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QUANTIFYING THE RELATIONSHIP BETWEEN RICE STARCH GELATINIZATION AND MOISTURE-ELECTRICAL CONDUCTIVITY OF PADDY DURING SOAKING

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ABSTRACT

This study formulates a mathematical relationship correlating the degree of starch gelatinization (DSG) of rice to the paddy moisture-electrical conductivity (EC) of paddy water during the soaking portion of the parboiling process. DSG values of rice were measured using differential scanning calorimetry (DSC). Paddy was parboiled by soaking at 60, 65, 70 and 75C. At each temperature paddy samples were selected at five different soaking times. Optimum soaking times for 60, 65, 70 and 75C were determined to be 240, 180, 120 and 80 min, respectively. Paddy moisture (22.43–34.93%, wet basis), EC of paddy water (1.63–2.71 mS/cm) and DSG of rice (5.38–36.90%) increased with increasing temperature and soaking time. It was found that a linear relationship exists between DSG and EC, as well as between DSG and moisture content during soaking. EC of paddy water correlates well with DSG of rice during soaking. An online measurement system of paddy water EC was manufactured and evaluated. The relationship between DSG and EC can be utilized for quick and simple determination of DSG during soaking and eliminating the need for conventional chemical analysis.

PRACTICAL APPLICATIONS

Parboiled rice enjoys high popularity because of its high nutritional content. The soaking stage is the most important stage of the parboiling process. Soaking conditions (temperature and time of soaking) largely determine the characteristics of the parboiled product and can be evaluated by DSG. Therefore, from an industrial point of view, it is important to apply the best processing conditions for parboiling rough rice. Hot soaking requires precise control because starch granules are gelatinized during soaking. Determination of DSG is commonly done by DSC instrument. This method is associated with high costs and cannot provide online data. Online measurement of EC values of paddy water during soaking can be used to easily and accurately predict the final time of the soaking stage. This study was developed as a quick and easy method for online determination of DSG values during soaking. The method presented here can be used for monitoring and controlling the soaking stage by measuring paddy water EC via an online system based on DSG values during soaking.

INTRODUCTION

Rice is one of the most important food crops in the world (Buggenhout *et al.* 2013) and is often consumed as milled rice (Takahashi *et al.* 2005). Parboiling is a hydrothermal treatment wherein a paddy is soaked in hot water, steamed to complete gelatinization, and dried and milled (Himmelsbach *et al.* 2008). During gelatinization, starch granules are close to the cracks present in the endosperm leading to consolidation of the grains. This process makes the grains translucent, hard and tough (Bauer and Knorr 2004; Ituen and Ukpakha 2011). Parboiling resulted in translucent kernels, increased swelling when cooked to desired softness, prolongation of rice storage time, and resistance to spoilage by insects and mold (Elbert *et al.* 2001; Heinemann *et al.* 2005; Cheevitsopon and Noomhorm 2011; Fofana *et al.* 2011). The gelatinization process is studied by using differential scanning calorimetry (DSC) and has been reported by numerous researchers (Chaiwanichsiri *et al.* 2001; Li *et al.* 2004; An and King 2007; Morales-Sanchez *et al.* 2007, 2009; Rohaya *et al.* 2013). Most studies on the gelatinization process were focused on the gelatinization endothermic transition curve and extraction of its characteristic parameters, such as the degree of gelatinization and onset (T_o), peak (T_p) and end (T_e) temperature (Himmelsbach *et al.* 2008). The degree of starch gelatinization (DSG) is closely related to many of the attributes of parboiled rice (Ayamdoo *et al.* 2013b).

Electrical conductivity (EC) values were previously evaluated for ohmic heating of rice bran at 20, 30 and 40% moisture content (MC). EC increased markedly with increasing temperature and MC, but was roughly independent of the voltage gradient in the range 44–72 V/cm (Dhingra *et al.* 2012). During ohmic heating of seawater, EC was investigated by Assiry *et al.* (2010). Various reports can be found in the literature on EC measurements by ohmic heating system of different agricultural products (Palaniappan and Sastry 1991; Castro *et al.* 2004; Icier and Ilicali 2004; Dhingra *et al.* 2012; Darvishi *et al.* 2013).

Numerous studies have obtained the gelatinization parameters (T_o, T_p and T_e) of starch using EC (Chaiwanichsiri *et al.* 2001; Li *et al.* 2004; Morales-Sanchez *et al.* 2007, 2009). Another approach to estimate starch gelatinization that has received less attention is enzymatic methods (Di Paola *et al.* 2003). To our knowledge, no researchers have proposed an online measurement of DSG values during paddy soaking. Therefore, this study aims to measure paddy MC and EC of paddy water, and check for correlation of these properties with the DSG of rice during soaking.

MATERIALS AND METHODS

Paddy Sample Selection

A local Iranian variety of long-grain paddy (Fajr) was purchased from the Rice Research Center of Mazandaran, Iran. Initial MC and amylose content of this paddy variety were 11 ± 1%, wet basis (w.b.) and 22.9%, respectively (AOAC 1995, Tabkhkar *et al.* 2012). The paddy was stored at 5C in plastic bags prior to use (Buggenhout *et al.* 2014).

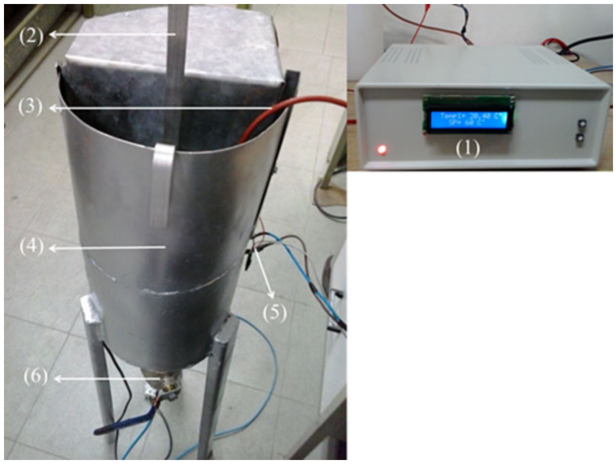

FIG. 1. PADDY SOAKING SYSTEM
1: temperature control; 2: basket; 3: thermocouple; 4: stainless steel container; 5: electrical heater; 6: valve.

Parboiling Process

The samples were parboiled on a laboratory-grade soaking and steaming conditions. As shown in Fig. 1, the soaking setup consisted of a stainless steel cylindrical container, a 2 kW electrical heater, a basket for soaking the paddy in water and a temperature control system. The thermocouple is connected to the temperature control system.

The paddy sample was poured into the basket and soaked in water at a controlled temperature of 60, 65, 70 and 75C (±0.5C). The different soaking times at each temperature are outlined in Table 1. These times were selected based on the optimal MC of the samples at the end of soaking, 35% (w.b.), as suggested by Das *et al.* (2004). After soaking, paddy samples were dried (avoiding sunlight) at 27 ± 1C and 60 ± 5 %RH to a final MC of 11 ± 1% (w.b.) over the course of 3 days (Fofana *et al.* 2011). The experiment was carried out in triplicate.

MC

MC of paddy samples was determined in triplicate by drying in an oven at 130C for 24 h (AOAC 1995).

TABLE 1. SOAKING TIME AT DIFFERENT TEMPERATURES

Soaking temperature (C)	Soaking times (min)				
60	15	45	75	135	240
65	15	45	75	120	180
70	15	30	45	75	120
75	15	30	45	60	80

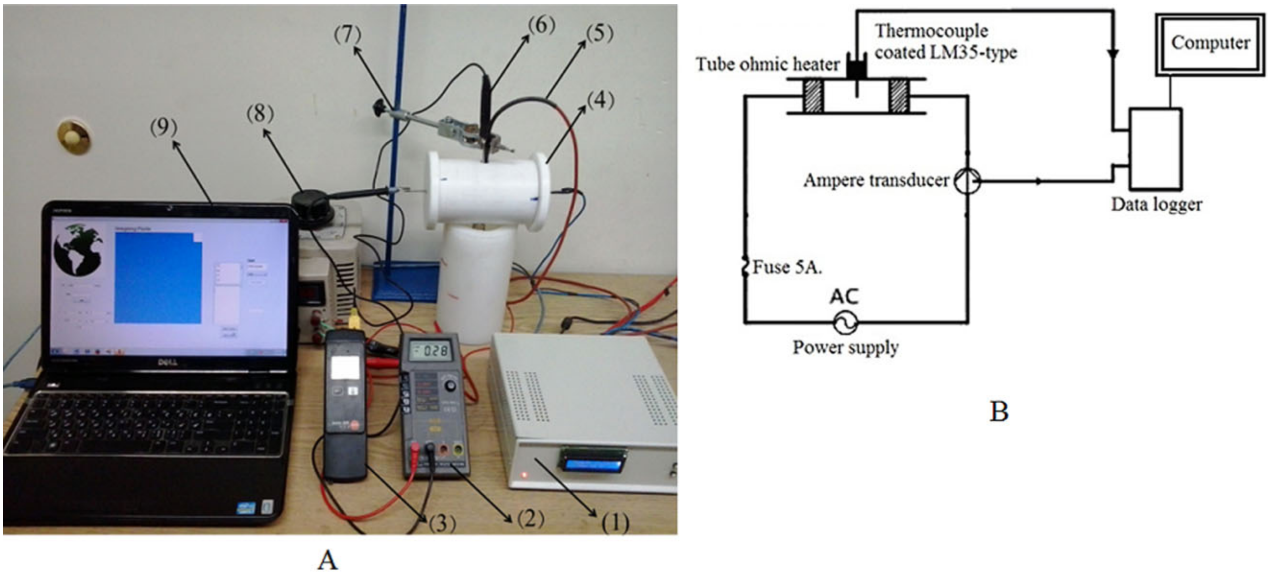

FIG. 2. SETUP FOR EC MEASUREMENT
(A) The system components are: 1: data logger; 2: wattmeter; 3: portable thermometer; 4: tube ohmic heater; 5: thermocouple; 6: thermometer connection; 7: holder; 8: power supply; 9: computer. (B) Complete schematic diagram of the system.

EC

The EC of paddy water[1] was measured using the system depicted in Fig. 2. It comprises a tube ohmic heater, thermocouple, data logger, power supply and computer. The batch tube ohmic heater was made of Teflon (Zareifard *et al.* 2003; Zell *et al.* 2011), with dimensions 14.5 cm in length, 6 cm in internal length, 7.2 cm in inner diameter and 7.6 cm in outer diameter, and has a hole for insertion of a thermocouple. It also had two cylindrical stainless steel electrodes (Ghnimi *et al.* 2008; Marra *et al.* 2009). The electrodes were inserted via two openings in the tube, parallel to each other with an electrode gap of 6 cm, and the cross-sectional area of the tube sample container was 25.806 cm^2. Its volume was 154.84 mL. Paddy water samples were poured into the ohmic heater through the hole. The paddy water was heated to 90C using an alternating current of 60 Hz at applied voltages of 264 ± 1 V, corresponding to electrical field strengths of 44 V/cm (Morales-Sanchez *et al.* 2009; Dhingra *et al.* 2012). The temperature at the geometric center of the paddy water was continuously measured with an LM35-T type, steel coated thermocouple to prevent water penetration and interference from the electrical field (Zareifard *et al.* 2003). The thermocouple was calibrated using a portable thermometer (Testo925, K type, Testo, Lenzkirch, Germany). Current measurements were performed with current transducers (ACS712, 5A, Allegro, Taipei, China), which were calibrated using a portable wattmeter (DW6060, Lutron, Mainland, Taiwan). The temperature and current data were recorded on a data logger at 0.5 s intervals.

[1] Paddy water: Paddy was soaked at a water tank. Electrical properties of water significantly changed during soaking. Some water was picked up from tank for measuring of EC value during soaking. This water was called "paddy water" in this study.

Conductivity was calculated according to the following equation (Icier *et al.* 2008):

$$EC = \frac{LI}{VA} \tag{1}$$

EC is the electrical conductivity (mS/cm), L is the distance between the two electrodes (cm), I is the current (A), V is the voltage (V), and A is the cell transversal area (cm^2).

DSG

The DSG of parboiled rice was evaluated during soaking according to the following equation (Patindol *et al.* 2008; Kraus *et al.* 2014):

$$DSG = \left[1 - \frac{\Delta H}{\Delta H^*}\right] \tag{2}$$

ΔH is the enthalpy change due to gelatinization of parboiled rice and ΔH^* is the enthalpy change of raw rice. The enthalpies were measured with a calorimeter instrument (Micro DSC 7, Setaram, Caluire, France) as described by Miah *et al.* (2002b). Parboiled rice was ground into flour with a grinder, and sieved (160 μ). Rice flour samples (30% flour + 70% distilled water) were selected randomly from different

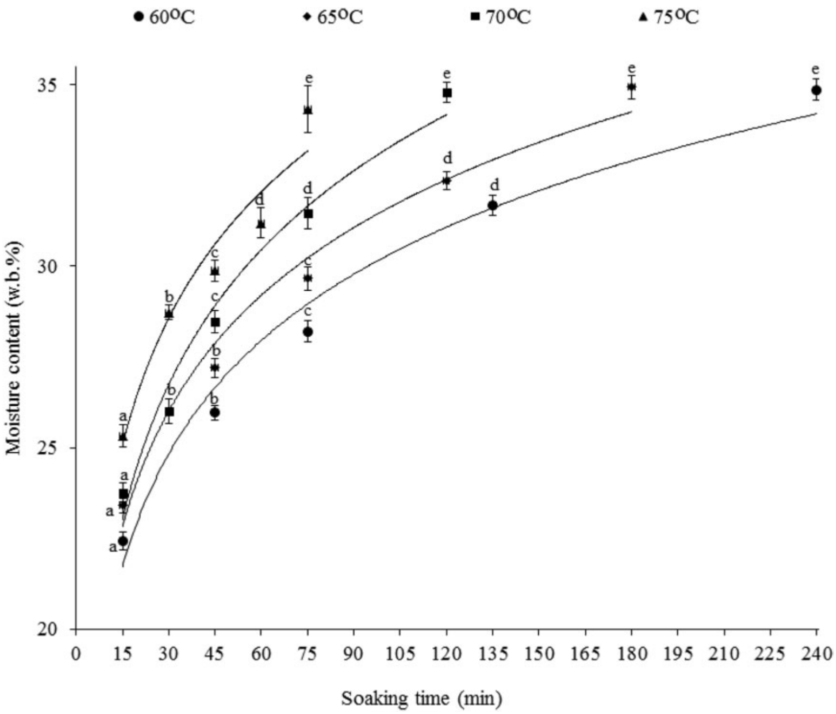

FIG. 3. HYDRATION OF ROUGH RICE AT VARIOUS TEMPERATURES
**Different letters indicate a significant difference ($P < 0.05$). The error bars represent ± one standard error of the mean.

temperatures and times of soaking as shown in Table 1. Rice flour samples were sealed in a pan and left to equilibrate at room temperature for 2 h (Himmelsbach *et al.* 2008). The pan was then heated in from 24 to 98C at a scanning rate of 1C/min (Miah *et al.* 2002b). From the resulting DSC curve, ΔH (transition enthalpy) was determined as the area under the peak after drawing a two-point baseline from T_o (onset temperature) to T_e (end temperature).

Data Analysis

A full-factorial design was used for experimental analysis. The obtained data were analyzed by SPSS software (version 15; SPSS Inc., Chicago, IL) and Matlab Software (2011, USA). Duncan's multiple range tests were used to determine the differences between treatments' mean values at a confidence level of 95%. All experiments were performed in triplicate and mean values are reported with standard deviations.

RESULTS AND DISCUSSION

MC

The optimum soaking condition is selected based on MC of samples at the end of soaking (35% w.b.) (Das *et al.* 2004). As shown in Fig. 3, the rate of hydration increased significantly ($P < 0.05$) and exponentially with temperature (Nawab and Pandya 1974; Bhattacharya 1985). The increase in MC of paddy during soaking may be due to moisture uptake accompanied by volume expansion of the starch under the influence of high temperature (Igathinathane *et al.* 2005). The Page model ($MC = \exp(K \times T^N)$, with K and N constants and T the soaking time, was found to be the most suitable for describing the hydration behavior of the rice (Tarom Mahali) during soaking (Kashaninejad *et al.* 2007). So this equation was used to explain the experimental data obtained for the paddy (Fajr). The Page model coefficients (K and N) and the regression coefficient (R^2) for each soaking temperature are shown in Table 2. In addition, optimum soaking time was selected when MC reached 35% w.b. According to Fig. 3, the optimum soaking times for 60, 65, 70 and 75C were determined to be 240, 180, 120 and 80 min, respectively.

EC

Figure 4 shows the EC of paddy water taken from soaked paddy at 60, 65, 70 and 75C as a function of temperature. EC increased linearly ($R^2 \approx 0.99$) with the temperature for water taken from soaked paddies at all temperatures. These findings are in agreement with the reported observations for ohmic processing of peach/apricot purees, flour, rice starch, rice bran, potato and seawater (Chaiwanichsiri *et al.* 2001; Icier and Ilicali 2005; Morales-Sanchez *et al.* 2007, 2009; Assiry *et al.* 2010;

TABLE 2. PAGE MODEL PARAMETERS FOR DIFFERENT SOAKING CONDITIONS AND THE REGRESSION COEFFICIENTS

	Page model		
Soaking temperature (C)	K	N	Regression coefficient (R^2)
60	2.708	0.04933	0.9963
65	2.748	0.04916	0.9965
70	2.7	0.05679	0.9939
75	2.801	0.05214	0.951

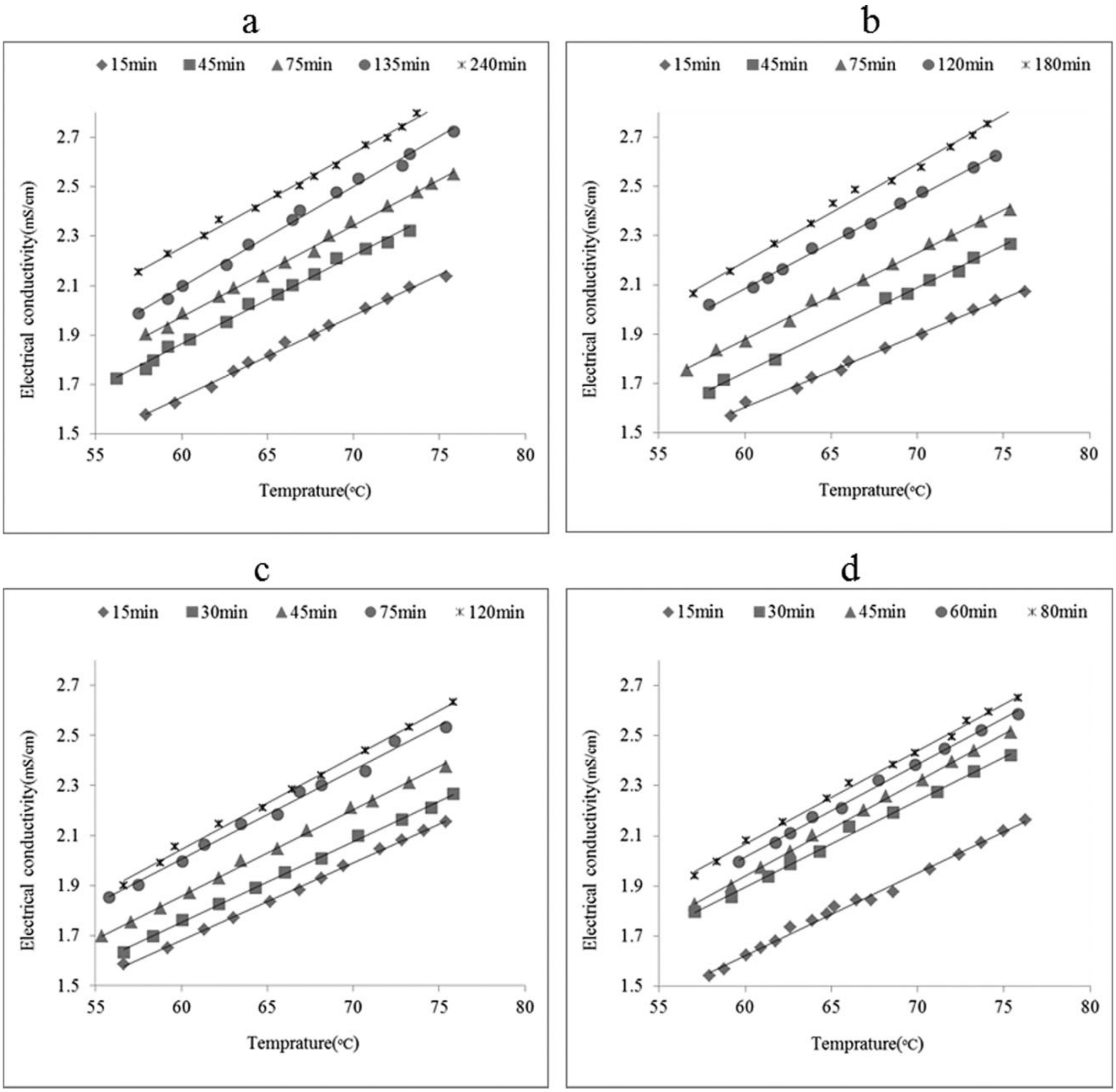

FIG. 4. ELECTRICAL CONDUCTIVITY AS A FUNCTION OF TEMPERATURE FOR PADDY WATER TAKEN FROM PADDIES SOAKED AT DIFFERENT TEMPERATURES (a: 60°C, b: 65°C, c: 70 °C AND d: 75°C)

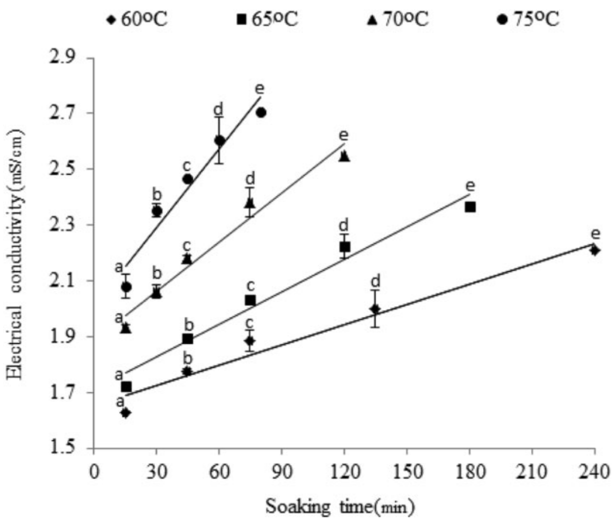

FIG. 5. ELECTRICAL CONDUCTIVITY AS A FUNCTION OF SOAKING TIMES FOR PADDY WATER AT DIFFERENT SOAKING TEMPERATURES (INDICATED IN THE FIGURE)

**Different letters indicate a significant difference ($P < 0.05$). The error bars represent ± one standard error of the mean.

Dhingra *et al.* 2012). The increase of EC with temperature may be attributed to the ionic mobility (Dhingra *et al.* 2012).

EC of paddy water as measured *in situ* for the different soaking temperatures is shown as a function of soaking time in Fig. 5. The results show that paddy water EC increased significantly ($P < 0.05$) in a linear fashion with soaking time ($EC = A \times T + B$, where A and B are constants, and EC and T are electrical conductivity [mS/cm] and soaking time [min], respectively). The linear model was deemed the best model fit for DSG level versus soaking time because it had the highest R^2 value (>0.94). The constant coefficient values of the linear model and R^2 at different soaking temperatures are shown in Table 3. When the paddy was heated in excess water, as soaking temperature reached the gelatinization temperature, the granules began to swell (Li *et al.* 2004). Two mechanisms are considered to increase the EC on heating. One mechanism is the increased ion mobility with increasing temperature while the other mechanism is the release of ions and polar molecules due to gelatinization (Chaiwanichsiri *et al.* 2001; Dhingra *et al.* 2012). So the reason for a change in EC is due to food structure alters (An and King 2007). The relationships of EC-T were distinct because the resistance to charged particles was different at various temperatures of soaking. To our knowledge, these results are reported for the first time here.

DSG

Table 4 shows the values of the onset (T_o), peak (T_p) and end (T_e) temperatures and the gelatinization enthalpy (ΔH) following soaking at different temperatures. T_o is the temperature at which rapid swelling begins. T_p is the temperature when endothermic reaction reaches its maximum rate, while T_e the temperature at which all the starch granules have fully gelatinized. All the parboiled rice flour samples produced T_o, T_p and T_e values of 57.44–60.33C, 64.40–66.23C and 70.28–75.42C, respectively. T_o, T_p and T_e values increased while the enthalpy decreased significantly ($P < 0.05$) by increasing the soaking time for all soaking temperatures tested. Soaking temperature at 75C had greater T_o, T_p and T_e as well as smaller enthalpy values than other treatments. DSG of parboiled rice is shown in Fig. 6. For all soaking temperature, DSG values (from 5.38 to 36.90%) increased significantly ($P < 0.05$) during soaking for all treatments. These results are in agreement with previous studies reporting that DSG increases with the extent of parboiling treatment (Islam *et al.* 2002; Lamberts *et al.* 2006; Manful *et al.* 2008). Miah *et al.* (2002b) suggest a third-order polynomial, $DSG = AT^3 + BT^2 + CT + D$, to fit DSG versus soaking time for long-grain rice variety (BR4), where A, B, C and D are constants, and DSG and T are degree of starch gelatinization (%) and soaking time (min), respectively. We therefore also fit the experimental data of DSG versus soaking time using this equation. The fitting coefficients and R^2 values obtained are presented in Table 5. Because of gelatinization during the heating/cooking process, starch granules irreversibly swell in the parboiled rice through water absorption and heating during soaking. Starch degradation to lower molecular weight chains may also occur, depending on the time/temperature applied in the process (Mahanta and Bhattacharya 1989; Takahashi *et al.* 2005). The amount of gelatinized starch is an indicator of the extent of the parboiling process, which depends on the in time and temperature used (Patindol *et al.* 2008; Oli

TABLE 3. LINEAR MODEL PARAMETERS AND REGRESSION COEFFICIENTS FOR RELATIONSHIP BETWEEN ELECTRICAL CONDUCTIVITY-SOAKING TIMES (MINUTES) OF PADDY WATER AT DIFFERENT TEMPERATURES DURING SOAKING

Soaking temperature (C)	A	B	Regression coefficient (R^2)
60	0.0024	1.6521	0.9619
65	0.0039	1.7102	0.9725
70	0.0059	1.8872	0.9692
75	0.0093	2.0159	0.9420

TABLE 4. EFFECT OF SOAKING TIME ON THE ONSET, PEAK AND END TEMPERATURES AND GELATINIZATION ENTHALPY UNDER DIFFERENT SOAKING TEMPERATURES

Soaking time (min)	Onset temperature (C)	Peak temperature (C)	End temperature (C)	Enthalpy (J/g)
Soaking temperature at 60C				
15	57.44[a]	64.40[a]	70.28[a]	2.39[e]
45	57.49[a]	64.52[a]	70.46[a]	2.33[d]
75	58.14[b]	64.62[a]	71.33[b]	2.15[c]
135	58.86[c]	65.13[b]	72.20[c]	2.02[b]
240	59.42[d]	65.41[c]	72.24[c]	1.93[a]
Soaking temperature at 65C				
15	57.68[a]	64.60[a]	70.44[a]	2.34[e]
45	57.96[a]	65.01[b]	71.46[b]	2.18[d]
75	58.14[b]	65.23[b]	71.64[c]	2.01[c]
120	58.86[c]	65.30[b]	71.87[d]	1.90[b]
180	61.32[d]	67.52[c]	74.64[e]	1.85[a]
Soaking temperature at 70C				
15	57.66[a]	64.77[a]	71.05[a]	2.26[e]
30	57.81[a]	64.92[a]	71.55[a]	2.12[d]
45	59.16[b]	65.01[a]	72.69[b]	1.99[c]
75	60.25[c]	66.16[b]	73.10[b]	1.77[b]
120	61.01[c]	66.67[c]	73.30[b]	1.66[a]
Soaking temperature at 75C				
15	57.70[a]	64.78[a]	71.56[a]	2.17[e]
30	57.80[a]	65.12[ab]	72.17[b]	2.00[d]
45	60.03[b]	65.79[bc]	73.17[c]	1.80[c]
60	60.27[b]	65.91[c]	73.30[c]	1.67[b]
80	60.33[b]	66.23[c]	75.42[d]	1.60[a]

**Different letters indicate a significant difference ($P < 0.05$).

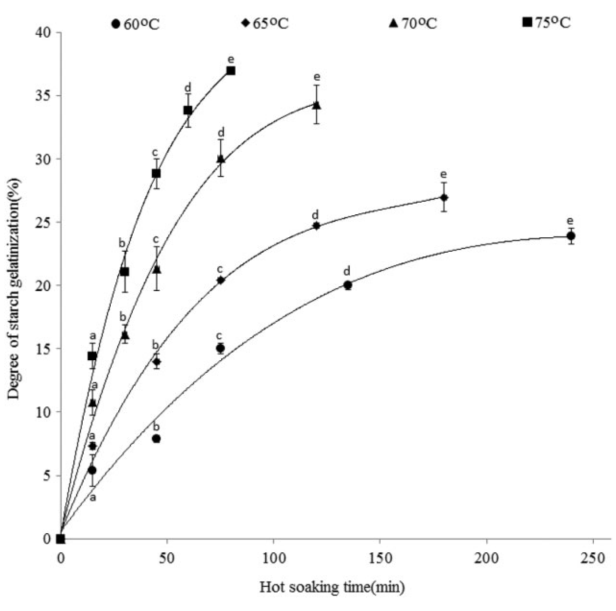

FIG. 6. EFFECT OF HOT SOAKING TIME ON GELATINIZATION AT DIFFERENT TEMPERATURES OF SOAKING
**Different letters indicate a significant difference ($P < 0.05$). The error bars represent ± one standard error of the mean.

et al. 2014). Parboiling leads to starch gelatinization, which is related to the extent of heat treatment (Islam *et al.* 2002; Miah *et al.* 2002b).

MC-EC and DSG Correlation

A linear correlation model ($DSG = A \times MC + B$ or $DSG = C \times EC + D$) was fitted to experimental data obtained for DSG (%) of parboiled rice versus MC (w.b.%) of paddy and EC (mS/cm) of paddy water, where A, B, C and D are constants. R^2 values (>0.88) were obtained for all cases. We deemed the linear model sufficiently robust to describe these relationships. DSG-MC and DSG-EC models were evaluated based on the sum of squares error (SSE); the coefficient of determination (R^2) and root mean square error (RMSE) values. These constants, along with the 95% confidence bounds, are summarized in Table 6. The values of SSE, R^2 and RMSE showed a good linear relationship between DSG and EC. Consequently, EC is consistent with DSG values during soaking, and it is an effective tool for quickly determining the amount of starch gelatinization. In other words, DSG values can be directly estimated from measurements of paddy water EC after evaluating an appropriate linear relation.

TABLE 5. THIRD-ORDER POLYNOMIAL PARAMETERS AND REGRESSION COEFFICIENTS FOR THE RELATIONSHIP BETWEEN DSG% AND SOAKING TIME OF PADDY AT DIFFERENT TEMPERATURES AND TIMES OF SOAKING

Soaking temperature (C)	A	B	C	D	Regression coefficient (R^2)
60	7E-07	–0.0007	0.2301	0.6176	0.9849
65	5E-06	–0.0023	0.4094	0.5842	0.996
70	1E-05	–0.0043	0.6516	0.5748	0.996
75	3E-05	–0.0092	0.9767	0.4047	0.9959

TABLE 6. DETAILS OF THE STATISTICAL ANALYSIS AND PARAMETERS OF THE LINEAR MODEL FOR THE RELATIONSHIP BETWEEN DSG% AND MOISTURE CONTENT-ELECTRICAL CONDUCTIVITY

Soaking temperature (C)	SSE	R^2	RMSE	A	B	C	D
DSG-EC (60)	14.11	0.9663	1.878	–	–	1.024	–14.27
DSG-MC (60)	49.23	0.8824	3.508	36.35	–54.82	–	–
DSG-EC (65)	13.04	0.9763	1.806	–	–	33.24	–49.68
DSG-MC (65)	42.18	0.9233	3.247	1.178	–15.55	–	–
DSG-EC (70)	8.893	0.9889	1.491	–	–	35.14	–55.24
DSG-MC (70)	58.19	0.9271	3.814	1.468	–19.28	–	–
DSG-EC (75)	19.72	0.9792	2.22	–	–	31.68	–50.09
DSG-MC (75)	86.44	0.9089	4.649	1.59	–20.02	–	–

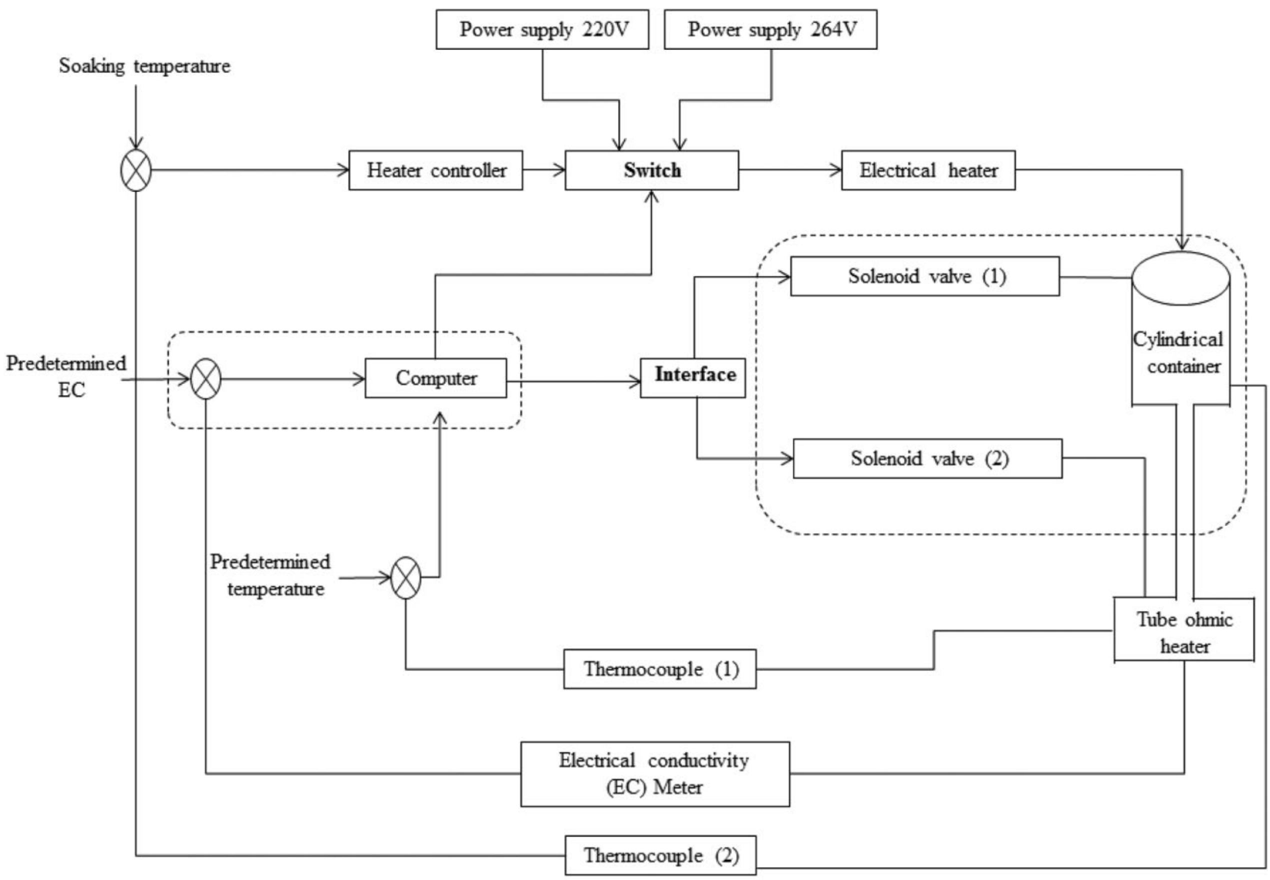

FIG. 7. COMPLETE SCHEMATIC DIAGRAM OF THE ONLINE MEASUREMENT SYSTEM OF ELECTRICAL CONDUCTIVITY

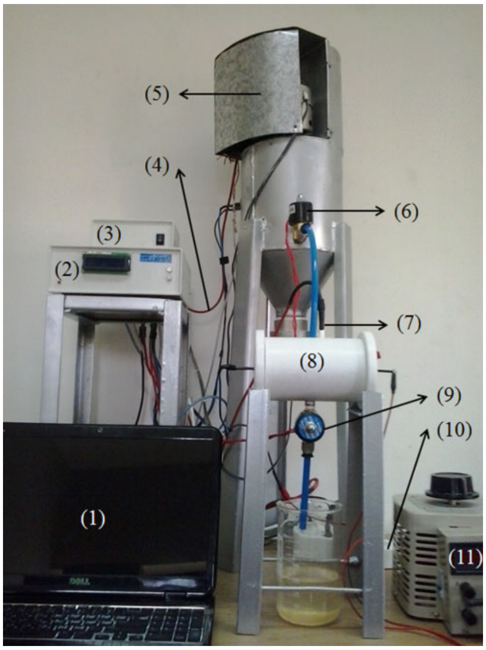

FIG. 8. THE SYSTEM COMPONENTS FOR ONLINE MEASUREMENT OF WATER PADDY EC ARE: 1: COMPUTER; 2: DATA LOGGER (1); 3: DATA LOGGER (2); 4: THERMOCOUPLE (2); 5: CYLINDRICAL CONTAINER; 6: SOLENOID VALVE (1); 7: THERMOCOUPLE (1); 8: TUBE OHMIC HEATER; 9: SOLENOID VALVE (2); 10: 220 V POWER SUPPLY; 11: 264 V POWER SUPPLY

Online Measurement System of EC

As shown in Fig. 7, the online measurement system of EC consists of the paddy soaking system, EC measurement system, two solenoid valves and a computer. The soaking setup is comprised of a cylindrical container, thermocouple (2), a heater controller, 220 V power supply and an electrical heater. The EC measurement system consists of a tube ohmic heater, EC meter, thermocouple (1), computer and 264 V power supply. The online measurement of paddy water EC was carried out by the system depicted in Fig. 8. This system was manufactured based on the schematic diagram shown in Fig. 7. A data logger (1) controlled the amount of soaking temperature and registered the value of EC and temperature of the tube ohmic heater. Before starting the online system, the soaking temperature, EC (predetermined EC) and the temperature of the tube ohmic heater (predetermined temperate) are selected. The opening and closing times of the solenoid valves were controlled by the data logger (2) during soaking. These times were selected based on soaking temperature. For example, at a soaking temperature of 65C, DSG and EC values at the completion of the soaking stage (180 min) were selected as 27% and 2.369 mS/cm, respectively. In other words, an EC of 2.369 mS/cm indicates a DSG of about 27% at the end of soaking. The solenoid (1) was set to be opened for 17 s after 150, 160, 175, 180, 195 and 210 min of soaking. As a result, the tube ohmic heater was filled with paddy water for 17 s and the EC was measured. After completing the EC measurement, the solenoid (2) was opened for 30 s and then closed. After closing of the solenoid (2), EC values were recorded by the online system and compared to the predetermined EC. If the EC value was higher than the predetermined EC (2.369 mS/cm), then the system would be switched off. Shutdown time of the system is equal to the end of soaking time. This online system was evaluated for soaking temperature of 65C in triplicate. Following the 180 min soaking time, the DSG was evaluated in a DSC experiment. The DSG was the same within the experimental error in all three experiments. We therefore conclude that this system can carefully predict the end of soaking time based on the relationship between the DSG and paddy water EC.

CONCLUSION

This study measured the paddy MC – both the EC of paddy water values and DSG of rice as a function of soaking temperatures and times. The relationship between DSG and MC-EC was elucidated. The results showed that MC of paddy increased significantly ($P < 0.05$) and exponentially during soaking for all soaking temperatures tested. EC of paddy water increased significantly ($P < 0.05$) and linearly during soaking as a result of ion release. At all temperatures tested, the increase of DSG values in the range 5.38–36.90% could be described using a third-order polynomial. Finally, a linear relationship was found between DSG of parboiled rice and paddy water EC. These results can be used to predict DSG values of parboiled rice following soaking under different temperature conditions. This leads us to the conclusion that it can be applied as a simple predictive tool of the amount of starch gelatinization during soaking.

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