COMBINATION SOAKING PROCEDURE FOR ROUGH RICE PARBOILING

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ABSTRACT: Soaking of rough rice is the most time-consuming operation in the parboiling process. A combination soaking procedure for parboiling of rough rice was developed based on the gelatinization temperature of rice starch to achieve rapid completion of soaking. The objectives of this study were to determine the gelatinization temperature of rice starch, the soaking characteristics of the rough rice, and prescribe the operating parameters of the combination soaking procedure. Medium-grain rough rice (‘Pankaj’) was selected, and its starch gelatinization temperature was determined as 72°C using alkali degradation and hot stage microscopy methods. Soaking characteristics of rough rice were studied at 60°C, 70°C, and 80°C. Below the gelatinization temperature, soaking proceeded in the normal way; however, above the gelatinization temperature, excessive water absorption, husk splitting, actual cooking of rice kernels, and loss of quality due to soak water contamination were observed. The combination soaking procedure, involving 80°C water as the first stage until an intermediate moisture content of 35.0% d.b. (approx. 45 min) followed by 70°C as the second stage up to the saturation moisture content of 42.7% d.b. (approx. 3 h 15 min), resulted in a 67% time reduction when compared with single-stage soaking at 70°C. Rice from the combination procedure resembled that obtained from 70°C single-stage soaking in all respects. In milling analysis, after parboiling the rough rice from both soaking methods, the polished rice did not show any difference in terms of head rice yield, broken grains produced, and cracked grains produced.

Keywords. Absorption, Alkali degradation, Gelatinization temperature, Microscope, Paddy, Parboiling, Rough rice, Soaking.

Parboiling of rough rice, or paddy, is essentially a hydrothermal treatment given prior to milling to accomplish gelatinization of the rice’s starch component. Parboiling causes physical and chemical modifications in the grain, leading to favorable changes such as easier shelling, higher head rice yield, fewer broken grains, increased resistance to insects, firmer cooked rice texture, less solids loss during cooking, better retention of nutrients (e.g., proteins, vitamins, and minerals), and higher oil content in the bran (Garibaldi, 1972; Bhattacharya, 1985; Pillaiyar, 1988). It has been established that cracks, chalkiness, and incomplete grain filling are totally rectified and many of the previous defects are cured when paddy is parboiled properly (Bhattacharya, 1969). However, a common problem with the parboiling process, especially in high temperature and pressure operations, is darkening of the rice and its consequent effect on consumer acceptability (Luh and Mickus, 1991).

In general, the parboiling process consists of three stages: soaking the cleaned raw rough rice to saturation moisture content, gelatinization of rice starch by adding heat to the moist kernels through steaming, and drying the product to a moisture content suitable for milling or storage. Parboiling of rough rice can be achieved through a variety of methods that differ basically in the intensity of the hydrothermal treatment (Bhattacharya, 1985; Pillaiyar, 1988). Soaking is the most time-consuming operation in the parboiling process, followed by drying and steaming.

In traditional parboiling, soaking uses water at room temperature and takes 1 to 2 days. Modern methods use hot water, and soaking can be completed in a shorter time depending on the temperature of the soak water. Long-duration cold water soaking leads to microbial growth and off-flavor development, whereas hot water soaking requires high energy inputs and produces unsatisfactory coloration of the kernels.

Chattopadhyay and Kunze (1986) determined a minimum hydrothermal treatment for packaged parboiled rice that restored fissured grains, eliminated grains with opaque cores, and imparted minimum color. They studied various treatments of hot soaking (60°C, 65°C, and 70°C) and steaming (103.51 kPa gauge) times with Brazos (medium-grain), Labelle, and Skybonnet (long-grain) varieties and found that the optimum combination of treatments depended on variety. A modern parboiling process developed at the Indian Institute of Technology, Kharagpur, India, utilizes 70°C to 80°C hot water soaking for 3.5 h, which also completes the starch gelatinization, thus eliminating the steaming process.
after which the soaked rough rice is dried (Ali and Ojha, 1976). For the conventional atmospheric-pressure soaking process, Velupillai and Verma (1982) reported that the steaming operation was more effective in producing translucent grains when the rough rice reaches saturation moisture content of approximately 43% d.b.

According to Chattopadhyay and Kunze (1986), the gelatinization temperature of rice starch can be used in setting the water temperature for hot soaking of rough rice during parboiling. The gelatinization point is the temperature at which further hydration and irreversible starch granule swelling take place and is specific for each variety (Ali and Ojha, 1976). Despite development of more efficient modern parboiling methods, a major portion of the world’s rough rice is still parboiled in the conventional way, involving soaking, steaming, and drying operations, possibly because of tradition, existing machinery, or familiarity. The efficiency of traditional parboiling can be improved by shortening the time of the soaking operation without sacrificing product quality. In general, achieving saturation moisture content should be the target of the soaking operation. Properly soaked rough rice can then be processed using several available methods of steaming, drying, and milling to obtain parboiled rice.

The objectives of this study were to determine the gelatinization temperature of rice starch, study the soaking characteristics of rough rice at temperatures around the gelatinization temperature, and develop a combination soaking procedure that achieves rapid completion of the soaking operation in rough rice parboiling.

**MATERIALS AND METHODS**

A medium-grain variety (‘Pankaj’) of rough rice was used in this study. The rough rice soaking experiments were carried out after determination of the gelatinization temperature of rice starch (Igathinathane, 1997). The rough rice used in the study was harvested at about 28.2% d.b., sun dried to about 14.9% d.b., cleaned, and stored in a metal bin prior to testing.

**DETERMINATION OF STARCH GELatinIZATION TEMPERATURE**

Two methods were followed for the determination of the gelatinization temperature of rice starch: alkali degradation, and hot stage microscopy. Alkali degradation is an approximate estimation method and provides a range for the gelatinization temperature, while hot stage microscopy determines the gelatinization temperature accurately.

**Alkali Degradation Method**

The alkali degradation method (Juliano, 1985) involves digestion of rice starch in an alkali medium for a specified period. The resulting degree of disintegration or the disintegration pattern serves as an indirect indicator of the approximate range of the gelatinization temperature. To ensure that the starch component of the rice interacts with the alkali, brown rice should be well polished to remove the bran layer. Hence, a sufficient polish of 8% (percent polish = weight of bran or polish produced × 100 / weight of brown rice input) was given to the brown rice samples before the alkali degradation test. The actual procedure involved arranging six to eight grains of raw polished rice in a petri dish and introducing 10 mL of 1.7% potassium hydroxide (KOH) solution so that the grains were completely immersed in the alkali. The petri dishes were covered and left undisturbed for at least 24 h. Three replications were made for observation. The disintegration pattern was observed better with a black background by keeping black sheets beneath the dishes. A score of 1 to 7, as proposed by Juliano (1985) based on the observed degree of grain disintegration, was used in the analysis. Low scores (1 to 2) corresponded to a gelatinization temperature >74°C, medium scores (3 to 5) corresponded to 70°C to 74°C, and high scores (6 to 7) corresponded to <70°C. A lower score indicates lesser grain disintegration and a higher starch gelatinization temperature, and vice versa. Complete disintegration means that it would be easy to digest the starch with the given strength of the chemical and a less severe thermal treatment would do for a complete gelatinization.

**Hot Stage Microscopy Method**

Rice becomes translucent after parboiling. Complete transluency indicates complete gelatinization of the starch granules throughout the endosperm, indicating the completion of parboiling. When gelatinized, the granules no longer exhibit birefringence under polarized light, and the orderly polyhedral structure of the compound granules changes into a coherent mass (Juliano, 1985; Pillaiyar, 1988). The change in optical properties under plane polarized light before and after gelatinization of moist starch due to heat is used to find the gelatinization temperature of the starch. A very small quantity of finely ground (80 mesh ASTM = 180 μm) raw rice sample was analyzed using a hot stage microscope (Bristolscope, Bristolinol) for determination of the gelatinization temperature. The sample was wetted with a drop of distilled water, held between glass slides, and mounted on the hot stage of the microscope. The optical properties of the starch granules were observed through the microscope as the heating proceeded. The temperature was continuously monitored using the pre-calibrated thermometer attached to the hot stage of the microscope.

**HOT SOAKING OF ROUGH RICE**

Soaking of raw rough rice is the first step in the parboiling process. To get a completely parboiled product, the soaking should be carried out to completion. The range of hot water temperatures chosen for the soaking study was based on the observed gelatinization temperature of rice starch so that the range covered one level above and two levels below the gelatinization point. When soaked completely, irrespective of the water temperature, rice kernels do not show any opaque, whitish core or white belly.

**Determination of Soaking Characteristics of Rough Rice**

The hot water soaking of rough rice was carried out in a thermostatically controlled hot water bath. The cleaned rough rice was placed in a perforated container that was kept inside the bath. Samples in triplicate were drawn at required intervals of time closely spaced during the initial period (0 to 8 h) and widely spaced at the later stage of soaking. The initial moisture content and the moisture contents of the samples drawn at different times were determined using the direct air-oven method (Araullo et al., 1976). A sample of 30 g was taken and kept in a hot air-oven at 100°C for 96 h, and the moisture content was determined gravimetrically.
The mean of the three replications was used in the analysis. During soaking, when there was no significant increase in the moisture content after 2 h duration, the sample was considered to have reached moisture saturation. The moisture content of the samples plotted against time produced the soaking characteristic curves. The final moisture content corresponding to the asymptotic region was considered as the saturation moisture content of the rough rice at the particular soaking temperature.

**Combination Soaking Procedure**

From the soaking characteristics at different temperature levels bordering the gelatinization point, the temperature-time combination to achieve a particular moisture content by soaking was estimated. The temperature levels of the two-stage combination soaking procedure were fixed arbitrarily closer to the determined gelatinization temperature. In the first stage, the water bath was set at a temperature a few degrees above the gelatinization temperature and the rough rice was soaked until its moisture content reached an intermediate level. Although higher temperatures enhance the absorption rate, they are energy intensive and are severe on the material. The intermediate moisture level was chosen so as to avoid the possibility of husk splitting during soaking at the temperature above the gelatinization point.

The second stage was performed in the same hot water bath. For the second stage, the bath temperature was set a few degrees below the gelatinization temperature. This low-temperature treatment ensured that the grains reached the final saturation moisture without the risk of splitting the husk. A much lower temperature would be less severe on the material, which would be good for product quality, but it would take more time to attain saturation moisture content. The water was brought immediately to the lower temperature by adding a calculated quantity of cold water estimated by trials. The second stage of soaking was carried out until the material reached the saturation moisture content. The samples were drawn at regular intervals and analyzed for the characteristics of the combination soaking procedure.

**Performance Evaluation of Soaked Rough Rice**

The performances of soaked rough rice from the combination soaking procedure and from the single-stage 70°C soaking treatment were evaluated after uniform parboiling and milling treatments in terms of head rice yield, broken grains produced, and cracked grains produced (Igathinathane, 1997). Parboiling was completed by steaming the rough rice samples in an autoclave at a gauge pressure of 98.07 kPa for 10 min, and drying in a laboratory fluidized-bed dryer at 90°C to a final moisture content of 13.6% d.b. Dried rough rice samples of 280 g were then dehusked in a laboratory model rubber roll sheller (THU class 35A Satake rice machine). From the brown rice obtained, samples of 210 g were polished using a laboratory model abrasive roller polisher (TM-05 Satake grain testing mill). A good polish of 8% was given to the samples. The polished rice samples were manually separated for broken and cracked grains. Cracks on the polished rice grains were detected using a backlit ground-glass platform and magnifier. Head rice yield (weight of head rice × 100 / weight of rough rice input), broken grains (weight of broken grains × 100 / weight of polished rice input), and cracked grains (weight of cracked grains × 100 / weight of polished rice input) were evaluated and expressed in percentages.

**Results and Discussion**

**Gelatinization Temperature of Rice Starch**

The determination of the gelatinization temperature is essential for setting the temperature for hot water soaking and for the combination soaking procedure. A medium degradation pattern was observed in the samples from the alkali degradation method, which signified that the starch of the rice variety belonged to an intermediate gelatinization group. The medium degradation pattern takes a score of 3 to 5, and the approximate gelatinization temperature falls in the range from 70°C to 74°C (Juliano, 1985). The gelatinization temperature range was also determined in a more objective manner using hot stage microscopy. In the hot stage microscope, under plane polarized light, all the rice particles were seen as tiny sparkles when the stage was cold, and they gradually lost their glow and became dark as the stage temperature increased. The temperatures at which the particles start losing their glow and at which all the particles became dark are considered as the onset and the end point of birefringence, respectively. The onset and end point temperatures of birefringence were observed to be 68°C and 73°C, respectively. It was observed that a 90% completion of rice starch gelatinization occurred at 72°C. This temperature was considered as the starch gelatinization temperature of the rough rice selected.

**Hot Water Soaking Characteristics of Rough Rice**

For proper parboiling, a completely soaked condition of the rough rice helps in the subsequent steaming operation. As the observed gelatinization temperature was 72°C, hot water soaking studies were conducted around this temperature. Two water temperatures (60°C and 70°C) were below and one (80°C) was above the observed gelatinization temperature were selected. The soaking characteristics of the rough rice at these temperatures are shown in figure 1. The moisture uptake was gradual when the soaking water temperatures were lower than the gelatinization temperature of the starch and followed the general soaking characteristics of grains (Bakshi and Singh, 1980; Velupillai and Verma, 1982; Igathinathane and Chattopadhyay, 1997; Tagawa et al., 2003).

The moisture absorption rate of the grains and the final saturation moisture content were higher when the soaking temperature was high; hence, the 70°C soaking curve was above 60°C. Below the gelatinization temperature, both curves follow the same trend and run almost parallel to each other. The moisture absorption rate was high during the initial 3 h of soaking, with moistures increasing to 33% to 35% d.b. from the initial moisture content of around 15.5% d.b. After 3 h, the moisture increase was gradual and slow, with the curves becoming almost flat at about 10 h of soaking. Flattening of the moisture curves indicates that the saturation moisture content has been reached. The final saturation moisture content obtained after 12 h of soaking were 41.6% and 42.6% d.b. for 60°C and 70°C, respectively. Grains soaked below the gelatinization temperature did not exhibit any sign of husk splitting, in visual observation, after attaining their final saturation moisture content.
An abrupt deviation in the soaking characteristics from the previous trend was observed when a water temperature above the gelatinization temperature was used. At 80°C, the moisture uptake continued to increase without flattening out in the time range studied. The increase of moisture content until 6 h of soaking may be due to moisture uptake accompanied by volume expansion of the starch under the influence of high temperature. A further sharp increase in the moisture content was also noticed after 6 h. This continued moisture increase may be due to the observed husk splitting and actual cooking of the rice kernels. Cooking results in greater kernel volume expansion and concomitant greater water absorption. This husk splitting, due to excessive expansion of the rice kernel, allows the water to come into direct contact with the rice kernel, thereby lowering the quality of the final product. It can be seen from the curve that the saturation moisture content of around 42% d.b., from the initial moisture content of around 15.5% d.b., took almost 12 h for the 60°C and 70°C soaking temperatures, but the same level of moisture content was reached within 2 h with 80°C.

Technically, the end of rough rice soaking is the attainment of saturation moisture content of around 42.9% d.b. (Battacharya, 1985). In actual production using traditional soaking, the end point may be determined by the elimination of white belly (ungelatinized opaque core) in soaked grains, and the time involved mainly depends on the temperature of the soak water. In modern methods with high-temperature soaking, rough rice is soaked for shorter durations (3 to 3.5 h at 70°C) below the level of saturation, since steaming is done immediately to complete the gelatinization, as in Central Food Technological Research Institute (CFTRI) method (Battacharya, 1985; Pillaiyar, 1988).

**Combination Soaking Procedure for Rough Rice**

To achieve a rapid completion of soaking of rough rice without husk splitting, a combination soaking procedure was developed. The combination soaking procedure was aimed at obtaining soaked rough rice resembling that produced when using a soak temperature below the gelatinization point and with no husk splitting. In this study, 70°C soaking was considered as the reference, based on the gelatinization temperature, and the combination soaking procedure tries to achieve the corresponding saturation moisture content in a shorter time. The time reduction was achieved in the first stage of soaking, which was carried out at a temperature (80°C) above the gelatinization temperature up to the intermediate moisture content. The second stage of soaking was a finishing stage aimed at preserving the quality of the product, and hence was carried out at a temperature (70°C) below the gelatinization temperature. An intermediate moisture level of 35.0% d.b. was chosen, which was 7.7% d.b. lower than the saturation moisture content at 70°C. Soaking characteristics of the combination procedure are shown in figure 2.

The exact treatment in the combination soaking procedure was a first stage of soaking at 80°C for 45 min followed by a second stage of soaking at 70°C for 3 h 15 min, with a total time of 4.0 h. The actual intermediate moisture content at the end of the first stage was 35.13% d.b., and the saturation moisture content after the second stage was around 42.72% d.b. As expected, the moisture uptake was rapid during the first stage at 80°C, and gradual variation was observed in the second stage of soaking at 70°C. Processing conditions and times for other varieties of rough rice can be obtained from the existing data on gelatinization temperature, saturation moisture content, and hot water soaking characteristics, or by
preliminary experiments following the procedure outlined in this study.

Visual observations showed that the quality of the soaked rough rice from the combination soaking procedure resembled that produced from single-stage soaking below gelatinization temperature (70°C) in all respects. By application of the combination soaking procedure (4 h total time), a clear 67% soaking time reduction was achieved over conventional hot water soaking of rough rice at 70°C (12 h).

When final moisture contents lower than the saturation moisture content of soaking are desired, as encountered in procedures with shorter soaking times like the CFTRI method (Battacharya, 1985; Pillaiyar, 1988), the combination soaking procedure will nevertheless achieve the required final moisture content with a corresponding time reduction. Since the soaking time reduction in combination soaking is essentially based on the enhanced soaking rate above the gelatinization temperature, and most current soaking methods operate below the gelatinization temperature, the combination soaking procedure is expected to produce time reduction irrespective of the final moisture content of soaking and the rough rice variety. Studies of the chemical and nutritional effects of the combination soaking procedure on the final parboiled rice were not carried out and should be considered for comprehensive evaluation of the procedure.

Performance of the soaking treatments was compared from the milling analysis of the finished parboiled rice. In the milling analysis, the parboiled polished rice samples from both soaking treatments did not show any difference between them in terms of head rice yield (around 73%), broken grains produced (0%), and cracked grains produced (0%) (Igathinathan, 1977). It is quite common to have no broken and cracked grains in parboiled rice, when the parboiling process is carried out properly.

Hot water soaking behavior of rough rice at lower temperatures (below 60°C) and at higher temperatures (above 80°C) were not considered in the present study, as the lower temperatures would produce very slow absorption and the higher temperatures would tend to cook the rough rice, as observed at 80°C. Any combination of 80°C at the first stage and any temperature below 70°C for the second stage would also produce a quality product, but it would require more time for completion. Use of still higher temperatures for the first stage to enhance the soaking rate, although energy intensive, and lower temperatures for the second stage, and their effects on the process time and quality of the product, need to be studied. The complete process of rough rice parboiling, including the combination soaking procedure, is outlined in figure 3.

From this study, it can be recommended that the best combination soaking procedure of rough rice, after determining the rice’s starch gelatinization temperature, would be a first stage of soaking at a few degrees above the gelatinization temperature up to an appropriate intermediate moisture below the desired saturation moisture content, followed by a second stage of soaking at a few degrees below the gelatinization temperature until completion. The proposed procedure is expected to work with other varieties of rough rice suitable for parboiling, and similar studies are required to determine the exact processing conditions.
CONCLUSIONS
The starch gelatinization temperature of a medium-grain rice variety (‘Pankaj’) was determined as 72°C using both alkali degradation and hot stage microscopy methods. This gelatinization temperature of rice starch was used to fix the operating parameters for a combination soaking procedure. The 60°C and 70°C soaking characteristic curves of rough rice below the gelatinization temperature followed the general moisture absorption trend, and the rough rice required almost 12 h to reach saturation moisture content. On the other hand, soaking the rough rice above the gelatinization temperature caused rapid and excessive moisture absorption. Soaking at temperatures below the gelatinization temperature takes more time but maintains desirable quality, while soaking at temperatures above gelatinization temperature may cause quality concerns because of husk splitting and soak water contamination. Using this information, a combination procedure was prescribed and tested, involving a first stage of soaking at 80°C up to an intermediate moisture content of 35.0% d.b. (approx. 45 min) followed by a second stage of soaking at 70°C until the saturation moisture content of 42.7% d.b. (approx. 3 h 15 min). This procedure resulted in a 67% time reduction when compared to single-stage soaking at 70°C. In milling analysis, the quality of the parboiled rice produced from the combination soaking procedure was comparable to that produced from single-stage soaking at 70°C.
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REFERENCES


