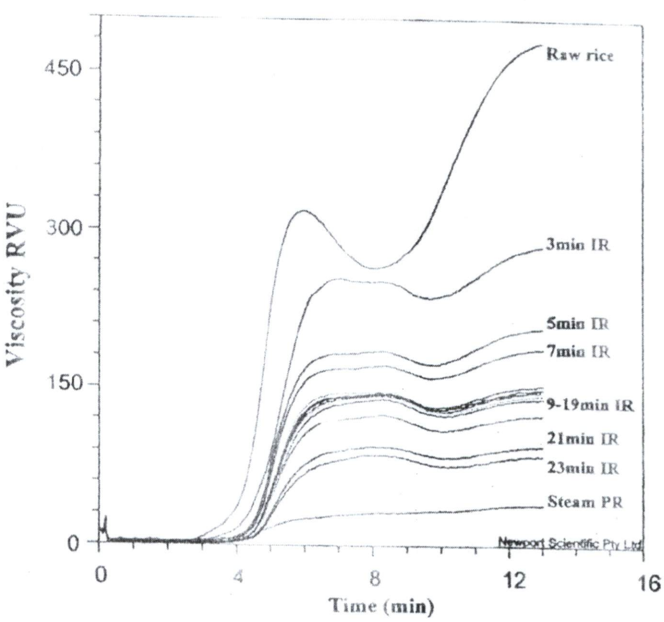

FIG. 8. Viscograph of raw rice flour and rice flour under IR heating at various exposure times and parboiled rice flour under steam of 1 kg/cm^2 for 10 min.

TABLE 1

Qualities evaluation, pasting properties, and thermal property of IR-heated sample with 30% IMC

Treatment	MC wb% after heating	HRY (%)	Yellowness (b-value)	Peak viscosity (rvu)	Breakdown viscosity (rvu)	Final viscosity (rvu)	Enthalpy (Jg^{-1})	Gelatinization (%)
Control sample (raw rice)	12.30 ± 0.07	34.66 ± 0.33	16.38 ± 0.29	361.67 ± 16.9	48.42 ± 42.5	476.92 ± 16.67	11.69	0.00
30%, 2,100 W, 10 min	24.60 ± 0.24	68.48 ± 0.28	19.72 ± 0.07	137.58 ± 7.3	13.97 ± 2.14	145.72 ± 9.79	7.34	37.21
30%, 2,100 W, 13 min	22.00 ± 0.56	67.19 ± 0.58	22.51 ± 0.62	123.88 ± 2.54	12.58 ± 3.00	128.25 ± 2.75	5.89	49.62
30%, 2,100 W, 15 min	20.03 ± 0.62	65.05 ± 0.34	23.67 ± 0.22	111.58 ± 0.58	13.67 ± 0.83	113.08 ± 1.41	5.24	55.18
30%, 2,100 W, 18 min	17.63 ± 0.02	62.76 ± 0.18	24.46 ± 0.05	106.33 ± 2.00	11.50 ± 2.08	110.17 ± 0.91	4.79	59.02
Control sample (steam 1 bar, 10 min)	34.11 ± 0.90	69.34 ± 0.24	28.80 ± 0.34	29.08 ± 48.29	3.29 ± 3.15	39.54 ± 45.60	1.95	83.32

TABLE 2

Quality evaluation, pasting properties and thermal properties of IR-heated samples with 32% IMC

Treatment	MC, wb% after heating	HRY (%)	Yellowness (b-value)	Peak viscosity (rvu)	Breakdown viscosity (rvu)	Final viscosity (rvu)	Enthalpy (Jg^{-1})	Gelatinization (%)
32%, 2,100 W, 10 min	25.43 ± 0.33	69.40 ± 0.13	21.74 ± 0.79	128.67 ± 0.22	13.14 ± 1.70	136.61 ± 1.09	5.53	52.69
32%, 2,100 W, 13 min	22.77 ± 1.19	68.72 ± 0.18	22.74 ± 0.02	108.96 ± 3.96	13.08 ± 0.00	116.54 ± 4.46	4.54	61.16
32%, 2,100 W, 15 min	20.82 ± 0.87	64.54 ± 0.34	24.20 ± 0.28	89.04 ± 9.88	10.00 ± 1.17	91.38 ± 8.29	4.23	63.82
32%, 2,100 W, 18 min	17.90 ± 0.36	60.60 ± 0.50	24.57 ± 0.78	83.94 ± 0.63	11.39 ± 0.98	89.31 ± 1.69	2.32	80.15

for the raw rice sample and conventional steam-parboiled rice. Ali and Bhattacharya[38] indicated that the low level of viscosity could be explained as a result of the higher degree of starch gelatinization. The raw rice sample showed the highest viscosity with nongelatinization, whereas conventional steam-parboiled rice showed the lowest viscosity with complete gelatinization. To indicate the level of gelatinization from the IR-heated samples, the methodology in this research followed the work of Marshall et al.[13] From the experiments it was discovered that the degree of starch gelatinization (SG) was in the range of 0–83.3%. SG of rice receiving 10-min IR heating produced the lowest value at 32.4% and the maximum value was 53.0% for 18 min of IR heating, which was significantly different from conventional steam-parboiled rice. Degree of gelatinization depended on the moisture content of grain and parboiling heat, so moisture removal from grain during IR heating may have caused a lower degree of gelatinization. In order to prove this phenomenon, an experiment with higher IMC of paddy was conducted. Normally, when the moisture content of paddy exceeds 30–32% wb, the hull splits open, leading to excessive hydration and leaching as well as deformed rice after the parboiling process. Thus, the IMC of 32% wb was selected.

Table 2 depicts the quality parameters of IR-heated samples with IMC of 32% wb. The results revealed that moisture content changed after IR heating; HRY, yellowness (b-value), pasting properties (PV, BKV, and FV), and degree of gelatinization (SG) were similar to the paddy sample with 30% wb IMC. The moisture content of samples after IR heating was slightly higher, about 0.5–1.5% compared to previous results. The milling yield was also affected by IR heating; 18-min IR heating produced a significantly low HRY of 60.66%, whereas shorter IR heating time yielded high HRY. This figure was close to the result for conventional steam-parboiled rice of 69.34%, especially for those samples that received 10 and 13 min of IR heating; 15 min of IR heating yielded an HRY value at 64.54%. The yellowness (b-value) of all IR-heated samples with 32% wb IMC gave a slightly higher b-value compared to IR-heated samples with 30% wb IMC. The b-value of samples receiving 18-min IR heating had the highest value at 24.57, which was lower than conventional steam-parboiled rice (28.80).

The pasting properties PV, BKV, and FV of IR-heated samples decreased with increased exposure time, consistent with previous results. However, the 32% wb IMC sample showed lower values of PV, BKV, and FV than the 30% wb IMC sample. The pasting properties of the IR-heated sample exhibited higher values than conventional steam-parboiled rice as a result of partial gelatinization. The degree of starch gelatinization in the 18-min IR sample produced the highest value at 80.2%. This was close to conventional steam-parboiled rice (83.3%), whereas other samples showed SG between 50 and 60%. The degree of starch gelatinization measured by DSC of samples heated by IR increased with increased IMC.

The energy requirement for producing 1 ton of parboiled paddy using IR heating and the conventional steam-parboiled process was estimated between 1,499.8 and 1,524.7 kWh, indicating considerable energy and cost savings. These figures excluded the warm-up time and power input of the steam generator. It was discovered that during the parboiling process IR heating consumed twice the energy but the drying process used less than 2.5 times the energy. In addition, moisture removal due to sensible heat during the cooling stage without consumption of energy was a very significant proportion.[24] For example, under 14-min IR heating less than 1% of moisture content was removed during heating and then nearly 10% of moisture content was released during the cooling stage. It can be concluded that elimination of the steaming process reduces energy consumption, consistent with research by Dash[10] and Pillaiyar et al.[11] Energy savings under IR heating was not considered significant, yet two advantages were revealed: Investment in a steam generator was not necessary, and fewer drying stages were required.

CONCLUSION

The locally designed and fabricated infrared radiation heating and vibrating apparatus was successfully demonstrated for parboiling paddy to meet the requirements of moving grain during the heating and gelatinization of grain. IR heating of 2,100 W (radiation intensity of 46.7 kW/m^2), selected exposure time of 18 min, and initial moisture content of 32% wb showed optimum qualities with IR parboiled rice: near-white rice appearance, significantly improved HRY, and acceptable flavor quality based on the pasting property (RVA) and degree of gelatinization (DSC) compared to the untreated control samples of paddy and conventional steam-parboiled rice. The IR-heated samples yielded low moisture content, which could reduce energy costs; however, that simultaneous parboiling and drying could reduce the process time of conventional steam-parboiled rice by two thirds was statistically nonsignificant. In summary, a process of simultaneous parboiling and drying through the use of IR heating should be developed and applied in the parboiled rice processing industry.

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