J Food Sci Technol (January–February 2010) 47(1):42–46

ORIGINAL ARTICLE

Hydration behaviour of food grains and modelling their moisture pick up as per Peleg's equation: Part II. Legumes

Singh Vasudeva · Vishwanathan K. H.

Revised: 26 December 2008 / Accepted: 26 June 2009

Abstract Hydration behaviour of legumes with and without seed coat in split form at room temperature (28°C) was studied. Equilibrium moisture content (EMC) on soaking at room temperature of these legumes with seed coat varied from 53 to 65% (wb). Soybean hydrated fast while horse gram, black gram and green gram hydrated very slowly. Legumes in split form hydrated fast and completed their hydration in 3 h. EMC at room temperature varied from 52 to 58%. Peleg's equation could be fitted to the hydration of all legumes except green gram and horse gram. Coefficient of correlation for legume and splits (*dhal*) varied from 0.96 to 0.99, thus proving the validity of Peleg's equation. EMC of masur *dhal* fitted perfectly to the Peleg's equation. EMC predicted from average k_1 and k_2 values remained almost same in legume splits.

Keywords Legume · Legume splits · Peleg's equation · *Dhal* · Hydration · Equilibrium moisture content

Introduction

Nisseren and Brian 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 equation. Because of the plasticity development in the seed coat of kidney beans while blanching, Peleg's equation could apply more adequately in the blanched beans compared to un-blanched beans. Sopade and Obekpa (1990) studied sorption behaviour of soybean, cow pea 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. In the present work legumes with and without seed coat were hydrated at room temperature (~28°C) and their hydration behaviour was studied. Attempts were also made to fit the sorption data of legumes to Peleg's equation (Peleg 1988).

Vasudeva S.[1] · Vishwanathan K. H.[2]
[1]Department of Grain Science and Technology,
[2]Department of Food Engineering, Central Food Technological Research Institute,
(Council of Scientific and Industrial Research),
Mysore - 570 020, India

Singh V. (✉)
E-mail: singhva2003@yahoo.co.in

Materials and methods

Legumes with seed coat including horse gram (*Dolichos biflorus*), green gram (*Phaseolus aureus* Roxb), chick pea or Bengal gram (*Cicer arietinum*), black gram (*Phaseolus mungo* Roxb), cow pea (*Vigna catjang*), tur (*Cajanus cajan*), kidney bean (*Phaseolus vulgaris*), soybean (*Glycine max*) and lentil (*Lens esculenta*) as well as *dhal* (splits) of these legumes were procured from the local market. In addition field bean (*Dolichos lablab*) and dehusked black gram pearl were also considered for studies, on hydration behaviour. EMC on soaking of rice, wheat and millets at room temperature and modeling of hydration behavior were studied as reported in the previous paper and the same methodologies were used for studies on hydration behaviour of legumes and the findings are reported here.

Results and discussion

Hydration behaviour of legumes with seed coat: Initial moisture content of all legumes ranged from 8 to 10% (Table 1). At 5 min soaking, 1 to 7% moisture increase was observed. Highest moisture absorption was in soybean and least in kidney bean and horse gram. At 30 min soaking the increase in moisture was from 1 to 24%; highest was in soybean and least in green gram and horse gram. At 3 h soaking, ~20% increase in moisture was seen in black gram, ~10% in green gram and ~13% in horse gram. In other legumes the moisture content was 35 to 50%. But the EMC of these were quite high which ranged from 53 to 65%. Black gram, green gram, horse gram and kidney bean hydrated

slowly. Probably the fiber content of seed coat of green gram may contain a specific type of hemicellulose, pentosans and some non-starchy polysaccharides which may hinder hydration initially up to 3 h and after acquiring some moisture, they may start absorbing to a greater extent.

Hydration of dhal: The hydration rate was quite different in the split forms of legumes. Splits are free from seed coat and moisture absorption was faster as compared to those with seed coat. In splits or *dhal*, initial moisture content ranged from 10 to 12% (Table 2). At 5 min hydration, the moisture increase was from 9 to 19% and at 3 h the EMC was reached.

Hydration studies of black gram pearl after removing seed coat, without splitting was also studied. In the initial 5 min hydration ~12% moisture was absorbed. From 30 to 60 min hydration moisture content was ~51% and at 3 h, the moisture content was almost 54% and this was the maximum. At the end of 3 h the moisture content in legumes with seed coat was almost 10% less compared to the EMC and absorption increased after 3 h till 24 h. However, in the *dhal* EMC had reached in 3 h.

Modeling the hydration data of legume splits or dhals: Experimental and predicted hydration behaviour of different *dhals* are shown (Table 3). Predicted values were high up to 1 h in Bengal gram compared to experimental values. In some *dhal* samples like masur, and pea the predicted EMC was almost equal to the experimental values validating the Peleg's equation. Average values predicted from k_1 and k_2 constants were either less or almost equal to experimental values.

Constant k_1 values for legume splits varied from 0.21 $\times 10^{-2}$ to 0.92 $\times 10^{-2}$ with minimum for masur *dhal* and maximum for field bean *dhal* (Table 4). The k_2 values varied from 0.69 $\times 10^{-2}$ to 1.06 $\times 10^{-2}$ with minimum value for tur *dhal* and maximum for masur *dhal*. Coefficient of correlation (r^2) varied from 0.96 to 0.99 indicating the appropriateness of Peleg's equation for the hydration behaviour of legume splits. Even the predicted moisture content on dry basis, for masur *dhal* the values were almost equal to experimental values thus proving the validity of Peleg's equation. For other legumes predicted values were higher by 7 to 24% on dry basis.

Average values of k_1 and k_2 were 0.49 $\times 10^{-2}$ and 0.8 $\times 10^{-2}$ respectively for the legume *dhal* samples studied. Moisture content values as seen from Table 4 are less up to 1 h ranging from 7 to 9% and with increase in time

Table 1 Hydration behaviour of legumes with seed coat and their EMC at room temperature

	Moisture content (% w b) with time						
	Initial	5 min	30 min	1 h	2 h	3 h	EMC
Bengal gram	8.2 ± 0.23	12.2 ± 0.13	27.3 ± 0.13	37.9 ± 0.14	46.4 ± 0.02	49.4 ± 0.56	58.7 ± 0.24
Black gram	8.9 ± 0.19	12.0 ± 0.45	15.1 ± 0.04	18.2 ± 0.14	22.7 ± 0.58	28.8 ± 0.34	58.7 ± 0.32
Cow pea	8.2 ± 0.14	9.7 ± 0.48	24.1 ± 0.09	21.9 ± 0.75	31.9 ± 0.14	nd	57.1 ± 0.65
Green gram	10.0 ± 0.32	10.3 ± 0.12	11.4 ± 0.12	11.5 ± 0.68	15.3 ± 0.78	20.7 ± 0.14	65.4 ± 0.58
Green pea	8.0 ± 0.13	9.5 ± 0.13	18.3 ± 0.34	27.6 ± 0.47	40.7 ± 0.11	47.7 ± 0.42	58.5 ± 0.34
Horse gram	9.1 ± 0.24	9.8 ± 0.14	11.1 ± 0.22	12.6 ± 0.28	16.7 ± 0.58	22.8 ± 0.21	53.1 ± 0.45
Kidney bean	9.1 ± 0.56	9.6 ± 0.15	12.7 ± 0.46	13.7 ± 0.03	28.8 ± 0.14	35.3 ± 0.12	59.1 ± 0.58
Masur gram	9.4 ± 0.75	11.6 ± 0.38	28.1 ± 0.08	38.1 ± 0.58	46.4 ± 0.38	49.3 ± 0.03	56.6 ± 0.14
Soybean	8.2 ± 0.24	15.3 ± 0.26	32.1 ± 0.47	38.7 ± 0.24	44.0 ± 0.58	48.9 ± 0.24	61.4 ± 0.48
Tur	8.8 ± 0.12	9.9 ± 0.27	17.4 ± 0.14	17.0 ± 0.21	36.0 ± 0.59	45.6 ± 0.12	60.9 ± 0.24

nd – Not determined, EMC = Equilibrium moisture content

Table 2 Hydration behaviour of legume *dhal* (split legume) and their EMC at room temperature

	Moisture content (% w b) with time						
	Initial	5 min	30 min	1 h	2 h	3 h	EMC
Bengal gram	11.8 ± 0.31	25.1 ± 0.04	36.4 ± 0.22	45.6 ± 0.22	53.9 ± 0.21	54.5 ± 0.03	55.4 ± 0.22
Black gram	11.8 ± 0.22	30.9 ± 0.13	47.8 ± 0.13	54.0 ± 0.09	55.1 ± 0.22	55.0 ± 0.02	55.8 ± 0.02
Black gram (pearl)	10.2 ± 0.54	21.7 ± 0.28	42.7 ± 0.61	50.5 ± 0.32	53.6 ± 0.21	53.7 ± 0.14	54.9 ± 0.03
Field bean	11.0 ± 0.03	19.9 ± 0.04	31.1 ± 0.52	39.1 ± 0.14	47.1 ± 0.71	50.7 ± 0.44	55.6 ± 0.14
Green gram	11.5 ± 0.43	27.0 ± 0.09	43.5 ± 0.19	50.5 ± 0.02	53.3 ± 0.22	54.0 ± 0.12	54.3 ± 0.04
Green peas	11.9 ± 0.22	22.2 ± 0.03	32.6 ± 032	41.4 ± 0.04	50.6 ± 0.04	52.6 ± 0.22	nd
Masur	11.7 ± 0.34	31.5 ± 0.16	44.5 ± 0.14	48.5 ± 0.14	50.3 ± 0.14	50.1 ± 0.13	51.9 ± 0.04
Tur	10.6 ± 0.32	26.0 ± 0.12	42.2 ± 0.11	51.6 ± 0.22	56.1 ± 0.03	56.6 ± 0.74	58.5 ± 0.03

nd - Not determined, EMC = Equilibrium moisture content

Table 3 Experimental and predicted hydration behaviour of different *dhal* (split legume)

		Moisture content (% d b) with time							
		Initial	5 min	20 min	30 min	1 h	2 h	3 h	EMC
Bengal gram	Expt*	13.4	33.5	48.0	57.2	83.8	116.8	119.6	124.2
	Pred	13.4	26.2	53.2	65.5	88.6	110.0	120.1	148.5
	Avg	13.4	28.4	57.5	69.6	90.9	109.1	117.2	138.4
Black gram	Expt	13.4	44.7	74.0	91.5	117.4	122.7	122.3	126.2
	Pred	13.4	41.3	79.6	91.5	108.6	120.3	124.9	135.3
	Avg	13.4	28.4	57.5	69.6	90.9	109.1	117.2	138.4
Black gram (pearl)	Expt	11.3	27.6	58.2	74.4	102.0	115.6	116.2	121.7
	Pred	11.3	27.5	58.3	70.8	92.6	110.8	118.8	139.5
	Avg	11.3	26.3	55.4	67.5	88.8	107.0	115.1	136.3
Field bean	Expt	12.4	24.8	37.6	45.1	64.2	89.0	102.8	125.2
	Pred	12.4	20.8	40.2	49.8	69.5	89.9	100.3	132.8
	Avg	12.4	27.4	56.5	68.6	89.9	108.1	116.2	137.4
Green gram	Expt	12.9	37.0	65.3	77.0	102.0	113.9	117.4	118.8
	Pred	12.9	33.8	67.6	79.6	98.4	112.4	118.2	132.0
	Avg	12.9	27.9	57.0	69.1	90.4	108.6	116.7	137.9
Masur gram	Expt	13.3	46.0	69.8	80.2	94.2	100.2	101.2	107.9
	Pred	13.3	41.2	72.4	80.8	92.0	99.1	101.7	107.6
	Avg	13.3	28.3	57.4	69.5	90.8	109.0	117.1	138.3
Pea	Expt	13.5	28.5	43.0	48.4	70.6	102.3	111.1	nd
	Pred	13.5	23.2	45.2	55.8	77.2	98.6	109.3	138.9
	Avg	13.5	28.5	57.6	69.7	91.0	109.2	117.3	138.5

*Exp: Experimental, Pred: Predicted by Peleg's Equation, Avg: Predicted by using the average values of k_1 and k_2 which were calculated by using the modified Peleg's equation, nd – Not determined

Table 4 Values of the constants in Peleg's equation for different split legumes

	k_1	k_2	r^2	$*M_{24}$	$*M_E$	$*M_a$
Bengal gram	0.59×10^{-2}	0.74×10^{-2}	0.9684	124.2	148.5	138.4
Black gram	0.23×10^{-2}	0.82×10^{-2}	0.9965	126.2	135.3	138.4
Black gram (pearl)	0.45×10^{-2}	0.78×10^{-2}	0.9913	121.7	139.5	136.3
Field bean	0.92×10^{-2}	0.83×10^{-2}	0.9634	125.2	132.8	137.4
Green gram	0.33×10^{-2}	0.84×10^{-2}	0.9983	118.8	132.0	137.9
Green peas	0.79×10^{-2}	0.78×10^{-2}	0.9552	nd	138.9	138.5
Masur	0.21×10^{-2}	1.06×10^{-2}	0.9986	107.9	107.6	138.3
Tur	0.41×10^{-2}	0.69×10^{-2}	0.9915	141.0	156.8	136.9

*M_{24}- Moisture content on dry basis after 24 h of soaking, M_E- Equilibrium moisture content on dry basis, M_a-Average moisture content on dry basis calculated using average k_1 and k_2 values

the values seem to be almost equal with marginal differences.

Modeling of hydration data of legumes with seed coat: Table 5 shows the experimental and predicted moisture content with Peleg's equation as well as predicted values from average k_1 and k_2. In legumes with seed coat, the predicted values used to be high by 2 to 6%. All predicted EMC values were high starting from 23 to 115% (db) moisture content. Only with tur, the predicted values were almost equal to experimental values. EMC values were low in tur. In addition, all the predicted values were almost equal to experimental values, thus proving the validity of Peleg's equation.

In horse gram and black gram, the hydration data could not be predicted by Peleg's equation, as the predicted moisture content values were 60 to 70% higher. Hence the hydra-

Table 5 Experimental and predicted hydration behaviour of different legumes with seed coat

		Moisture content (% d b) with time							
		Initial	5 min	20 min	30 min	1 h	2 h	3 h	EMC
Bengal gram	Expt*	11.2	16.4	44.8	49.3	60.8	81.5	95.5	142.4
	Pred	11.2	18.7	36.6	45.8	65.3	86.4	97.7	136.2
	Avg	11.2	14.5	23.6	29.1	43.4	64.9	80.4	175.2
Cow pea	Expt	11.5	11.8	13.0	15.1	30.8	69.4	96.5	133.3
	Pred	11.5	16.8	30.7	38.5	57.0	80.7	95.3	156.4
	Avg	11.5	14.8	23.8	29.3	43.6	65.2	80.6	175.4
Faba bean	Expt	10.4	10.4	12.4	12.5	12.7	32.6	59.6	123.8
	Pred	10.4	12.2	17.3	20.7	30.1	46.7	60.9	242.9
	Avg	10.4	13.6	22.7	28.2	42.5	64.0	79.5	174.3
Green gram	Expt	13.9	15.0	15.2	16.7	17.3	29.1	46.4	134.8
	Pred	13.9	16.1	22.3	26.3	37.1	55.1	69.6	199.1
	Avg	13.9	17.1	26.2	31.7	46.0	67.5	83.0	177.8
Green pea	Expt	10.7	12.7	28.5	35.6	43.6	63.6	80.7	133.0
	Pred	10.7	14.2	23.9	29.7	44.6	66.6	82.0	169.4
	Avg	10.7	14.0	23.1	28.5	42.8	64.4	79.8	174.7
Kidney bean	Expt	13.1	14.3	18.3	18.4	43.5	71.8	74.9	141.6
	Pred	13.1	16.0	24.4	29.6	43.5	65.7	82.5	205.4
	Avg	13.1	16.3	25.4	30.9	45.2	66.7	82.2	177.0
Masur gram	Expt	13.6	17.3	25.2	34.9	52.2	86.0	95.2	122.9
	Pred	13.6	18.8	32.2	39.7	56.9	78.3	91.1	141.8
	Avg	13.6	16.9	25.9	31.4	45.7	67.3	82.7	177.5
Soybean	Expt	12.2	15.4	29.0	33.0	46.7	65.8	87.2	163.3
	Pred	12.2	15.6	25.1	31.0	46.4	70.5	88.3	212.2
	Avg	12.2	15.5	24.5	30.0	44.3	65.9	81.3	176.1
Tur	Expt	9.1	9.6	10.1	10.5	11.6	17.3	22.5	155.6
	Pred	9.1	9.6	11.0	11.8	14.4	18.8	22.5	67.56
	Avg	9.1	12.4	21.4	26.9	41.2	62.8	78.2	173.0

*Refer Table 3

Table 6 Values of the constants in Peleg's equation for different legumes with seed coat

	k_1	k_2	r^2	$*M_{24}$	$*M_E$	$*M_a$
Bengal gram	1.03×10^{-2}	0.80×10^{-2}	0.9957	142.4	136.2	175.2
Cow pea	1.50×10^{-2}	0.68×10^{-2}	0.9605	133.3	156.4	175.4
Faba beans	4.65×10^{-2}	0.43×10^{-2}	0.9615	123.8	242.9	174.3
Green gram	3.77×10^{-2}	0.53×10^{-2}	0.8945	134.8	199.1	177.8
Green pea	2.32×10^{-2}	0.62×10^{-2}	0.9714	133.0	169.4	174.7
Red kidney bean	2.75×10^{-2}	0.51×10^{-2}	0.9577	141.6	205.4	177.0
Masur	1.53×10^{-2}	0.78×10^{-2}	0.9871	122.9	141.8	177.5
Soybean	2.40×10^{-2}	0.50×10^{-2}	0.9886	163.3	212.2	176.1

*Refer Table 4

tion data of these two legumes were not considered. In green gram, faba beans, chick pea, soybean, masur, green pea, kidney bean, cow pea and tur the hydration data was collected and attempts were made to fit the data to Peleg's equation.

Prediction of moisture contents from the average Peleg's constants for legumes with seed coat: Table 6 shows the calculated k_1 and k_2 values from the Peleg's equation. The value of k_1 varied from 1.50×10^{-2} to 4.65×10^{-2}, whereas

that of k_2 varied from 0.43×10^{-2} to 0.80×10^{-2}. Averages of these for k_1 are 2.5×10^{-2} and k_2 is 0.61×10^{-2}, respectively. The r^2 ranged from 0.96 to 0.99 except in green gram where it was 0.89. Thus r^2 value proves the authenticity of the predicted values. The moisture values were calculated by the equation,

$$M_t = M_0 + t / (k_1 + k_2 t)$$

Conclusion

Hydration of legumes with seed coat is generally slow. Among the legumes green gram, horse gram and black gram hydrated very slowly and soybean hydrated fast. Slow hydration may be due to hemicellulose and pentosans in the seed coat which hinder penetration of water. Hydration was quite fast, among the splits, where within 3 h maximum absorption occurred and even EMC reached. Probably the middle lamella in legumes without seed coat may absorb the moisture fast. High EMC may be due to the high content of protein in legumes. The data generated will be useful for processing of legumes in food industry.

Acknowledgement Authors are thankful to the Director Prakash V, for showing keen interest in this work. They also thank Subramanian R, for his suggestions on the usage of models for hydration data. Vishwanathan KH is grateful to CSIR for award of senior research fellowship.

References

Nissreen A, 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 Eng 32:391–401

Peleg M (1988) An empirical model for description of moisture sorption curves. J Food Sci 53:1216–1218

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