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High pressure induced water absorption and gelatinization kinetics of paddy

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ABSTRACT

The effect of high pressure on water absorption, diffusion and gelatinization Characteristics of paddy (Basmati cv.) were studied in the pressure range 350–550 MPa. Two different soaking conditions were considered, in first condition, grains were pre-soaked at 40 °C for 6 h prior to treatment, and in second condition grains were treated directly without pre-soaking. These two conditions were exposed to pressure at 350, 450 and 550 MPa; temperature of 30, 40 and 50 °C for 300, 600, 900 and 1200 s, respectively. The pressure was found to act synergistically with temperature influencing the water absorption in grains and facilitating moisture absorption up to 50% (db) in pre-soaked grains. However, the rate of water absorption was even higher in case of un-soaked grains with diffusivity values of $9.30 \times 10^{-10}\ m^2/s$. Therefore, treatment of unsoaked grain at 450 MPa at 30 °C for 600 s was found sufficient to reach 40% moisture content (db). On the other hand, maximum gelatinization up to 25% was achieved in pre-soaked grains treated at highest pressure and temperature studied (550 MPa for 50 °C). The rate of gelatinization followed first-order kinetic model at any given pressure and temperature and the rate constant (k) was observed to be vary minimally with pressures and temperatures. The Arrhenius model and Eyring's model was used for the prediction of the activation energy (E_a) and activation volume (ΔV) for the reaction, which was indicative of restricted gelatinization of paddy starch.

Industrial relevance: In order to use high pressure as an alternative technique to thermal parboiling, a full understanding of pressure-induced water absorption, diffusion and gelatinization kinetics are necessary. Adoption of high pressure processing for water absorption by paddy can be very much promising in order to reduce the processing time.

1. Introduction

Rice is one of the major sources of carbohydrate used throughout the globe. Several advancements in process technologies lead to the development of various rice-based products in world market. Among various kinds of products from rice, parboiled rice has been well accepted in many parts of the world due to improving nutritional potential and milling properties. Technically, parboiling process involves major three unit operations such as soaking of paddy in water followed by subsequent steaming and drying to safe moisture level (Oli, Ward, Adhikari, & Torley, 2014). The above process is based on the principle of rice starch gelatinization in order to develop harder and compact texture in the kernel, which could sustain harsh milling action.

Parboiling of paddy has received significant interest and emerged as the most important technique in rice processing sector. Among the three unit operations discussed in the previous text, soaking of grains takes longer time due to slow penetration of water into the endosperm. Various modifications in soaking operation have been detailed in literature, in which temperature has a profound effect on soaking time. Subsequently, penetration of sufficient amount of water (40% db) leads to gelatinization of the starch during steaming, which is considered most desired for enhancement in hardness and compaction of rice kernel.

In order to achieve desirable gelatinization, soaking and steaming are highly essential where the soaking temperature plays a major role. Soaking at a temperature below the gelatinization temperature (T_g) was associated with water absorption only. When soaking temperature > T_g, then it results in simultaneous water absorption and gelatinization. Thus, soaking temperature > Tg is always beneficial in order to accomplish soaking at faster rate. On the other hand, very high-temperature soaking and subsequent steaming adds to the processing cost along with many limitations (Goyal, Jogdand, & Agrawal, 2012). Presoaking at higher temperature may be helpful to completely eliminate the steaming step but reported to have negative effects such as, bursting of grain, inadequate gelatinization and presence of white belly (Oli et al., 2014). Alternatively, pressure parboiling method has been

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considered to reduce the processing time by treating paddy at higher pressure. Pressure parboiling is most preferred technology as far as quick processing is a concern. However, the pressure parboiled rice exhibit discoloration and very hard texture, which reduces sensory appeal and increases cooking time (Taghinezhad, Khoshtaghaza, Minaei, & Latifi, 2015). Therefore, separate soaking at the mild hot water (below T_g) is beneficial. However conventional soaking conditions take very long time (3–3.5 h) for presoaking at 60–70 °C, as described in CFTRI method of parboiling.

In this perspective high pressure (> 100 MPa) induced soaking may be an alternative way to increase the moisture content of paddy near to 40% quickly, which is essential for gelatinization.

High pressure processing (HPP) is considered as safe technique to alter food properties, being well known for uniform treatment of the food material, irrespective of its size and shape (Leite, de Jesus, Schmiele, Tribst, & Cristianini, 2017; Oli et al., 2014). High pressure application on starch could result in gelatinization or homogenization or compression based on pressure range used (Ahromrit, Ledward, & Niranjan, 2007). High pressure treated foods showed minimum chemical changes because they do not affect the covalent bonds in foods thereby preserving their color, flavor and nutrients (Mújica-Paz, Valdez-Fragoso, Samson, Welti-Chanes, & Torres, 2011).

Several studies have been carried out earlier by exposing the rice to high pressure for inducing gelatinization with the aim of producing quick cooking rice (Ahmed, Singh, Ramaswamy, Pandey, & Raghavan, 2014; Boluda-Aguilar, Taboada-Rodríguez, López-Gómez, Marín-Iniesta, & Barbosa-Cánovas, 2013). Knorr, Heinz, and Buckow (2006) investigated the mechanism of high pressure induced gelatinization in comparison to thermal gelatinization. They reported that, under high pressure, starch granules experience partial disintegration as compared to thermally treated sample, which leads to poor solubilization of amylose and better stabilization of amylopectin. Studies related to water uptake of the glutinous rice under high pressure and its kinetics revealed the positive effect of high pressure on water absorption (Ahromrit et al., 2007). High pressure induced gelatinization were studied in other starches including rice(Huang, Jao, & Hsu, 2009; Oh, Hemar, Anema, Wong, & Neil Pinder, 2008), wheat, corn, potato and tapioca(Bauer & Knorr, 2005; Liu, Selomulyo, & Zhou, 2008), which showed positive effect of HPP on starch gelatinization. However, high pressure induced water absorption in paddy has not been addressed so far. To utilize high pressure technology for quick water absorption of paddy, a thorough investigation on water absorption behavior and changes in gelatinization status are desirable. Hence, this work aims to evaluate the effect of high pressure on water absorption characteristics and moisture diffusivity aspects followed by a study of gelatinization behavior in paddy.

2. Materials and methods

2.1. Materials

Commercially available long grain paddy (Golden Basmati) was purchased from Expert seeds private Limited, India. The grains were cleaned thoroughly to remove dirt, immature grains and other impurities and the cleaned grains were then stored at cool, dry place for further use. The average moisture content of the raw paddy was found to be 10% on dry basis. The grains were subjected to two soaking condition One set of grains was soaked at 40 °C for 6 h prior to HPP in a temperature controlled water bath and other set of grains was directly used for HPP. Above temperature and time selected for soaking was based on a preliminary study to achieve 40% moisture content. These two sample segments were considered as un-soaked paddy and pre-soaked, which were further used for HPP.

2.2. High pressure treatment

For each experiment, 10 g of paddy grains were packed together with 40 ml distilled water (paddy to water ratio, 1:4) in an LDPE pouch and the pack was sealed with minimum head space. Then the packaged sample was subjected to HPP in temperature controlled pressure vessel system (model: S-IL-100-250-09-W; make: Stansted Fluid Power, UK). The pressurization was accomplished by compressing 30% mono-propylene glycol which served as the transmitting medium. The pressurizing rate was fixed at 300 MPa min^{-1} and a rapid decompression was achieved (< 10 s). After the treatment, it was removed from the pressure vessel and the water was drained. Further, the treated grains were blotted using filter paper and de-husked prior to analysis.

2.3. Processing conditions

The experimental design constituted three parameters viz. pressure (P, MPa), temperature (T, °C) and dwell time (t, s). Three levels of pressure (350,450,550), three levels of temperature (30, 40, 50), four levels of time (300, 600, 900, 1200 s) with two different conditions (pre-soaked and un-soaked) was investigated. All experiments were duplicated.

2.4. Moisture content

The moisture content of the treated grains was determined by evaporating moisture in a convection oven. Approximately, 10 g of de-husked rice were weighed and dried in oven at 105 ± 2 °C for overnight and the loss in weight was reported as moisture content (%) dry basis.

2.5. Degree of gelatinization (DG)

For calculating the degree of gelatinization from the moisture content values, a standard graph was developed, in which completely gelatinized paddy (severely treated for 1 h at 120 °C) and raw paddy (in a wet condition) were manually constituted at a different proportion to get a series of the degree of gelatinization. Further, the samples were used for moisture content determination and the moisture content was calculated on (g/100 g) dry basis. Further, the moisture content was correlated with the degree of gelatinization by plotting a standard graph between known gelatinization percentage and moisture content (Fig. 1) to obtain the model in Eq. (1). A similar method was also reported in the literature (Ahromrit et al., 2007).

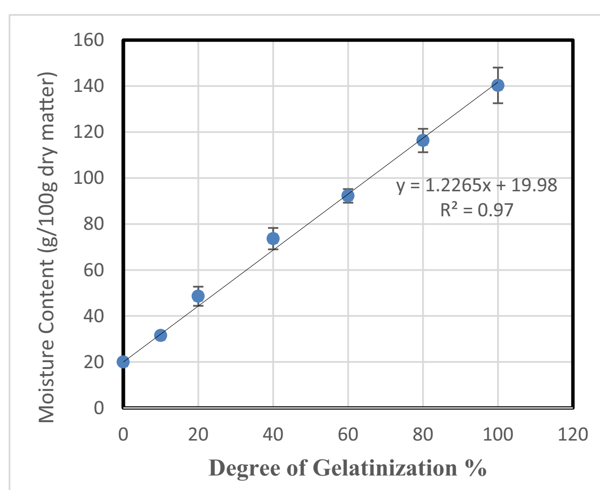

Fig. 1. Relationship between degree of gelatinization and moisture content.