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Comparative study on hydration kinetics of selected Indian paddy varieties

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Abstract
Paddy is one of the major food crops in the world as well as staple food for more than half of the world population. It is rich source of carbohydrates, proteins vitamins and minerals. It is processed by different techniques, among that parboiling is widely used in industries. Soaking is an important process in parboiling and needed to be optimized for different paddy varieties. In this study hydration kinetics of two selected paddy varieties (*ADT43* and *CO-51*) were studied by soaking at different temperatures of 30°C, 40°C, 50°C, 60°C and 70°C for a particular time period of 8 h. For the study, samples were kept in water bath maintained at constant temperatures and samples were withdrawn at 30 min interval until 4 h and 60 min interval until 8 h. It was found that hydration kinetics of grains is a function of temperature; chemical composition also affects the same. The starch content found to be 65.78% for *ADT43* and 80.20% for *CO-51* due to varietal difference. The amylose content found to be 26.79% for *CO-51* and 23.69% for *ADT43.* This study will be helpful in optimizing the parboiling conditions and other processing techniques of paddy.

Keywords: Paddy, hydration kinetics, soaking temperature, chemical properties

1. Introduction

Paddy is one of mostly cultivated and consumed crop in the world. Rice is rich source of nutrients and it is staple food for more than half of the world's population (Saikrishna, Sayantani, Vijayalakshmi, Moses, & Anandharamakrishnan, 2018) [17]. Paddy grain consists of two major components, brown rice and husk and a layer of bran exists between these two. Complexity in structure of paddy and variations in physicochemical properties have the practical concerns in processing, handling and storage (Shittu, Olaniyi, Oyekanmi, & Okeleye, 2012) [20]. Parboiling is a regular process in rice industries which is the pre-milling hydrothermal treatment of the paddy for physico-chemical changes in it (Ejebe, Kwofie, & Ngadi, 2019) [19]. It has other benefits also, such as retention of nutrients, improved milling yield, sterilization, resistance to insect attack and increased shelf life (Behera & Sutar, 2018) [3]. Parboiling of paddy generally involves soaking, steaming and drying processes. Soaking or hydration is the main step, which has subsequent effects on quality of end product of rice. During hydration process, the time-temperature combination plays a major role; these conditions also change depending on the variety due to its chemical composition and grain type. In hydration process, breakdown of starch molecules takes place due to simultaneous application of heat and water which also leads to other physical, chemical and functional changes (Balbinoti, Jorge, & Jorge, 2018b; Behera & Sutar, 2018) [2, 3]. In parboiling process, 30% of the moisture content is required to complete gelatinization of starch (Cheevitsopon & Noomhorm, 2011) [5]. In a commercial unit, generally hot water soaking is done at 60-65°C for 3.5-4 h (cold water soaking done at room temperature for overnight), until kernels get saturated. The traditional method of parboiling is therefore highly time consuming, requires more energy and highly laborious. The present study aimed at examining the influence of time-temperature conditions on hydration kinetics and physical, engineering and biochemical properties of two selected medium slender varieties of rice that would be helpful in industrial parboiling operations.

2. Materials and Methods

2.1 Materials and sample preparation

Two medium slender paddy varieties *ADT43* and *CO-51* were procured from Tamil Nadu Rice Research Institute at Aduthurai, Tamil Nadu, India (Fig. 1). Samples were manually cleaned to remove chaff, dust, stones and any other foreign matter. For chemical analysis, rice flour were prepared and finally ground to get rice flour (0.2 mm). All chemicals for analyses were of AR grade and purchased from Sigma-Aldrich, India and Hi-Media, India.

Fig 1: Picture of selected paddy varieties (a) *ADT43* (b) *CO-51*

2.2 Estimation of moisture content of paddy

The moisture content of paddy samples was estimated by AOAC (2000) method, using a hot air oven at 105°C. 3 g of sample was weighed and kept in oven for 24 h. The experiment was continued until a constant weight was achieved, gravimetrically.

2.3 Physical properties of paddy

Physical properties of paddy like length (L, mm), width (W, mm) and thickness (T, mm) were measured by Vernier caliper for 30 randomly selected grains. Using this data, volume (V, mm^3), geometric mean diameter (D_g, mm), sphericity (Φ), surface area (S, mm^2) and aspect ratio (R_a) of the paddy were calculated as per equations used in previous studies (Vimala Bharathi *et al.*, 2016). Bulk density was estimated from the ratio of mass of paddy grains to volume occupied by bulk grain including volume of intergranular air and grains. True density of the paddy was determined as the ratio of mass of grains to the volume occupied sample and was done employing liquid displacement method. As a liquid, toluene was used instead of water, to prevent absorption or penetration of moisture into the sample matrix. Based on the true and bulk density values, porosity was worked out, by using the following equation. Specific gravity of cultivars was also calculated based on the following formula (eq. 8) (Pandiselvam & Thirupathi, 2014) [15].

$$V = 0.25[\frac{\pi}{6} L(W+T)^2] \quad (1)$$

$$Dg = \sqrt[3]{LWT} \quad (2)$$

$$\Phi = \frac{\sqrt[3]{LWT}}{L} \quad (3)$$

$$S = \pi(D_g)^2 \quad (4)$$

$$R_a = \frac{W}{L} * 100 \quad (5)$$

$$\varepsilon = \left(\frac{\rho_t - \rho_b}{\rho_t}\right) * 100 \quad (6)$$

$$D_p = \left[4L\left(\frac{W+T}{4}\right)^2\right]^{1/3} \quad (7)$$

$$\text{Specific Gravity} = \frac{\text{Specific Gravity of Toluene} * \text{Weight of Grain}}{\text{Weight of the Toluene Displaced by the Grain}} \quad (8)$$

2.3 Hydration studies

For soaking the paddy, a thermostatic water bath was used. Hydration studies were carried out for 8 h at different temperatures of 30, 40, 50, 60 and 70°C. In a set, about 3 g of sample was weighed and packed in muslin cloth. The desired temperature was maintained in a water bath and multiple beakers filled with distilled water were placed in water bath once the desired temperature was achieved. The samples were withdrawn at every 30 min, for 4 h, and at an interval of an hour until 8 h. The water absorbed by the grains was estimated.

2.4 Estimation of starch, amylose and amylose to amylopectin ratio

Starch content of the grains was calculated according to the method suggested by Sadasivam and Manickam, (2008) by anthrone reagent method at 630 nm (UV-1800, SHIMADZU, Japan). Amylose content was determined using iodine calorimetry method as reported by Yadav & Jindal (2007) [23]. The ratio of amylose to amylopectin was calculated from starch content and amylose content (amylose content/starch content- amylose content).

2.5 Color measurement

Color of paddy samples was determined using Hunter Lab (Color Flex EZ, Virginia, United States) and expressed in terms of L, a*, b* values (Dutta & Mahanta, 2012) [6]. Since discoloration occurs post parboiling, in this study also color of grains was estimated post hydration.

2.6 Pasting properties of rice

Pasting properties of raw rice flour under treatment was examined using Rheometer (Anton Paar, modular compact Rheometer MCR52, Austria) using starch cell. For this, 3 g of powdered sample was mixed with 25 ml of water. The sample was heated from 50°C to 95°C at a speed of 160 revolutions per min (rpm). The sample was held at 95°C for 2.5 min and cooled to 50°C, prior to instrumental analysis (Saleh & Meullenet, 2015) [18]. The pasting parameters were assessed using Rheoplus software. From the obtained pasting curve, attributes such as peak viscosity, final viscosity, breakdown, setback from peak, setback from trough and pasting temperature were calculated.

2.7 Differential scanning calorimetry (DSC)

For investigation of thermal characterization of paddy during parboiling, DSC (214 *Polyma* NETZSCH, Selb, Deutschland) of samples was performed. The instrument was calibrated with pure indium with a heat of fusion of 28.41 J/g and a melting temperature of 156.66°C. A sample of 2.5 mg was weighed in aluminum pan with an accuracy of ±0.001 and distilled water was added to it with a micropipette. Water was added in the ratio of 1:4 (Sample: water) and then the aluminum pan was hermetically sealed and left for 2 h. DSC was done with heating of 25°C to 150°C @ 10°C/min. The empty aluminum pan used as reference. During the scan, nitrogen was flushed to avoid condensation.

3. Results & Discussion

3.1 Physical and engineering properties of paddy

Physical properties are helpful in designing of processing equipments, handling and storage. Some physical and engineering properties of selected two paddy varieties have been described in Table 1. The average values of length, width and thickness of *ADT 43* were 7.819, 2.119 and 1.707

mm, respectively; while the same for *CO-51* were 8.028, 2.353, 1.798 mm, respectively. These findings are similar to Pandiselvam & Thirupathi, (2014) [15] who reported the length in the range of 7.78 to 7.80 mm, width 2.37 to 2.39 mm and thickness 1.75 to 1.78 mm for *ADT43* with 11.86% initial moisture content. Other properties like geometric mean diameter (D_g), sphericity (ϕ), aspect ratio (r_a), true density, bulk density, porosity, specific gravity of two paddy varieties were estimated and detailed in Table 1.

Table 1: Physical properties of different paddy varieties

Property	ADT43	CO-51
Grain type	Medium slender	Medium slender
Length (mm)	7.819	8.028
Width (mm)	2.119	2.353
Thickness (mm)	1.707	1.798
Geometric mean diameter (Dg, mm)	3.047	3.238
Sphericity (Φ)	0.390	0.403
Surface area (S, mm^2)	29.148	32.931
Aspect ratio (R_a)	27.101	29.306
True density (ρ_t, kg/ m^3)	1258.57	1228.14
Bulk density (ρ_b, kg/ m^3)	547.81	573.86
Porosity (%)	56.474	53.274
Specific gravity	1.242	1.212
Equivalent diameter (D_p, mm)	3.059	3.258

3.2 Hydration kinetics of paddy

Hydration is the controlled diffusion process of water absorbed (wet basis) by grain during soaking. The hydration behavior of selected paddy varieties is presented in Figs. 2 & 3, All hydration curves followed similar trend in Figs 2 and 3, at different temperatures. The water absorption was found to be more in *ADT43* compared to *CO-51* for all the temperatures. Water absorption was found to be 20.78%, 25.03%, 28.54%, 31.14% and 37.16% for *ADT43*, whereas for *CO-51* it was 19.68%, 21.67%, 24.51%, 26.66% and 36.42% at 30, 40, 50, 60 and 70°C, respectively (Fig. 2). Similar results were achieved by other researchers for rice, and they have opined that difference in water absorption in different varieties may be due to the variations in chemical composition of grain like amylose and amylopectin content (Balbinoti *et al*., 2018b; Balbinoti, Jorge, & Jorge, 2018a; Foke & Madhava, 2013; Sridhar & Manohar, 2003) [2, 1, 8, 22]. The rate of water absorption was initially higher than later; possibly due to cracks and internal fissures in the grain. The water absorption was more at higher soaking temperature (70°C) compared to lower soaking temperature (30°C) (Fig. 3). These results revealed that temperature has an influence on water absorption of paddy.

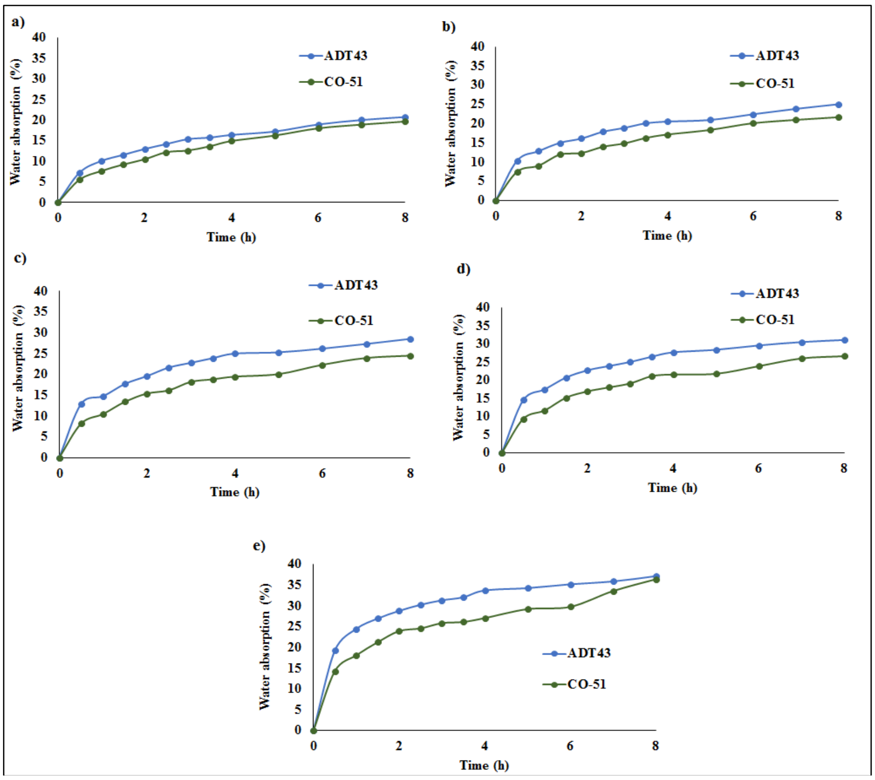

Fig 2: Water absorption characteristics of two varieties at different soaking temperatures, a) 30°C, b) 40°C, c) 50°C, d) 60°C, e) 70°C.

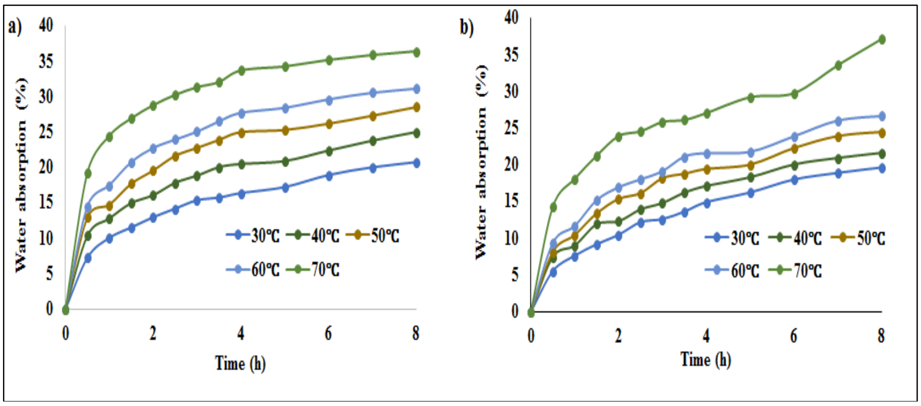

Fig 3: Hydration kinetics of two varieties at different soaking temperatures, a) *ADT43* (b) *CO-51*

3.3 Color analysis of paddy

Fig. 4 indicated that lightness value of paddy decreased with increasing soaking temperature. For *ADT43* raw samples, the color values were found to be L*=56.31, a*=7.41, b*=28.28; and when soaked at 70°C for 8 h the color values were L*=52.53, a*= 9.80, b*=27.21. Similar trend also observed in *CO-51* variety. These results revealed that, the 'L*' value reduced with increase in soaking temperature of rice. The find was in agreement with previous research by Siriamornpun *et al*., (2008); and also indicated that low soaking temperature would produce rice with lighter shade. Many researchers opine that maillard type non-enzymatic browning is responsible for discoloration, owing to the said processing. Investigators have suggested that during soaking the diffusion of husk pigments occurs into the endosperm that ultimately leads to decrement in color intensity (Lamberts, Brijs, Mohamed, Verhelst, & Delcour, 2006; Mir, John, & Bosco, 2013) [10, 12].

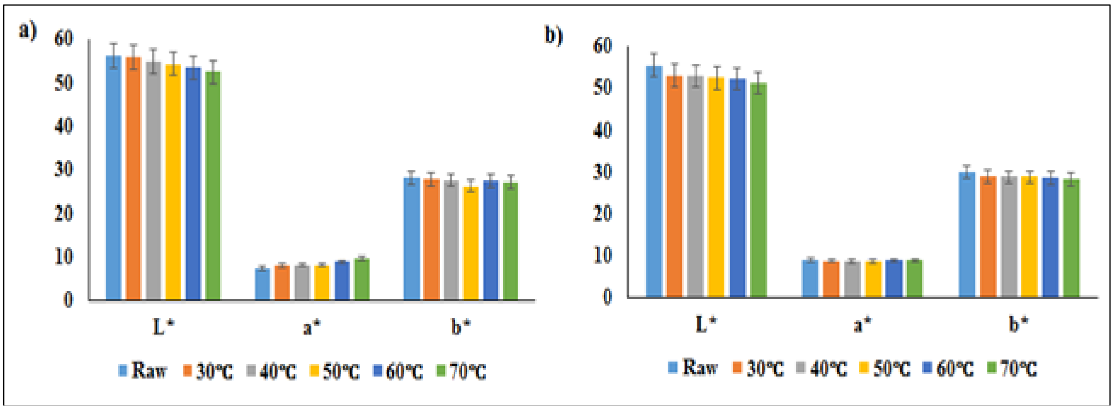

Fig 4: Colour values of two selected paddy varieties post hydration at different temperatures, a) *ADT43* (b) *CO-51*

3.4 Starch content, amylose content and amylose to amylopectin ratio

Starch is one of the main components of rice that plays a major role in determination of rice quality. The starch content for *CO-51* was 80.20% and in case of *ADT43* it was 65.78%. The amylose content of *CO-51* was found to be 26.79 % and 23.69 % for *ADT43*. The amylose to amylopectin ratio for *CO-51* was 0.501 and *ADT43* was 0.563. The said ratio in *ADT43* indicated low starch and high amylose content. Similar results have been reported by Kale *et al*. (2015) [9], wherein the starch content was estimated for soaked and unsoaked rice samples. The values were between 65.14-73.24%, amylose content 23.58-27.26%, respectively, for basmati rice.

3.5 Pasting properties of rice

The parameters of pasting properties such as peak viscosity, final viscosity, breakdown, setback from peak, setback from trough and pasting temperature have been tabulated in Table 2. For *CO-51*, the peak viscosity found to be less compared to *ADT43*, and a reverse trend was followed for final viscosity as well. In case of breakdown viscosity, the value for *CO-51* was more compared with *ADT43*. Setback values from peak and trough for *CO-51* were lesser than *ADT43*. The pasting temperature of *CO-51* was found to be 72.28°C, which is lower than *ADT43* (67.60°C). The pasting temperature is known to depend on the amylose content of rice variety. Lin *et al*. (2010) [11] have mentioned that the bond between amylose molecules are strong due to hydrogen bonding, and pasting of rice flour with high amylose content is difficult than with low amylose content. Possibly, owing to the same reason, *CO-51* has higher pasting temperature than *ADT43*. Similar observations have been made erstwhile as well, wherein pasting properties of rice flour has been found to be influenced by starch, protein, lipid contents and the degree of starch damaged during processing (Mir *et al*., 2013) [12].

Table 2: Pasting properties of selected paddy varieties

Variety	Peak viscosity, cP	Final viscosity, cP	Break down, cP	Setback from peak, cP	Setback from trough, cP	Pasting temperature, °C
ADT43	934.6	4848.0	843	-3913.0	4756.0	67.60
CO-51	1788.0	4294.0	1408.0	-2507.0	3915.0	72.28

3.6 Volume expansion during soaking

The volume of the paddy was calculated for raw samples as well as samples soaked at different temperatures. The variation of expansion in grains was found to be very less (Fig. 5). Similar results was also obtained by Balbinoti *et al*. (2018b) [2] who found 16.452 to 25.981% expansion (post 15 h of soaking at 35-60°C), which was less compared to other researchers. This is may be due to the presence of husk which acts as barrier for the rice from expansion. According to Saikrishna *et al*., (2018) [17] ageing of rice influences the volume expansion of rice when it is cooked or soaked and also freshly harvested rice shows low volume expansion compared to aged rice.

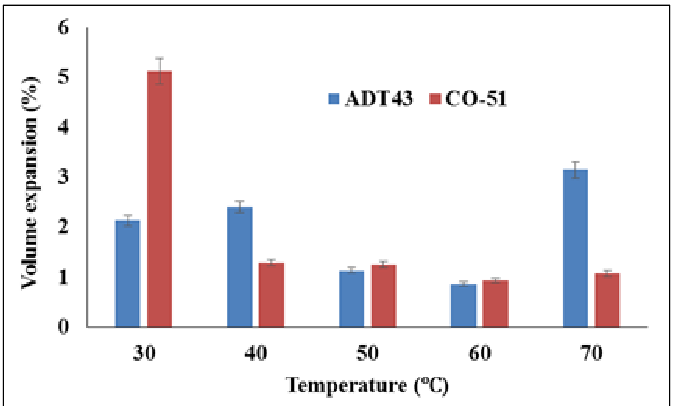

Fig 5: Volume expansion of grains of two varieties

3.7 DSC analysis of rice samples

From the DSC curves, the gelatinization temperature was found to be 72.9°C for *CO-51* and 67.1°C for *ADT43*. These results are similar with Normand & Marshall, (1989) [13] who reported gelatinization temperature in the range of 66.6-75.9°C for four varieties of milled rice flour. In another study Odenigbo *et al*., (2013) [14] studied the gelatinization properties of 13 local and improved non parboiled rice varieties. He found that that gelatinization temperature is in the range of 67.66- 81.27°C for all 13 varieties.

4. Conclusion

Study of hydration kinetics of paddy is very helpful to understand the soaking behavior of the same during parboiling process. The present study provides an insight into time- temperature combinations at different soaking temperatures (30°C, 40°C, 50°C, 60°C and 70°C) and corresponding behavior of the grains of *CO-51* and *ADT43* varieties. These data establish the difference in hydration rate between two varieties, probably owing to chemical composition. The present study also highlighted that parboiling affects color of the grain. This study will be helpful in optimizing the parboiling conditions and other processing techniques where rice is used as raw ingredient. From this study, we can develop scientific protocols for industrial applications. This study can be also applicable to other cereals, pulses and millets.

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