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Application of Peleg's equation to model the water absorption behaviour of green gram during soaking

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ABSTRACT : The water absorption of green gram was studied by soaking in water at room temperature (29^{0}C), 40 and 50^{0}C in water bath upto 60 min. Moisture content of green gram was increased from 11.01% d.b to 19.43, 23.7 and 30.27% d.b. as soaking temperature and time increased. The linear increase in moisture content was observed for each soaking temperature upto 60 min. The water absorption data was modeled by using Peleg's model. Peleg's equation adequately described the soaking behaviour of sample using short time data under the experimental condition ($R^2 \geq 0.82$). The Peleg's rate constant, k_1 decreased from 6.658 to 2.034 min%d.b^{-1} while Peleg's capacity constant, k_2 increased from 8 x10^{-3} to 2.08 x10^{-2} as temperature increased from 29 to 50^{0}C for green gram demonstrating hydration rate decreased and absorption capacity increased with temperature. Both the Peleg's constants were expressed by a linear function ($R^2 \geq 0.86$) for relating to with temperature. The modified Peleg's equation could be used for prediction of moisture content within experimental condition.

KEY WORDS : Green gram, Water absorption, Peleg's model

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Green gram (*Vigna radiata*) is one of the important pulse crops in India. In India, Green gram was grown in about 37.71 lakh ha area and production was about 14.8 lakh tones (2012-13). The major cultivating states of India are as follows: Maharashtra (23.88%), Andhra Pradesh (13.93%) and Rajasthan (26.77%). It is rich protein food which contains about 24 per cent protein, almost three times that of cereals, 1.3 per cent fat and 56.6 per cent carbohydrates (Anonymous, 2012).

Grains need to be hydrated first to facilitate processing operations such as milling, cooking or preparing value added products from it (Abu-Ghannam and McKenna,1997). Excessive soaking causes extensive quantitative leachate loss and qualitative, colour and smell changes. Soaking at room temperature provoke microbial attack. Warm water soaking shortens the soaking duration. 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 (Vengaiah *et al.*, 2012). 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 temperature. Mathematical modeling of hydration process is known to be important for the design and optimization of food process operations. These models are classified to theoretical, empirical and semi-empirical and despite of the widespread application of computers and their associated software's, empirical equations are still extensively used in view of their simplicity and ease of computation (Yildirim *et al.*, 2010).

The present work was carried out to study the water absorption behaviour of green gram during soaking and modeling of hydration behaviour using Peleg's equation.

METHODOLOGY

Green gram of variety BKN 750 was procured from local market in Akluj. The sample was cleaned manually to remove the chaff and foreign matter in order to obtain kernels of uniform size. The experimental work was carried out in Department of Agricultural Processing and Food Engineering, Shriram College of Agricultural Engineering, Paniv to study water absorption behaviour of green gram using short time data. The sample was placed in air-tight sealed polyethylene bags to prevent moisture loss or moisture gain and recontamination. The samples were stored at room temperature before being used for the experiment.

Experimental procedure:

The soaking test was conducted in a constant temperature water bath which was adjusted to the required temperature. Hydration of grains was determined by soaking 10 ± 0.1g of sample in 200 ml glass bottles containing 50 ml of water. The soaking temperature studied were 29 (room temperature), 40 and 50^{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. The grains were soaked at each temperature upto 60 min and bottle with soaked samples were withdrawn from the water bath at regular time intervals of 10 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 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. This procedure was established based on previous studies (Vengaiah *et al.*, 2012 and Fernando *et al.*, 2008).

Modeling of hydration data:

Peleg's equation is popular empirical non-exponential model and some of its parameters are of immense practical significance in hydration kinetics that applied to weight gain during hydration. The model can be applied to check its applicability for prediction of hydration behaviour since the model, particularly in its linear form, offers a simple and convenient way to test its own applicability by linear regression. Its applications have been demonstrated for several cereals and legumes (Vasudeva *et al.*, 2010; Peleg's 1988).

The original form of the Peleg's model is as in Eq. 1:

$$M = M_0 + \frac{t}{(k_1 + k_2 t)} \qquad ...(1)$$

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

$$\frac{t}{(M - M_0)} = k_1 + k_2 t \qquad ...(2)$$

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}.

According to Eq. 2, a plot of t / (M-M_0) against time gives a straight line, where k_1 is the intercept on the ordinate and k_2 is the slope of the line. The values of k_1 and k_2 were calculated by linear regression by using data analysis tool box regression software's of given data (Quicazan *et al.*, 2012).

RESULTS AND DISCUSSION

The initial moisture content of green gram was found to be 11.01 per cent dry basis. The results of water absorption data of green gram between 29 and 50^{0}C temperature is shown in Fig. 1. The experimental moisture content values for green gram during soaking from 0 to

60 min at 29, 40 and 50^{0}C temperature were increased from 11.01% d.b to 19.43, 23.7 and 30.27% d.b., respectively. The major component absorbing water in legumes is protein, although other components such as mucilages, cellulose, starch and pectic substances contribute to the phenomenon (Vengaiah *et al.*, 2012). The amount of water absorbed at lower temperature (29^{0}C) was less than higher temperature (40^{0}C and 50^{0}C). Also a linear increment of moisture content was observed with time for all the temperature studied which indicate that the green gram hydrated slowly with time and temperature. Other researchers, Fernando *et al.* (2008) and Vengaiah *et al.* (2012) obtained identical curves during the soaking of rice, soybean, wheat and black gram, respectively. This behaviour probably due to fibre content of seed coat which may contain a specific type of hemicelluloses, pentosans and some non-starchy polysaccharides which may hinder hydration upto several hours and after acquiring some moisture, it might start absorbing to a greater extent (Vasudeva *et al.*, 2010). It was observed that trend obtained for the amount of water absorbed at 50^{0}C was higher as compared at 29 and 40^{0}C. It may be due to higher temperature inducing softening to the seed coat which leads to higher rate of water penetration (Abu-Ghannam and McKenna, 1997).

It can be seen from the water absorption curve (Fig. 1) for green gram, the time of soaking required for attaining particular amount moisture content was reduced as the temperature was increased. Thus, the application of higher temperature has a potential to shorten the soaking time necessary to reach given moisture content (Turhan *et al.*, 2002).

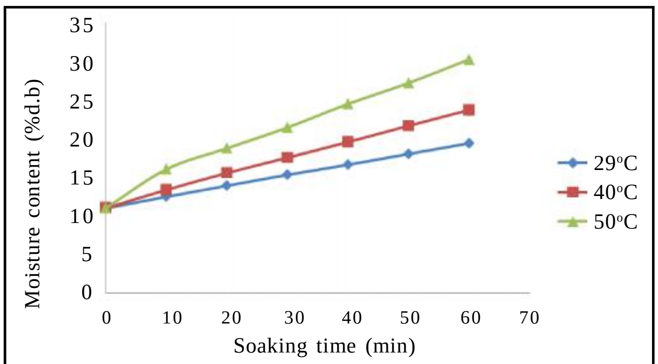

Fig. 1 : Moisture absorption behaviour of green gram at various soaking time and temperature

The estimated parameters from the linear regression analysis of Peleg's model are presented in Table 1. The co-efficient of determination (R^2) varied between 0.82 to 0.92 indicating a good fit of experimental data to Peleg's model at the examined temperature. For the three soaking temperatures tested, the constants k_1 shown tendency to decrease while k_2 increased with increase of temperature. The k_1 could be likened to a diffusion coefficient or mass transfer, in other words lower value of this constant leads to higher water absorption. Therefore, it would be more appropriate to say that the reciprocal of k_1 characterizes the diffusion co-efficient (Vasudeva *et al.*, 2010). These observations are in contrast with finding the observations in the literature for other products. Abu-Ghannam and McKenna (1997) found that the Peleg's constant k_1 was fairly constant with temperature during water hydration of red kidney beans. Similar results were reported by Fernando *et al.* (2008) for hydration of rice and by Turhan *et al.* (2002) during water soaking of chickpea. Vasudeva *et al.* (2010) confirmed the same results for hydration kinetics of pigeonpea, horse gram, rice and black gram.

The relationship between k_1 and k_2 with temperature for grains was represented in the form of linear function eqs. (3 and 4) as follows:

$$k_1 = -0.220T + 13.02, \quad R^2 = 0.99 \qquad ...(3)$$

$$k_2 = 0.001T - 0.010, \quad R^2 = 0.861 \qquad ...(4)$$

These equations can be used in the Peleg's equation successfully by the interested processors to predict the amount of water absorbed by green gram at any specific temperature for a known period of hydration (Eq.5).

$$M = M_0 + \frac{t}{(-0.220T + 13.02) + [(0.001T - 0.010)t]} \qquad ...(5)$$

The study can be concluded as the moisture content of green gram increased with increasing soaking time and temperature. Higher soaking temperature resulted in a shorter soaking time. Peleg's model adequately

Table 1: Peleg's equation constant at different temperatures for green gram

Temperature (^{0}C)	k_1 (min % d.b^{-1})	k_2 (% d.b^{-1})	R^2
29 (Room temp)	6.658	8.0 x 10^{-3}	0.9231
40	4.181	1.03 x 10^{-2}	0.8722
50	2.034	2.08 x 10^{-2}	0.8205

described the water absorption behaviour of green gram using short time hydration data at different temperature. Modified Peleg's model could be used for prediction of moisture content within experimental condition.

Calculation of activation energy:

The temperature dependence of the reciprocal of k_1 could be expressed by an Arrhenius-type relationship (Eq.6) as:

$$\ln\frac{1}{k_1} = \ln A - \frac{Ea}{RT} \qquad .....(6)$$

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 green gram is shown in Fig. 2. The activation energy was 16.38 kJ/mol for green gram with co-efficient of determination, $R^2 > 0.9$. The activation energy found for this research is in agreement with other researchers (Turhan *et al.*, 2002; Abu-Ghannam and Mc Kenna, 1997).

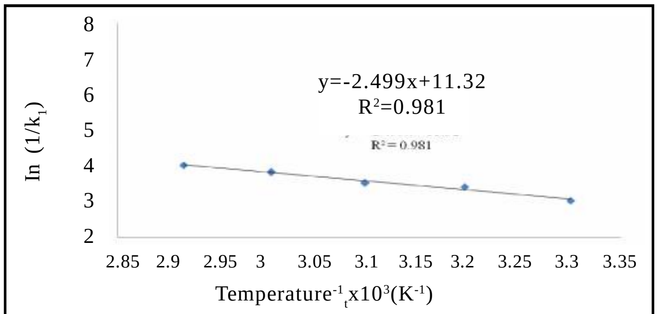

Fig. 2 : Arrhenius plot of green gram during soaking at different temperature

The activation energy was the higher for dhal indicating that the reciprocal of k_1 tends to be the most temperature sensitive for whole grain. This finding suggests that raising the temperature of a soaking process will affect the water absorption behaviour of dhal more than whole grain.

Conclusion:

The moisture content of green gram increased with increasing soaking time and temperature. Higher soaking temperature resulted in a shorter soaking time. Peleg's model adequately described the water absorption behavior of both the samples using short time hydration data at different temperature. The Arrhenius equation adequately described interpreting effect of temperature on Peleg's rate constant (k_1) with activation energy values of 16.38 kJ/mol for green gram.

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