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Modeling of water absorption behaviour of black gram and dhal during soaking

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ABSTRACT : The hydration kinetics of black gram and black gram dhal was studied by soaking in water at temperatures of 30, 40, 50, 60 and 70^{0}C in water bath up to 180 min during the year 2012-13. 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 samples under the experimental condition ($R^2 = 0.95$). The Peleg's rate constant, k_1, decreased from 4.80 $\times 10^{-2}$ to 1.17 $\times 10^{-2}$ for black gram and 3.11 $\times 10^{-2}$ to 0.77 $\times$ 10^{-2} for dhal. Peleg's capacity constant, k_2 decreased from 1.32 $\times 10^{-2}$ to 0.393 $\times 10^{-2}$ from 30 to 50^{0}C and then increased to 0.476 $\times 10^{-2}$ up to 70^{0}C for black gram while k_2 for dhal was increased from 7.2 $\times 10^{-3}$ to 8.0 $\times 10^{-3}$ with an increase in temperature from 30 to 70^{0}C, demonstrating that the water absorption rate increased and water absorption capacity decreased with increase in temperature. Both the Peleg's constants were expressed by a polynomial function (R^2=0.9) for relating to the temperature. The temperature dependence of $1/k_1$ followed an Arrhenius type relationship. The activation energy was 20.78 kJ/mol and 31.57 kJ/mol for black gram and dhal, respectively.

KEY WORDS : Blackgram, Dhal, Hydration, Peleg's equation, Modeling

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Black gram (*Vigna mungo* L.) or*Urad* is one of the important pulse crops in India. In India, black gram was grown in about 31.92 lakh ha area and production was about 18.3 lakh tones in 2011- 2012. The major cultivating state of India is Madhya Pradesh 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). Peleg (1988) proposed a non exponential empirical sorption equation and tested its applicability on milk powder and rice during soaking. Other researchers also studied the hydration kinetics for cereals and legumes by Peleg's model (Turhan *et al.,* 2002; Yildirim *et al.,* 2010).

The present work was carried out to study the water absorption behaviour of black gram and black gram dhal (LBG 752 variety) during soaking and modeling of hydration behaviour using Peleg's equation and to estimate activation energy for hydration process also to study leaching loss during soaking.

METHODOLOGY

Black gram of variety LBG 752 was procured from local market in Bapatla. The sample was cleaned manually to remove all the chaff and foreign matter in order to obtain kernels of uniform size. Black gram dhal was prepared by overnight soaking of the black gram in water and followed by sun drying for two days (Singh and Sahay, 2007). Milling was done to obtain dhal using mini dhal mill (Indosaw, India). The broken grains and dust were separated from the dhal using standard mesh.

Experimental procedure :

The soaking test was conducted in a constant temperature water bath which was adjusted the 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 determination of leaching loss. 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. This procedure was established based on other previous studies (Vengaiah *et al.*, 2012; Quicazan *et al.*, 2012).

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

$$M = M_0 + \frac{t}{(k_1 + K_2 t)} \quad (1)$$

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

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

As $t \to \infty$

$$M = M_0 + \frac{1}{k_2} \quad (3)$$

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

Leaching loss determination :

Leaching loss was determined during hydration experiment of the black gram and dhal with 15 min interval 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 then dry residue 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 (Quicazan *et al.*, 2012).

■ RESULTS AND DISCUSSION

The initial moisture content of black gram and dhal was found to be 9.76 and 11.9 per cent d.b. The results of the water absorption data of black gram and dhal between 30 and 70^{0}C temperature is shown in Fig.1 and 2. The experimental moisture content values for black gram (Fig. 1) during soaking from 0 to 180 min at temperatures of 30, 40, 50, 60 and 70^{0}C were increased from 9.76 per cent d.b. to 43.02, 64.22, 81.54, 92.13 and 95.02 per cent d.b. The amount of water absorbed at lower temperature (30^{0}C) was less than higher temperature (40 to 70^{0}C). Also a linear increment of moisture content was observed with time for all the temperature studied which indicate that black gram hydrated slowly with time and temperature. 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 up to 3 h and after acquiring some moisture, it might start absorbing to a greater extent (Vasudeva *et al.,* 2010).

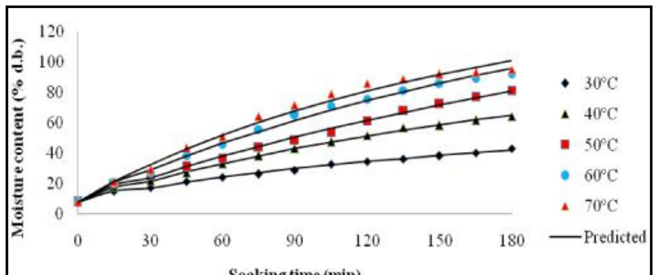

Fig. 1 : Comparison of experimental and predicted moisture content of black gram at different temperatures

The experimental moisture content values for black gram dhal (Fig. 2) during soaking from 0 to 180 min at different temperatures 30, 40, 50, 60 and 70^{0}C were increased from 11.9 per cent d.b. to 130.20, 132.65, 134.4, 134.5 and 135.11 per cent d.b. It was observed that after 3 h soaking moisture content values were very close to each other for all the temperature studied. There was a rapid increment in moisture content for soaking from 0 to 15 min from moisture content 11.9 per cent d.b. to 61.90, 75.65, 96.6, 104.58 and 107.07% d.b. for the temperature ranging from 30 to 70^{0}C. In dhal soaking, the initial rapid water uptake was probably due to filling of capillaries and cracks on surface. In later stages amount of water absorbed was very less. It may be due to reduced water holding capacity due to higher leaching loss (Abu-Ghannam and McKenna, 1997). It was observed that the amount of water absorbed by black gram was lower than that of dhal within experimental condition (Fig. 1 and 2). As dhal was free from seed coat due to which moisture absorption was faster and higher or might be due to the middle lamella in legume without seed coat which absorb moisture faster (Vasudeva *et al.,* 2010).

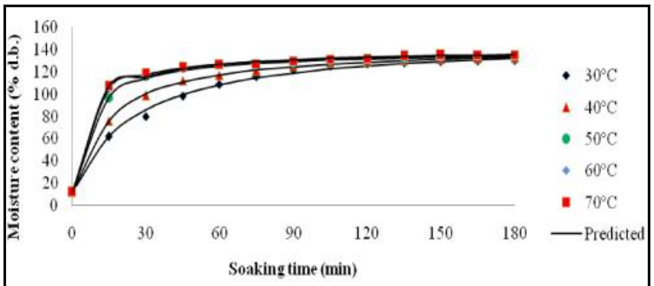

Fig. 2 : Comparison of experimental and predicted moisture content of black gram dhal at different temperatures

The rate of water absorption was initially rapid and slowed down with continuity of hydration. This behaviour may be due to capillary inhibition of external layers from pericarp or by high matrix potential of grain tissues (Turhan *et al.*, 2002). 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).

It can be seen from the water absorption curve (Fig. 1 and 2) for black gram and dhal, 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 (Yildirim *et al.,* 2010). Sopade and Obekpa (1990) studied on sorption behaviour of soybean, cowpea and peanuts at low, room and high temperatures and reported that Peleg's constant k_1 varied with temperature while Peleg's constant k_2 was not affected.

The estimated parameters from the linear regression analysis of Peleg's model are presented in Table 1. The co-efficient 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. Also predicted moisture content was very close to experimental moisture content proving validity of Peleg's model.

From Table 1 it can be concluded that Peleg's rate constant (k_1) decreased with increasing the soaking temperature for black gram and dhal. Peleg's capacity constant, k_2 values for both sample 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 (Yildirim *et al.*, 2010; Turhan *et al.*, 2002). The k_1 could be likened to a diffusion co-efficient 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 co-efficient (Vasudeva *et al.*, 2010). The different trend regarding k_2 was observed in black gram and dhal. The value of k_2 for black gram was decreased from 1.32 x 10^{-2} to 0.393 × 10^{-2} per cent d.b.$^{-1}$ for temperature from 30 to 50^{0}C and then increased up to 0.476 x 10^{-2} for 70^{0}C. Black gram dhal showed that Peleg's capacity constant for temperature from 30 to 70^{0}C increased from 7.2 × 10^{-3} to 8.0 × 10^{-3}. The changes of k_2 values with change in temperature was may be due to differences in solid losses at different temperature (Yildirim *et al.,* 2010). Also such discrepancies depend on seed type and chemical composition of seed and may be related to differences in the expression of moisture and correction for the loss of solid (Quicazan *et al.,*

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

Sample	Temperature(^{0}C)	k_1 (h% $^{-1}$)	k_2 (%$^{-1}$)	Me (% d.b.)	R^2
Black gram	30	4.80 × 10^{-2}	1.32 × 10^{-2}	83.05	0.9614
	40	3.27 × 10^{-2}	0.654 × 10^{-2}	160.60	0.9825
	50	2.92 × 10^{-2}	0.393 × 10^{-2}	262.15	0.8602
	60	2.16 × 10^{-2}	0.429 × 10^{-2}	240.80	0.8902
	70	1.17 × 10^{-2}	0.476 × 10^{-2}	217.73	0.8357
Black gram dhal	30	3.11 × 10^{-3}	7.2 × 10^{-3}	150.78	0.9971
	40	1.8 × 10^{-3}	7.6 × 10^{-3}	143.47	0.9997
	50	0.98 × 10^{-3}	7.8 × 10^{-3}	140.10	0.9996
	60	0.78 × 10^{-3}	7.9 × 10^{-3}	138.48	0.9999
	70	0.77 × 10^{-3}	8.0 × 10^{-3}	136.9	0.9697

2012). The k_2 values were associated with water absorption capacity. This means a lower value indicates higher water absorption by the product. This statement clearly confirms present results that black gram 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 increased (Table 1). It might be due to the enhanced plasticity of grain cells at high temperatures during soaking. Therefore, the grain imbibed more water at high temperatures (Abu-Ghannam and McKenna, 1997). Nisseren and McKenna (1997) studied hydration phenomenon in red kidney beans in blanched and unblanched form at four temperatures and hydration data was fitted to Peleg's (1998) equation .

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

for black gram,

$$k_1 = 0.0008\,T^2 - 0.1237\,T + 5.8019,\ R^2 = 0.9740 \qquad (4)$$

$$k_2 = 1 \times 10^{-5}\,T^2 - 0.0014\,T + 0.0451,\ R^2 = 0.978 \qquad (5)$$

for black gram dhal,

$$k_1 = 0.0002\,T^2 - 0.0183\,T + 0.6002,\ R^2 = 0.9989 \qquad (6)$$

$$k_2 = -8 \times 10^{-7}\,T^2 + 10^{-4}\,T + 0.0051,\ R^2 = 0.9989 \qquad (7)$$

here, k_1 is in min per cemt d.b^{-1} and k_2 per cent d.b.$^{-1}$

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

for black gram,

$$M = M_0 + \frac{t}{(0.0008T^2 - 0.1237T + 5.8019) + ((1 \times 10^{-5}T^2 - 0.0014\,T + 0.0451)\,t)}$$

for Black gram dhal,

$$M = M_0 + \frac{t}{(0.0002T^2 - 0.0183T + 0.6002) + ((-8 \times 10^{-7}T^2 T + 0.0051)\,t)}$$

Leaching loss :

The variation of solids leached with time during the soaking of black gram and dhal at different temperatures (30-70^{0}C) is shown in Fig. 3 and 4. At any given time, the amount of solids leached increased with increase in temperature. The leaching loss curves showed linear nature (R^2 = 0.8) at hydration temperature studied. Solid migration rate increased with temperature for all samples. During soaking from 15 min to 180 min, the amount of solid leached for black gram and dhal (Fig. 3 and 4) were about 0-1.2 per cent, 0.2-3.3 per cent, 0.4-5.9 per cent, 0.6-8.4 per cent and 0.8-9.8 per cent and 1.1-5.3 per cent, 2.1-7.4 per cent, 3.8-10.8 per cent, 5.6-11.9 and 6.7-12.8 per cent for 30, 40, 50, 60 and 70^{0}C, respectively. 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 might be a result of hammering and the dehulling process of black gram by which structure of the kernel softens, the permeability of the cell membrane is affected and, therefore, the more materials can diffuse out.

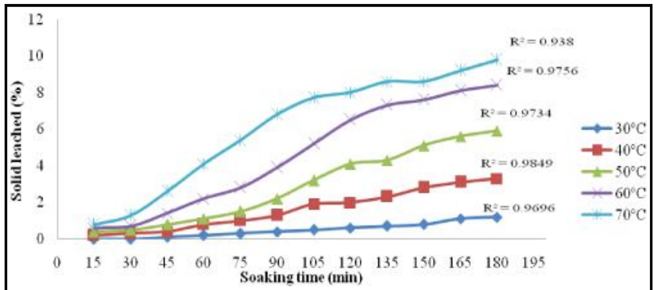

Fig. 3 : Solids leached during soaking of black gram at different soaking temperatures and time

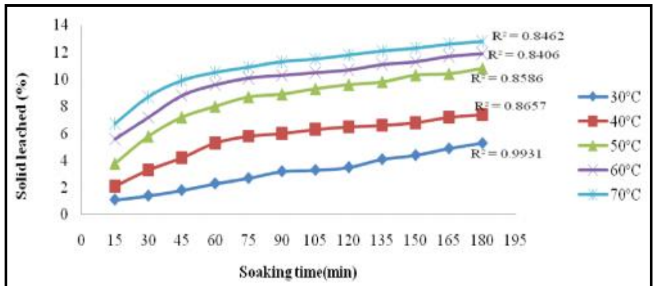

Fig. 4 : Solids leached during soaking of black gram dhal at different soaking temperatures and time

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. In order to maximize nutrient retention, the hydration time, temperature and amount of soaking water should be optimized. To keep the kernel intact and soaking losses at minimum, hydration of kernels should be performed at lower temperatures (Quicazan *et al.*, 2012).

Calculation of activation energy :

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

$$\ln\frac{1}{k_1} = \ln A - \frac{Ea}{RT} \qquad (10)$$

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 black gram and dhal is shown in Fig. 5. The activation energy was 20.78 kJ/mol and 31.57 kJ/mol for black gram and dhal, respectively 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).

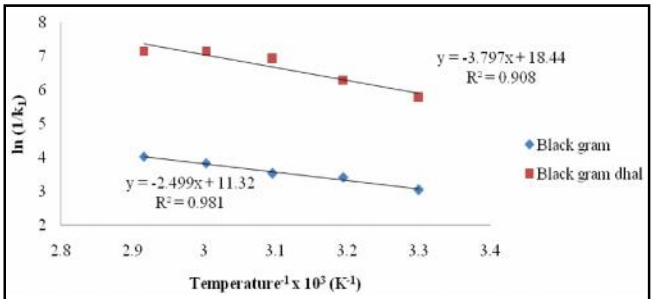

Fig. 5 : Arrhenius plot of black gram and dhal during soaking at different temperature

The activation energy was the higher for dhal indicating that the reciprocal of k_1 tends to be the most temperature sensitive for dhal than 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 black gram and dhal increased with increasing soaking time and temperature. Higher soaking temperature resulted in a shorter soaking time. The leaching loss increased linearly with increase in soaking temperature for black gram ($R^2 > 0.9$) and black gram dhal ($R^2 > 0.8$). Peleg's model adequately described the water absorption behaviour 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 20.78 and 31.57 kJ/mol for black gram and dhal, respectively.

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REFERENCES

Abu-Ghannam, N. and McKenna, B. (1997). Hydration kinetics of red kidney beans (*Phaseolus vulgaris* L.). *J. Food Sci.*, **62**(3): 520-523.

Nissreen, A. and Brian, McKenna (1997). The application of Peleg's equation to model water absorption during the soaking of red kidney beans (*Phaseolus vulgaris* L.). *J. Food Engg.*,**32**:391–401.

Peleg, M. (1988). An empirical model for the description of moisture sorption curves. *J. Food Sci.*, **53**(4) : 1216-1219.

Quicazan, M.C., Caicedo, L.A. and Cuenca, M. (2012). Applying Peleg's equation to modelling the kinetics of solid hydration and migration during soybean soaking. *Ingeniería E Investigación*, **32** (3): 53-57.

Singh, K.K. and Sahay, K.M. (2007). *Unit operations of agricultural processing*. Vikas Publishing House, NEW DELHI (INDIA).

Sopade, P.A. and Obekpa, J.A. (1990). Modeling water absorption in soybean, cowpea and peanuts at thee temperatures using Peleg's equation. *J. Food Sci.*, **55** : 1084–1087.

Turhan, M., Sayar, S. and Gunasekaran, S. (2002). Application of Peleg model to study water absorption in chickpea during soaking. *J. Food Engg.*, **53** : 153-159.

Vasudeva, S., Vishwanathan, K.H., Aswathanarayana, K.N. and Indhudhara, S.Y.M. (2010). Hydration behaviour of food grains and modelling their moisture pick up as per Peleg's equation: Part 2. Legumes. *J. Food Sci. & Technol.*, **47**(1) : 42-46.

Vengaiah, P.C., Raigar, R.K., Srivastav, P.P. and Majumdar, G.C. (2012). Hydration characteristics of wheat grain. *Agric. Engg. Int. CIGR J.*, **14** (1) : 116-119.

Yildirim, A., Mehmet, D.O. and Mustafa, B. (2010). Modeling of water absorption of ultrasound applied chickpeas (*Cicer arietinum* L.) using peleg's equation. *Tarým Bilimleri Dergisi-J. agric. Sci.*, **16**: 278-286.

WEBLOGRAPHY

Anonymous (2012). Black gram. 23 June 2012. *http://www.spiceflair.com/Food /black gram-urad dal.*

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