Power Ultrasound Enhanced One-Step Soaking and Gelatinization for Rough Rice Parboiling

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Abstract

The conventional parboiling of rough rice is a lengthy process that takes 24-28 h to complete. It would be beneficial to the industry if the processing time could be reduced. The objective of this study was to develop an ultrasound based one-step protocol for soaking and gelatinization during rice parboiling. The gelatinization temperature was measured by alkali (KOH) degradation and found to be 72°C. The combined soaking and gelatinization was conducted at 75°C with or without sonication (control). The moisture content during soaking was measured following the AOAC oven method. Starch gelatinization was evaluated by differential scanning calorimetry (DSC). Moisture content after 3 h of ultrasonic soaking (48.6% w.b.) was equivalent to 10 h conventional soaking (44.0% w.b.), indicating that ultrasound reduced some 70% of soaking time. DSC showed that the retrogradation peaks (Tr) values for 80°C soaking and ultrasonic horn (US.horn) soaking, which were accomplished during 4 h, was 53.8°C and 53.5°C, respectively. This showed that US.horn soaked samples at 75°C partially gelatinized at the same time frame (4 h) with the samples soaked at 80°C. This study showed the feasibility of ultrasound to enhance the rice parboiling by reducing processing time.

KEYWORDS: power ultrasound, parboiling, rice

1. INTRODUCTION

Rice, one of the most extensively grown and consumed cereal grains, serves as the staple food for nearly half of the population in the world (Miah *et al.,* 2002; Thakur and Gupta, 2006).

Paddy or rough rice parboiling is a hydrothermal process which involves three different steps: soaking, steaming (to gelatinize the starch), and drying. Soaking is an important step, since sufficient water content is crucial to secure an adequate gelatinization in the subsequent steaming step (Bello *et al.,* 2006). However, the husk of rough rice does not wet easily and is a barrier to water passage into the kernel. Habitually, air is trapped within the husk and inhibits the entrance of water to the kernel. The husk has a poor thermal conductivity and slows down heat transfer to the kernel. As a result, a significant amount of time and thermal energy is needed in wetting and heating the mass of husk (Kar *et al.,* 1999). Some alternative methods had been proposed to reduce the soaking time. Igathinathane *et al*., (2005) proposed the use of combination soaking procedure, which reduced the soaking time to 4 h. The major concern for this and other methods of the same kind is the involvement of high temperatures during soaking, which could lead to loss of quality of milled rice (Bhattacharya, 1996). Conventional method of parboiling conducted at room temperature is time-consuming and susceptible to microbial contamination, whereas hot soaking requires a strict control of temperature, because steep temperature and moisture gradients may result in surface sloughing-off before hydration up to the middle of the kernel is attained.

In this study, ultrasound enhanced soaking was used as a tool to increase the rate of soaking and replace the steaming process, so that a synchronized soaking and gelatinization procedure for rough rice parboiling could be developed.

The use of ultrasound in the food industry has been a subject of research and development for many years. Ultrasound has been used physically or chemically in many aspects of food processing and preservation, for example pasteurization, sterilization, generation of emulsions, disruption of cells, promotion of chemical reactions, inhibition of enzymes, tenderizing meat and modification of crystallization (Mason *et al.,* 1996; Chemat and Hoarau, 2006).

The objective of this study was to develop an ultrasound enhanced one-step soaking and gelatinization procedure for rough rice parboiling and to examine the efficacy of the ultrasound procedure in comparison to control.

2. MATERIALS AND METHODS

2.1. Materials

A long grain variety, Wells, of 9.5% w.b. initial moisture content was obtained from Busch Agricultural Resources, Inc (Jonesboro, AR).

2.2. Gelatinization temperature determination of rough rice kernels

Determination of rice starch gelatinization temperature was carried out before soaking experiments using the alkali degradation technique. Alkali degradation is a method of estimation and offers a range for the temperature of gelatinization (Igathinathane *et al.,* 2005). The procedure involved arranging 6-8 grains of raw rough rice in a Petri dish and covering them with 20 ml solution of 1.7% potassium hydroxide (KOH). The Petri dishes were covered and left undisturbed for at least 24 hours. A lower score of 1-2 corresponded to a gelatinization temperature of $>74^{\circ}$C, a medium score of 3-5 for 70 to 74°C and 6-7 for $< 70^{\circ}$C (Juliano, 1985). A score of 1-7 was obtained for the rice used in this study based on the observed degree of grain degradation.

2.3. Hot soaking of rough rice kernels

Rough rice was cleaned manually to remove any debris. The broken grains were separated and removed. The conventional soaking (CS) of rough rice was conducted in a waterbath set at 75°C, a temperature above gelatinization temperature of the rice, for 10 h. A sample of 1000 g rough rice was placed in a perforated container which was in turn immersed in the waterbath. Samples of 3 g each were drawn at 1 h intervals from the waterbath for determination of moisture content of the rough rice by measuring the moisture content of the samples following the AOAC standard air oven method 925.10 (AOAC, 1996). Another set of rice samples about 1000 g was soaked at 80°C for 7 h, which was regarded as gelatinized and used as a control to compare with the ultrasound treated samples.

2.4. Ultrasound enhanced soaking of rough rice

Two ultrasonic systems with different acoustic energy densities (AED) were used. The first was an ultrasonic tank (US. tank) (model No. T400.1H, Zenith Ultrasonic., Norwood, NJ) with AED of 0.03 W/cm^3 and output frequency of 25, 40 and 80 kHz (which could be operated individually or all three simultaneously). The second was an ultrasonic horn (US. horn) (model S3000, Misonix Inc., Farmingdale, NY) with the AED of 0.10 W/cm^3 and output frequency of 20 kHz.

Samples were sonicated at 75°C for up to 10 h in the ultrasonic tank system or up to 5 h in the ultrasonic horn system. In both systems, samples of 3 g each were drawn at intervals of 30 min for moisture content determination following the AOAC standard method.

2.5. Monitoring the temperature course during soaking

Rough rice temperatures during the conventional soaking at 75°C and the ultrasound assisted at 75°C, were recorded using a data logger (model FSDaqPRO-5300, Fourier Systems Inc., New Albany, IN). Four type-T thermocouples were employed, with two inserted to the bottom of the sample and the other two to the top portion of the rice sample.

2.6. DSC measurement of gelatinization properties of rice

In order to quantitatively compare the gelatinization properties of rice between conventional and ultrasound-enhanced soaking, measurements were performed using a differential scanning calorimeter (DSC) (Pyris-1, Perkin-Elmer, Norwalk, CT). The rice samples (1-2 g) were dehulled by hand and ground with a mortar and pestle. A sample of rice flour (approx. 4 mg, db) of both unsoaked and soaked was weighed in aluminum DSC pans, and 8.0 μL of deionized water was added with a microsyringe. The aluminum pan was hermetically sealed, equilibrated at room temperature for at least 1 h, and then scanned from 20 to 120°C at a rate of $10^{o}C$/min. The onset peak and end temperatures and the enthalpy of the gelatinization endotherm were computed.

3. RESULTS AND DISCUSSION

3.1. Gelatinization temperature of unsoaked rice kernels

Gelatinization temperature was vital for setting appropriate soaking water temperature in this study. An intermediate degradation pattern for the rice was observed from the potassium hydroxide degradation method, which showed that the starch of the rice variety belonged to an intermediate gelatinization group. The intermediate degradation pattern took a score of 3-5, and the approximate gelatinization temperature fell in the 70-74°C range. The mean temperature 72°C was taken as the gelatinization temperature of this specific variety of rice. Therefore, to ensure a complete gelatinization a hot water temperature of 75°C was chosen, which was slightly above 72°C and high enough to ensure starch gelatinization, and yet low enough to prevent rice from being cooked.

3.2. The temperature course during soaking

Figures 1 shows the change of temperature in the soaked rice during CS, US.tank and US.horn soaking. It was observed that the mean temperatures developed during the entire soaking period of the study were 76.7±0.5°C, 75.6±0.7°C and 76.4±0.7°C for CS, US.tank and US.horn, respectively. Although a minor deviation of temperature of the soaked rice from the set temperature during the entire soaking period was observed, the temperatures were generally within ±0.7°C range. It can be concluded that the targeted soaking temperature of 75°C was met during the parboiling process.
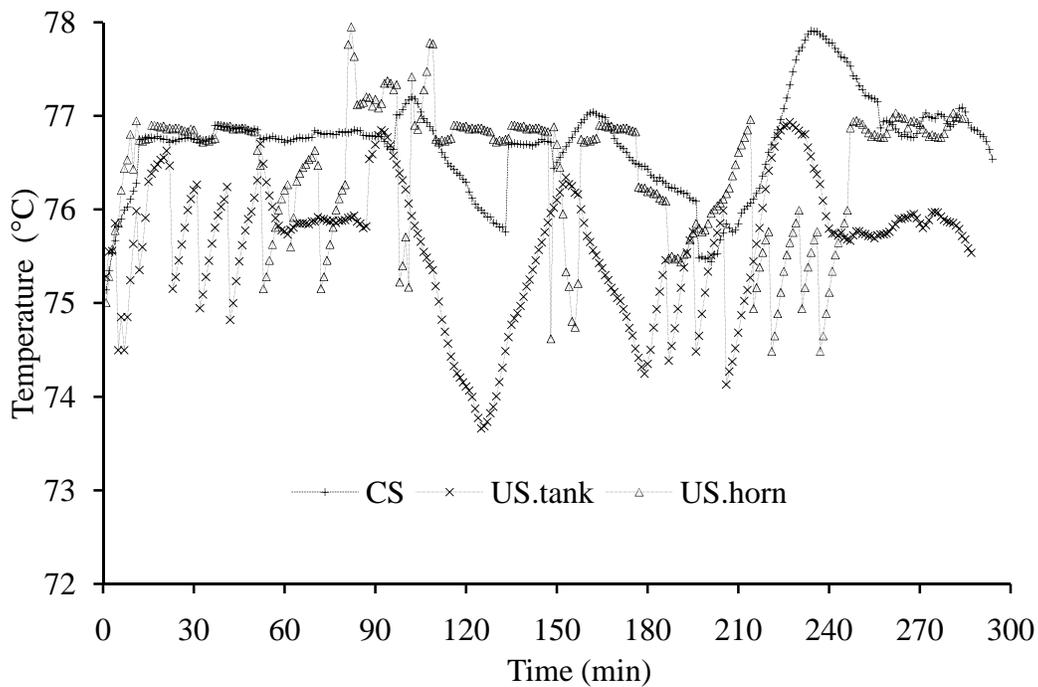

Fig. 1: Temperature development in the soaked rice during conventional soaking (CS), ultrasonic tank (US.tank) and ultrasonic horn (US.horn) enhanced soaking at 75°C. The mean temperatures developed were 76.7±0.5°C, 75.6±0.7°C and 76.4±0.7°C for CS, US.tank and US.horn, respectively. +, CS; ×, US.tank; Δ, US.horn.

3.3. Moisture content during soaking

The initial moisture content of the rough rice used in this study was 9.5±1.2% w.b. Figure 2 shows the moisture content vs. soaking time for conventional

soaking (CS), ultrasonic tank soaking (US.tank) and ultrasonic horn soaking (US.horn) at 75°C. During the conventional soaking the moisture content appeared to be slow and similar to the general behavior of rice grains (Igathinathane *et al.,* 2005). As indicated in Fig. 2, the moisture content after 5 h of US.horn (67.6±0.9%) and 10 h of US.tank (46.9±2.0%) soaking was higher than 10 h of conventional soaking (44.0±0.9%).
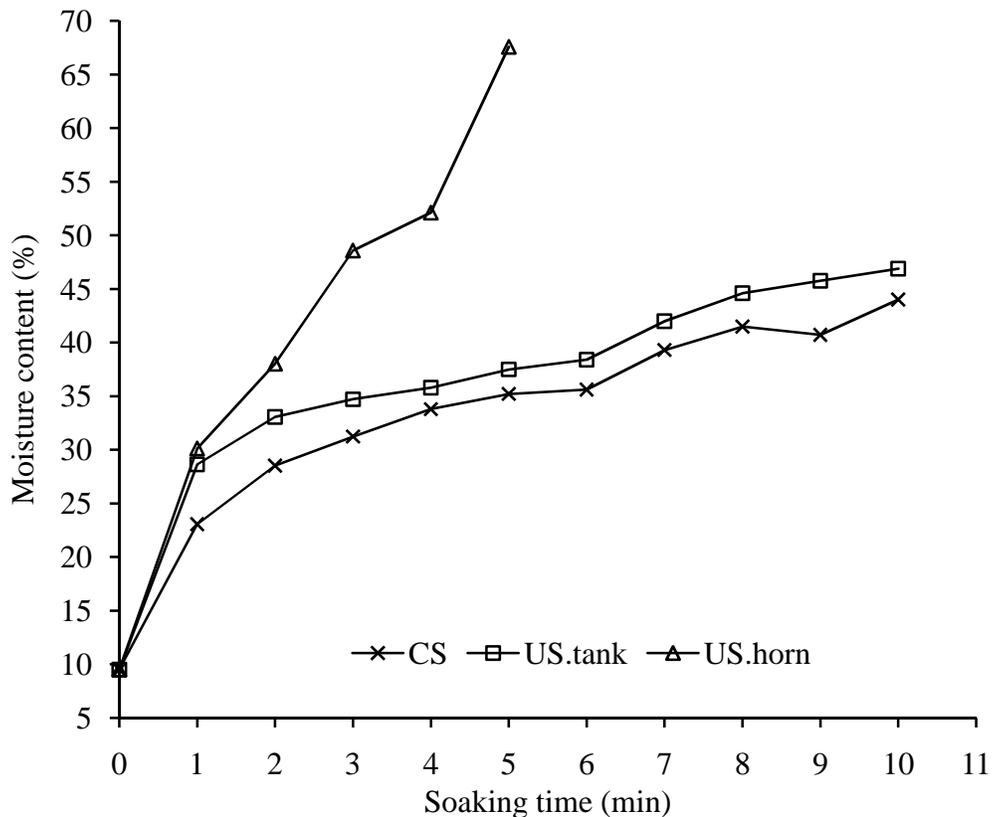

Fig. 2: Moisture content profile of soaked rough rice during conventional soaking (CS), ultrasonic tank soaking (US. tank) and ultrasonic horn soaking (US. horn) at 75°C. Each datum point was the average of 3 measurements, with standard deviations ranged from 0.4-3.9 for CS, 0.6-5.1 for US.tank and 1.2-3.2 for US.horn. ×, CS; □, US.tank ; Δ, US.horn.

According to Fig. 2, the moisture uptake rate for CS and US.tank procedures was higher during the first hour of soaking. After that, the rate was gradual and slow, with the curves becoming nearly flat at about 8 h of soaking for US.tank and CS. The moisture curves flattering showed that the saturation

moisture content has been reached. During US.horn soaking at 75°C, there was a constant increase in moisture content without flattening out during 5 h of soaking. The moisture content increased continuously up to the end of soaking durations tested. Also, a sharp increase in the moisture content was observed after 4 h. This may be because of the higher power intensity of the ultrasonic horn that created a more effective cavitation. The continued effect of moisture content increase may be because of the observed husk splitting of the rice grains.

It was found that the moisture content of rough rice after 3 h of US.horn soaking (i.e., 48.6±3.2% w.b.) was statistically equivalent to 10 h conventional soaking (i.e., 44.0±0.9% w.b.), indicating that ultrasound horn-soaking reduced approximately 70% of soaking time - a significant amount of time saving during the parboiling process. Similarly, after 5 h of US.horn-soaking there was a 67% in moisture content of rough rice as compared to 35% and 38% for CS and US.tank-soaking, respectively, at the same conditions. This result indicated that US.horn soaking generated almost a double increase in moisture content as compared to conventional soaking at this duration.

Table 1. DSC characteristics derived from rough rice grains soaked at 80°C (as a control)

Soaking time (h)	Moisture content (%)	T_r(°C)	ΔHr (J/g)	T_o (°C)	T_p(°C)	T_e(°C)	ΔH (J/g)
0	11.0			71.1 ± 0.1	75.5 ± 0.1	80.4 ± 0.3	9.7 ± 0.3
1	10.3			74.6 ± 0.5	79.1 ± 0.1	83.9 ± 0.3	8.9 ± 0.4
2	9.9			77.8 ± 0.5	81.6 ± 0.6	86.3 ± 0.7	7.9 ± 0.4
3	11.1			78.5 ± 0.1	82.3 ± 0.1	87.0 ± 0.2	6.9 ± 0.0
4	11.2	53.8 ± 0.6	1.2 ± 0.3	78.0 ± 0.9	83.6 ± 0.5	88.1 ± 0.1	4.3 ± 0.2
5	10.2	53.5 ± 0.0	1.7 ± 0.7	79.8 ± 0.3	84.1 ± 0.3	88.8 ± 0.1	3.6 ± 0.2
6	10.8	55.3 ± 2.0	1.6 ± 0.9	81.3 ± 0.3	85.1 ± 0.6	89.2± 0.7	1.7 ± 0.1
7	10.7	54.9 ± 0.6	2.6 ± 0.1	82.4 ± 0.3	86.9 ± 0.6	90.2 ± 0.4	1.2 ± 0.0

Means ±SD of three duplicate determinations

Note: MC- moisture content, h – hour, T_o – Onset, T_P – Peak, T_e – End,– T_r - retrogradation peak, ΔHr – enthalpy of retrogradation.

3.4. Gelatinization characteristics as determined by DSC

The DSC offers an effective tool for characterizing the thermophysical changes of parboiled rice (Islam *et al*., 2004). Normally, gelatinization comprises the uncoiling and melting of external chains of amylopectin that are packed together as double helices in clusters (Cooke and Gidley, 1992). During parboiling, starch granules gelatinize partly or completely depending on the processing conditions.

Table 2. DSC characteristics derived from rough rice during ultrasound horn enhanced-soaking at 75°C

Soaking time (h)	Moisture content (%)	T_r(°C)	ΔHr (J/g)	T_o(°C)	T_p(°C)	T_e(°C)	ΔH (J/g)
0	11.0			71.1 ± 0.1	75.5 ± 0.1	80.4 ± 0.3	9.7 ± 0.3
1	10.2			73.3 ± 0.3	78.0 ± 0.0	83.2 ± 0.2	9.0 ± 0.5
2	9.9			76.0 ± 0.3	80.1 ± 0.1	84.8 ± 0.4	9.0 ± 0.6
3	10.5			77.4 ± 0.1	81.3 ± 0.0	86.2 ± 0.2	8.1 ± 0.4
4	10.4	53.5 ± 0.0	1.1 ± 0.0	78.0 ± 0.4	82.4 ± 0.3	86.4 ± 0.1	4.2 ± 0.4
4.5	10.0	53.5 ± 0.0	1.8 ± 0.2	78.5 ± 0.2	82.6 ± 0.3	87.1 ± 0.4	3.8 ± 0.2
5	11.0	54.0 ± 0.5	3.0 ± 0.5	80.3 ± 0.1	84.3 ± 0.2	87.8 ± 0.8	1.2 ± 0.1

Means ±SD of three duplicate determinations
Note: MC- moisture content, h – hour, T_o – Onset, T_P – Peak, T_e – End, T_r - retrogradation peak, ΔHr – enthalpy of retrogradation.

DSC Characteristics of the unsoaked, US.horn and 80°C soaked rice are shown in Tables 1 and 2.). Because, It was observed that the moisture content (which is a key factor for starch gelatinization) of rough rice after US.horn soaking was statistically higher than CS and US.tank. Also, to determine the level of gelatinization for US.horn-soaked rice the sample soaked at 80°C was selected as a control sample, because at this high temperature the rice would be was presumed mostly gelatinized. In this study, we anticipated that gelatinization of rough rice would be achieved in a short time with the ultrasound-enhanced, one-step soaking and gelatinization process. The effect of 80°C soaking and US.horn soaking at 75°C on gelatinization was notable during 4 h of soaking. The effect

could be observed due to the occurrence of the retrogradation peaks, T_r. Normally, after the starch is gelatinized, it does then retrograde, and the retrogradation peak is usually located at a much lower temperature, around 40-50°C. Therefore, the T_r values for 80°C soaking and US.horn soaked samples, which were accomplished during 4 h treatments, was 53.8°C and 53.5°C, respectively. This showed that US.horn soaked rice at 75°C partially gelatinized at the same time frame (4 h) with the samples soaked at higher temperature (80°C). The main peak enthalpy increased steadily because rice starch was soaked at a high temperature for an extended period of time, which is called annealing. There was a decrease in enthalpy (ΔH) with an increase in the treatment time for all soaking treatments. Based on the ΔH (9.7 – 1.2 J/g), it could be conceded that approximately 88% of starch was gelatinized during 7 h of 80°C soaking; likewise the same percentage of starch was gelatinized during 5 h of US.horn soaking at 75°C. The amylose-lipid complex characteristics did not have much change. The variation observed may mostly be from variations of the raw samples.
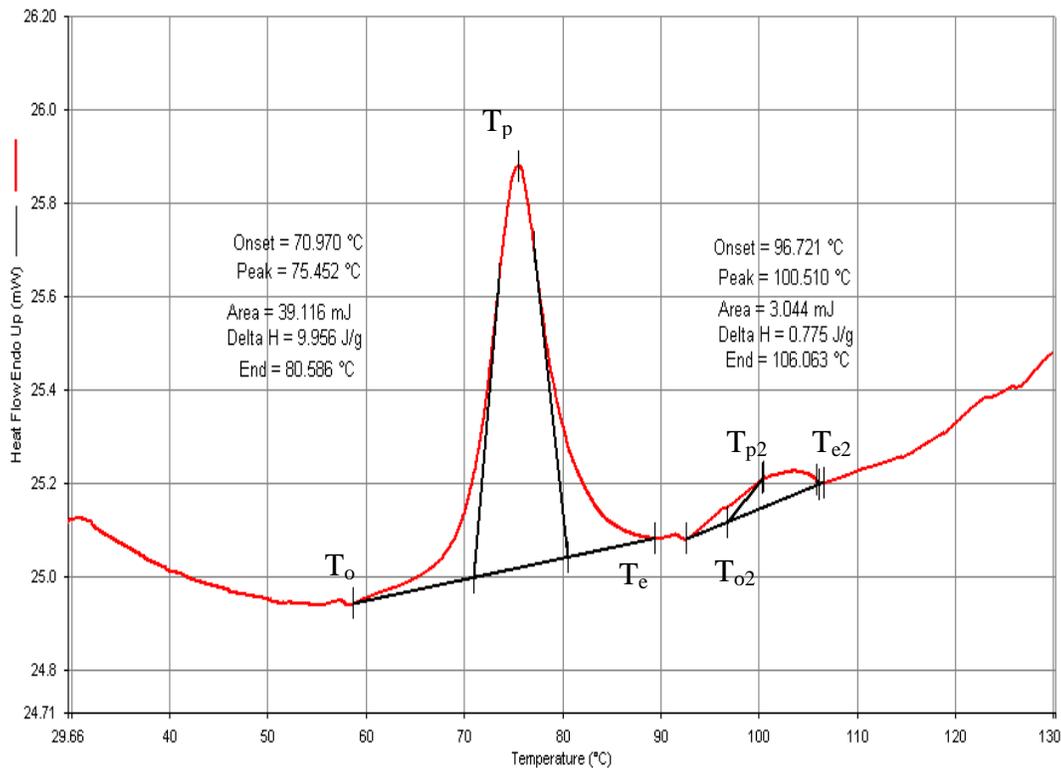

Fig. 3. Typical DSC heating curve showing the gelatinization endotherms for unsoaked rough rice grain with 11.0% w.b. moisture content.

Unsoaked rice sample that was thermally scanned in a DSC at 11% w.b. moisture content exhibited two heterogeneous endothermic peaks. The main peak, around 70-80°C is due to the gelatinization of starch (i.e., disorganization of amylopectin structure), and the second peak around 90-100°C is the melting of amylose-lipid complex as described by Walters *et al.* (2005). The DSC scanning of unsoaked rice sample was used as a second method, after alkali degradation, to determine the gelatinization temperature and time of the rice. The onset (T_o), gelatinization (T_p) and final temperatures (T_e) for the rice were 70.9°C, 75.4°C and 80.6°C, respectively (Fig. 3). Therefore, the peak value (75.4°C) which is regarded as a gelatinization temperature was in the same range as the value estimated by the alkali degradation method. Likewise, this gelatinization temperature obtained was found to fall within a range similar to those reported in literature (Ong and Blanshard, 1995).
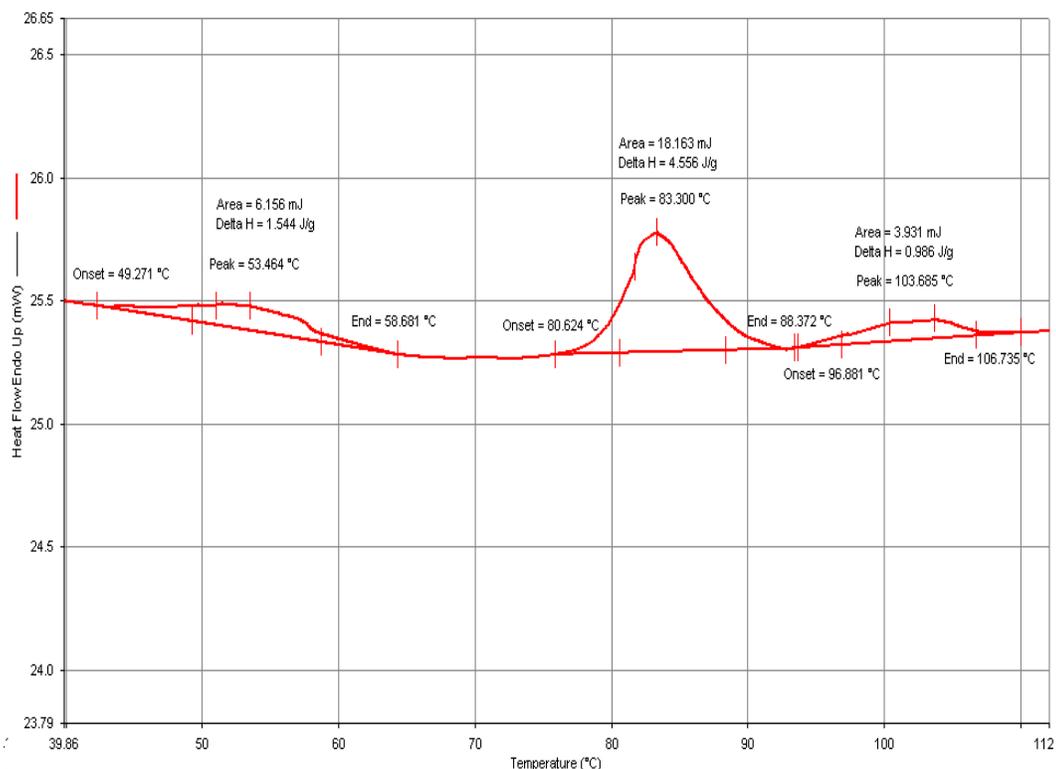

Fig. 4. DSC thermograms of soaked rough rice grains for 4 h at 80°C

According to Figure 4 and 5, three peaks were observed for the rice soaked at 80°C for 4 h and US.horn soaking for 4 h at 75°C. The first small peak indicated that starch was pre-gelatinized by the experimental treatments (80°C

and US.horn). After the starch gelatinized, it then retrograded, and the retrogradation peak was located at a much lower temperature. Therefore based on the occurrence of the retrogradation peak, the gelatinization effect of the experimental treatments was assumed to have commenced at the 4th h of soaking. The final peaks in Figs. 4 and 5 were due to the melting of amylose-lipid complex. These results indicate that despite the ultrasonic horn soaking being conducted at lower temperature, it was still capable of increasing the rate of gelatinization of rough rice to a level comparable to soaking at a higher temperature (80°C) as conducted in this study.
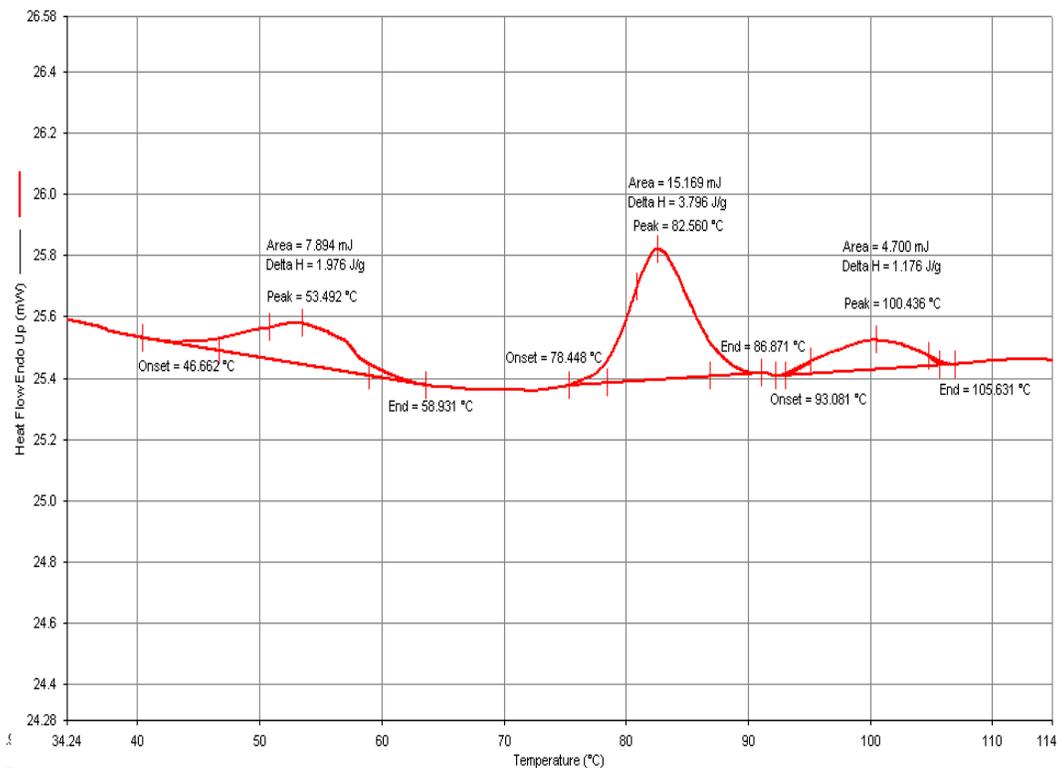

Fig. 5. DSC thermograms of ultrasonic horn-enhanced soaked rough rice for 4 h at 75°C

4. CONCLUSION

The introduction of ultrasound reduced the soaking times of rough rice to achieve the same outcome as with conventional soaking method. The lower temperature associated with the ultrasound enhanced soaking could suggest some advantages over the conventional soaking process in terms of nutritional quality of the rough rice. However, it could not be confirmed that the ultrasound soaking leads to a

lowering of the energy requirement. It needs to be determined whether the rice quality resulting from ultrasound-assisted soaking treatment can justify its use for rice soaking. Further studies are needed to improve the processing equipment in conjunction with industrial requirements in order to apply this technology in the food industry. Finally, the ultrasound enhanced soaking described in this study will facilitate the advancement in the study of the mechanisms involved for the aim of extending the application of this technology.

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