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Modelling of hydration kinetics of brown rice during soaking

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ABSTRACT : The hydration kinetics of BPT 5204 and NLR 92 rice varieties was studied by soaking in water at temperatures of 30, 40, 50, 60 and 70^{0}C in water bath up to 180 min. To optimize the soaking conditions and design food processing equipment, the hydration data are very useful. The amount of water absorbed was high at the early stage of hydration followed by a decreased rate. Peleg's equation adequately described the hydration characteristics of rice under the experimental condition ($R^2 = 0.95$). The Peleg's rate constant, k_1, and Peleg's capacity constant, k_2 decreased with an increase in temperature from 30 to 70^{0}C for both varieties of rice demonstrating that the water absorption rate increased and water absorption capacity decreased. Both the Peleg's constants were expressed by a polynomial function (R^2=0.9) for relating to the temperature. Leaching loss found to be linearly related to time and temperatures. The temperature dependence of $1/k_1$ followed an Arrhenius type relationship. The activation energy was 26.33 kJ/mol and 31.17 kJ/mol for BPT 5204 and NLR 92 rice, respectively.

KEY WORDS : Rice, Hydration, Peleg's equation, Modelling

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Rice (*Oryza sativa* L.) is a staple food of people in many parts of the world. It is cultivated in over 100 countries. The total production area is about 165.1 million hectares and the annual production of rice is about 488.2 million metric tons globally. India is one of the world's largest producers of white rice, accounting for 20% of all world rice production.

Rice production of India was about 104.32 million tons during the year 2011-2012 (FAO, 2012). Prior to processing, rice undergoes some kind of hydrothermal treatment such as soaking. This is the first operation of the rice parboiling process, which is followed by steaming and drying of the grain. Soaking is an essential step in wet milling (Kashaninejad *et al.,* 2007). Warm water soaking is a common method to shorten the soaking time, because increasing temperature increases hydration rate. However, soaking temperature below that of starch gelatinization (73-86^{0}C) is recommended to minimize splitting of the kernel and the subsequent leaching of solids (Bello *et al.,* 2004). Soaking at room temperature may provoke microbial contamination, which affect the quality attributes such as colour, taste and smell. Understanding these factors that influence the soaking medium is an effective way to accelerate water uptake by the grain as it shortens the soaking time (Bhattacharya, 1985).

From engineering point of view, one is interested not only in knowing how fast the absorption of water can be accomplished, but how it will be affected by processing variables such as temperature and also how to predict the soaking time under given conditions (Kashiri *et al.,* 2010). Thus, the quantitative data on the effect of processing variables are necessary for application to optimize and characterize the soaking conditions, design food processing equipment and predict water absorption as a function of time and temperatures. Mathematical modelling of hydration process is known to be important for the design and optimization of food process operations. At the processes that can be modeled, such as hydration, two types of models can be used: theoretical and empirical. The first ones, based on laws and theories, usually are complex and involve parameters that are not convenient to computational practices in most of the situations. Empirical models usually don't possess a theoretical foundation, however, they are more simple and easy to use (Fernando *et al.,* 2008). Peleg (1988) proposed a two parameter sorption equation and tested its prediction accuracy during water vapor adsorption of milk powder and whole rice, and soaking of whole rice. Other researchers also applied Peleg's model on various cereals and legumes (Fernando *et al.*, 2008; Sopade *et al.*, 1992; Vengaiah *et al.*, 2012).

The present work was carried out to study the water absorption behavior of rice (BPT 5204 and NLR 92) during soaking and modelling of hydration behavior using Peleg's equation and also to determine leaching loss and to estimate the energy of activation for rice using a linearized Arrhenius equation.

METHODOLOGY

The Experimentation on hydrations kinetics was conducted during the year 2012-13 in College of Agricultural engineering, Bapatla, Andhra Pradesh. Two varieties of paddy namely 'BPT 5204' and 'NLR 92' were procured from Agricultural College Farm, Bapatla as these varieties of paddy were grown and consumed in large area in this region. Paddy was cleaned manually to remove all the chaff, foreign matter and broken grains in order to obtain kernels of uniform size and dehusked in the laboratory rubber roll sheller to obtain brown rice.

Experimental procedure :

The soaking test was conducted in a constant temperature water bath which was adjusted to required temperature of soaking. Hydration of grains was determined by soaking 10 ± 0.1g of samples in 200 ml glass bottles containing 50 ml of water. The soaking temperature studied was 30, 40, 50, 60 and 70^{0}C. Before performing hydration experiment the glass bottles with water placed in water bath at required soaking temperature to reach thermal equilibrium. The completion of temperature equilibrium was inspected by using digital thermometer. Then, grains were poured into the glass bottle and metal cap was fixed on it to prevent evaporation. The grains were soaked at each temperature upto 3 hours and bottle with soaked samples were withdrawn from the water bath at regular time intervals of 15 min for moisture content determination. The soaked grains were allowed to drain through 14 mesh wire gauge for 1 min and the grain surface adsorbed water was eliminated by slight rubbing with a tissue paper. The drained water was used for leaching loss determination. Then, the soaked grains were weighed with a digital weight balance with 0.01 g accuracy and the grains were placed in an oven at 130^{0}C for 1 hour for moisture content determination. This procedure was followed at each predetermined time for every experimental temperature. The experiment was replicated thrice.

Modeling of hydration data :

Peleg's model (Eq.1) is a two parameter non exponential empirical equation and some of its parameters are of immense practical significance in hydration kinetics.

$$\mathbf{M = M_O + \frac{t}{(k_1 + k_2 t)}} \qquad (1)$$

This equation is usually written in rather simple way to test its ability to fit experimental curves (Eq.2):

$$\mathbf{\frac{t}{(M - M_O)} = k_1 + k_2 t} \qquad (2)$$

As t $\rightarrow \infty$

$$\mathbf{M_e = M_o + \frac{1}{k_2}} \qquad (3)$$

where, M is moisture content at time t in % d.b; M_0 is initial moisture content in % d.b.; k_1 is the Peleg's rate constant in (time % d.b.)$^{-1}$; k_2 is the Peleg's capacity constant in % d.b^{-1}.

Leaching loss determination :

Leaching loss was determined after each 15 min interval of hydration experiment of the BPT 5204 rice and NLR 92 rice, at different temperature of 30, 40, 50, 60 and 70°C. The leachate was decanted from the glass bottles, water in the leachate or filtrate was allowed to evaporate by keeping in an incubator for 6 hours at a temperature of 105°C. The dry residue was weighed. The leaching loss was calculated as the weight of solids present in the filtrate divided by the initial weight of sample and expressed as per cent solids to initial sample weight (Bello *et al.*, 2004; Kashaninejad *et al.*, 2007).

RESULTS AND DISCUSSION

The initial moisture content of BPT 5204 rice and NLR 92 rice was found to be 15.69 and 16.64% d.b. The results of the water absorption data of both rice variety between 30 and 70^{0}C temperature are shown in Fig.1 (a and b). The experimental moisture content values for BPT 5204 rice and NLR 92 rice [Fig. 1 (a and b)] during soaking from 0 to 180 min for the temperatures of 30, 40, 50, 60 and 70^{0}C were increased from 15.69 % d.b. to 36.44, 38.30, 39.91, 42.21 and 51.56 % d.b., and 16.64 % d.b. to 35.79, 37.62, 39.46, 42.43 and 49.90 % d.b., respectively. It was observed that there was a rapid increment in water absorption during soaking from 0 to 15 min for both variety of rice for the temperatures ranging from 30 to 70^{0}C. In later stages increment in water absorption observed but at lower rate. The initial rapid water uptake may be due filling of cracks on grain surface and internal fissures, which formed during dehusking (Engels *et al.*, 1986).

The predicted values were close to the experimental moisture content values (Fig.1 a and b). Sopade *et al*. (1992) noted that the major component absorbing water in seeds is protein, although other components such as mucilages, cellulose, starch and pectic substances contribute to the phenomenon. A regular increase in water absorption was

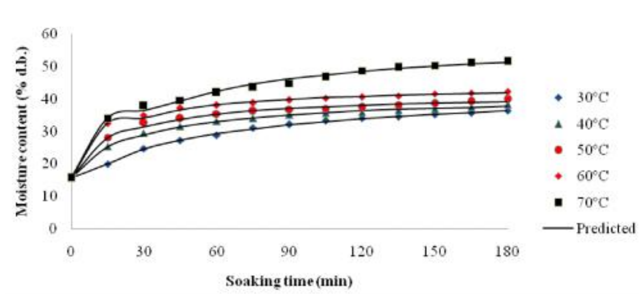

Fig. 1(a) : Experimental and predicted moisture content of BPT 5204 rice at different temperatures

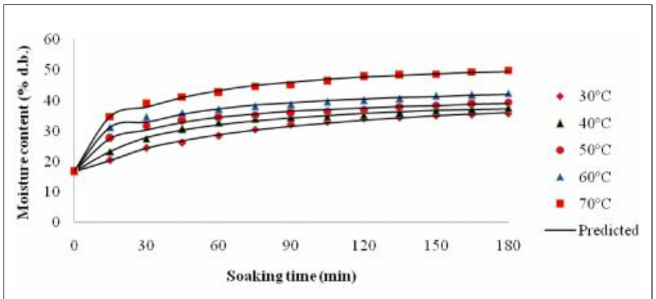

Fig. 1(b) : Experimental and predicted moisture content of NLR 92 rice at different temperatures

observed as temperature increased from 30 to 60^{0}C for both the variety of rice but a different behavior was observed at 70^{0}C *i.e.* more water absorbed compared to 60^{0}C probably due to starch gelatinization or may be due to effect of high temperature inducing softening of grain (Bhattacharya, 1985). The gelatinization of grain rice gradually increases between 60 and 70^{0}C, and saturates around 80^{0}C (Kashaninejad *et al.*, 2007). In this study for both rice soaked at 70^{0}C absorbed more water than other condition because at this temperature starch gelatinization commences.

It can be seen from the water absorption curve [Fig. 1 (a and b)] for BPT rice and NLR rice, the time of soaking required for attaining particular amount moisture content was reduced as the temperature was increased. The temperature of the soaking medium was a major factor in reducing the soaking time of gains. Thus the application of higher temperature has a potential to shorten the soaking time necessary to reach given moisture content. A shorter soaking step not only means less processing time but also signifies retention of more soluble solids in the grains (Kashaninejad *et al.*, 2007; Vengaiah *et al.*, 2012).

The estimated parameters from the linear regression analysis of Peleg's model are presented in Table 1. The coefficient of determination were found to be very high in both cases (R^2 >0.99) indicating a good fit of experimental data to Peleg's model at the examined temperature.

From table 1 it can be concluded that Peleg's rate constant (k_1) decreased with increasing the soaking temperature for both the variety of rice. Peleg's capacity constant, k_2 values for rice were also found to be function of temperature. The order of magnitude of k_1 values of this work is in agreement with those of other researcher for millets, rough rice, rice and sorghum (Fernando *et al.*, 2008; Sopade *et al.*, 1992, Vengaiah *et al.*, 2012). The Peleg's rate constant k_1 could be likened to a diffusion coefficient or mass transfer, in other words lower value of this constant leads to higher initial rate of water absorption. Therefore, it would be more appropriate to say that the reciprocal of k_1 characterizes the diffusion coefficient. The Peleg's capacity constant, k_2 values were associated with water absorption capacity. This means a lower value indicates higher absorption by the product (Peleg's, 1988). This statement clearly confirms our results that rice absorbed the lower water and the dependence of k_2 on temperature indicated that different equilibrium moisture contents would be obtained for different soaking temperatures. As soaking temperature was increased the equilibrium moisture content of the cereals increased (Table 1).

The relationship between k_1 and k_2 with temperature for rice was represented in the form of polynomial function equations (4-7) as follows;

Table 1 : Peleg's equation constants and equilibrium moisture contents at 30, 40, 50, 60 and 70^{0}C soaking temperature

Rice variety	Temperature (^{0}C)	k_1 (h% $^{-1}$)	k_2 (%$^{-1}$)	Me (% d.b.)	R^2
	30	4.12 x 10^{-2}	3.98 x 10^{-2}	39.42	0.9583
	40	1.81 x 10^{-2}	3.93 x 10^{-2}	41.12	0.9979
BPT 5204	50	1.43 x 10^{-2}	3.51 x 10^{-2}	44.10	0.9865
	60	1.41 x 10^{-2}	3.09 x 10^{-2}	48.04	0.9791
	70	1.15 x 10^{-2}	2.34 x 10^{-2}	58.40	0.9491
	30	4.71 x 10^{-2}	4.13 x 10^{-2}	40.84	0.9411
	40	2.43 x 10^{-2}	4.01 x 10^{-2}	41.52	0.9969
NLR 92	50	1.69 x 10^{-2}	3.62 x 10^{-2}	44.23	0.9756
	60	1.30 x 10^{-2}	3.42 x 10^{-2}	45.87	0.9867
	70	1.07 x 10^{-2}	2.47 x 10^{-2}	56.97	0.9978

For BPT 5204 rice,

$k_1 = 0.0022\,T^2 - 0.2496\,T + 7.7617,\qquad R^2 = 0.9823$ (4)

$k_2 = -2 \times 10^{-5}\,T^2 + 0.002\,T - 0.004,\qquad R^2 = 0.9856$ (5)

For NLR 92 rice,

$k_1 = 0.0019\,T^2 - 0.2416\,T + 8.2666,\qquad R^2 = 0.9761$ (6)

$k_2 = -2 \times 10^{-5}\,T^2 + 0.0019\,T - 0.0012,\qquad R^2 = 0.997$ (7)

Here, k_1 is in min % d.b^{-1}. and k_2 % d.b.$^{-1}$

These equations can be used in the Peleg's equation (1) successfully by the processors to accurately predict the amount of water absorbed at any specific temperature for a known period of hydration (Eq.8 & 9).

For BPT 5204 Rice,

$$M = M_O + \frac{t}{(0.002T^2 - 0.2496T + 7.7617) + [-2x10^{-5}T^2 + 0.002T - 0.004)t]} \tag{8}$$

For NLR 92 Rice,

$$M = M_O + \frac{t}{(0.0019T^2 - 0.2416T + 8.2666) + [-2x10^{-5}T^2 + 0.0019T - 0.0012)t]} \tag{9}$$

Leaching loss :

The variation of solids leached with time during the soaking of BPT 5204 rice and NLR 92 rice at different temperatures (30-70^{0}C) is shown in Fig.2 (a and b). At any given time, the amount of solids leached increased with increase in temperature. The leaching loss curves show linear nature (R^2 = 0.8) at hydration temperature studied. During soaking from 15 min to 180 min, the amount of solid leached were about 0.1-0.8 %, 0.1- 1.1%, 0.3 -1.6%, 0.4- 2.1% and 0.5-2.4% for BPT 5204 rice and for NLR 92 rice, the amount of solid leached were 0.1-0.8 %, 0.1- 1.1%, 0.2 - 1.5%, 0.4- 1.8% and 0.5-2.2% for 30, 40, 50, 60 and 70^{0}C, respectively [Fig.2 (a &b)].

It was observed that, the amount of solid loss at low soaking temperatures (30 and 40°C) was less than the temperatures of 50, 60 and 70°C. It may be a result of hammering and the dehulling process of paddy by which structure of the kernel softens, the permeability of the cell membrane is affected and therefore, the more materials can diffuse out. The leached solids in cereals and legumes have been reported to be phytic acid, non-protein nitrogenous compounds, sugars, minerals (Fe, Cu. Zn, Mn, P, Ca, Mg), and water soluble vitamins such as thiamine, riboflavin and niacin. (Kashaninejad *et al.*, 2007).

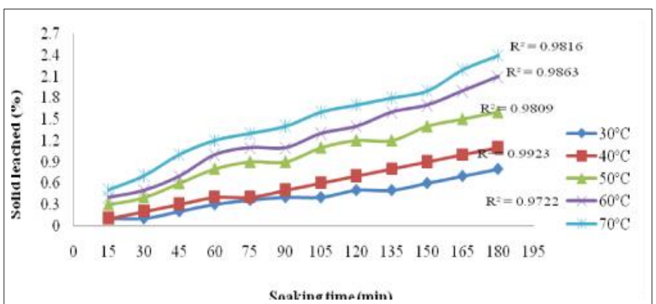

Fig. 2(a) : Solids leached during soaking of BPT 5204 Rice at different soaking temperatures and time

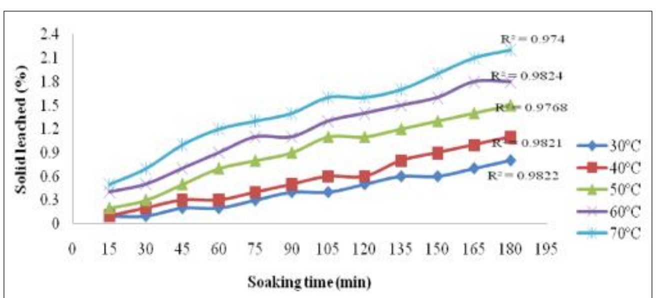

Fig. 2(b) : Solids leached during soaking of NLR 92 Rice at different soaking temperatures and time

Calculation of activation energy :

The temperature dependence of the reciprocal of k_1 could be expressed by an Arrhenius-type relationship (Eq.10) as;

$$\ln\frac{1}{k_1} = \ln A - \frac{Ea}{RT} \tag{10}$$

where, A is a constant (h%$^{-1}$); Ea is activation energy (kJ/mol); R is universal gas constant (8.314 kJ/mol/K); and T is absolute temperature (K).

The Arrhenius plot for the Peleg's rate constant, $k_{1,}$ during soaking of rice is shown in Fig. 3. The activation energy was 26.33 kJ/mol and 31.17 kJ/mol for BPT 5205 and NLR 92 rice, respectively with coefficient of determination, R^2 >0.85. The activation energy values obtained were comparable to those for cereals and legumes. Kashaninejad *et al.* (2007) and Bello *et al.* (2004) reported Ea for brown rice and long grain rice as 34.17 and 34.26 kJ/ mol. The activation energy was the higher for NLR rice indicating that the reciprocal of k_1 tends to be the most

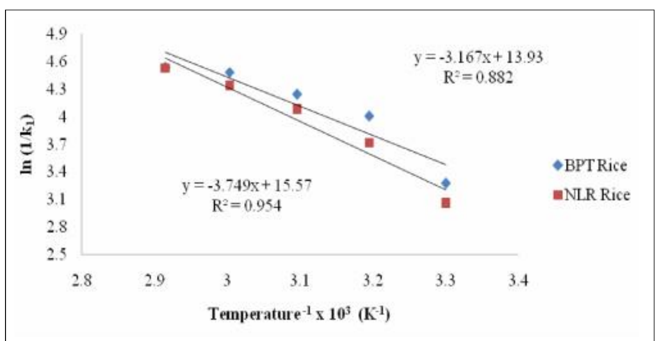

Fig. 3 : Arrhenius plot for calculation of activation energy for BPT 5204 and NLR 92 rice during soaking at different temperature

temperature sensitive than BPT rice. This finding suggests that raising the temperature of a soaking process will affect the water absorption behavior of NLR rice more than BPT rice.

Conclusion:

Peleg's model adequately described the water absorption behavior of both the samples using short time hydration data at different temperature. The relation for Peleg's rate constant and capacity constant (k_1 and k_2) with temperature of particular sample can be used in Peleg's model to estimate the moisture content at given soaking time and temperature within the experimental condition. The leaching loss increased linearly with increase in soaking temperature up to 180 min for BPT 5204 rice ($R^2 > 0.97$) and NLR 92 rice ($R^2 > 0.97$). The Arrhenius equation adequately described interpreting effect of temperature on Peleg's rate constant (k_1) with activation energy values of 26.33 and 31.17 kJ/mol for BPT 5204 rice and NLR 92 rice, respectively.

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