Temperature dependence on hydration kinetic model parameters during rehydration of parboiled rice

Aasima Rafiq · Juri Chowdhary ·
Manuj Kumar Hazarika · Hilal Ahmad Makroo

Revised: 21 February 2015 / Accepted: 26 February 2015 / Published online: 15 March 2015
© Association of Food Scientists & Technologists (India) 2015

Abstract A study was carried out to relate the hydration behaviour with processing conditions of low amylose content parboiled rice which was dried at various temperatures (40, 50 and 60 °C). The rehydration characteristics of the parboiled rice (dehusked only) was then studied at various soaking temperatures (30, 40 and 50 °C) and time (upto 3 h at every 30 min interval) and equilibrium moisture content of rehydration (EMC) was determined. The data were tested on three hydration equations viz., Peleg's, Exponential and Weibull equations. The experimental data were used to determine the model parameters. The goodness of fit for the models were evaluated by coefficient of determination (R^2) and sum of square error (SSE). The results were indicated that the Weibull model fits better than the exponential model and Peleg's equation. Also, water transfer to paddy, was described by applying the Fick's diffusion model and the moisture diffusivity (D) was calculated. The Diffusivity values varied between 1.06 and 4×10^{-11} m²/s.

Keywords Hydration kinetics · Rehydration · Parboiled rice · Diffusivity

A. Rafiq (✉)
Department of Food and Science and Technology,
Punjab Agricultural University, Ludhiana, India
e-mail: aasima203@gmail.com

J. Chowdhary · M. K. Hazarika · H. A. Makroo
Department of Food Engg and Technology, Tezpur University,
Tezpur, Assam, India

J. Chowdhary
e-mail: jurifeb1688@gmail.com

M. K. Hazarika
e-mail: mkhazarika@tezu.ernet.in

H. A. Makroo
e-mail: hilalmakroo@gmail.com

Introduction

Rice is the best cereal crop in terms of food energy per production area and is consumed in various forms. However, most consumption of rice is as cooked rice. Rice as a comfort food is economical, delicious, nutritious, versatile, easy to prepare, and bland enough to pair with other foods.

Parboiled rice is rice that has been partially boiled in the husk. The three basic steps of parboiling are soaking, steaming and drying (Miah et al. 2002). About 50 % of the world's paddy production is parboiled (Pillaiyar 1981). Parboiling drives nutrients, especially thiamine, from the bran to endosperm (Kyritsi et al. 2011) hence parboiled white rice is 80 % nutritionally similar to brown rice. The starches in parboiled rice become gelatinized, and then retrograded after cooling. Through gelatinization, alpha-amylose molecules leach out of the starch granule network and diffuse into the surrounding aqueous medium outside the granules (Hermansson and Svegmarm 1996) which, when fully hydrated are at maximum viscosity (Eliasson 1986). The parboiled rice kernels should be translucent when wholly gelatinized. Cooling brings retrogradation whereby amylase molecules re-associate with each other and form a tightly packed structure. This increases the formation of type 3-resistant starch which can act as a prebiotic and benefit gut health in humans (Helbig et al. 2008). However, this also makes the kernels harder and glassier. Parboiled rice takes less time to cook and is firmer and less sticky.

One rice variety of India called '*Komal Chawal*' is a low amylose content rice, due to which, the process of absorption of water after parboiling is much easier and mere soaking renders the grains edible. Parboiled rice produced from this paddy variety is known as '*komal chawal*' (meaning '*soft rice*') and is consumed by soaking for around 15–20 min. The '*komal chawal*' varieties are used by the Assamese people for preparation of variety of traditional dishes. It is also

useful for extreme conditions like floods, disasters etc. when one could not afford fuel for cooking. The properties of starches from low-amylose rice cultivars have been studied by several research groups (Okuno et al. 1983; Asaoka et al. 1989; Asaoka et al. 1993; Kuno et al. 2000). Low-amylose rice cultivars exhibited higher peak viscosity and breakdown and lower setback.

Cereal grains absorb water at different rates, thus there has been interest in characterizing the rehydration process of the material. Rehydration of dried material depends on certain intrinsic properties of the tissue and also on how the rehydration process is carried out (process conditions) and on the previous pre treatments applied to the product. In the present work, the kinetic of rehydration of parboiled ‘chokua’ rice as affected by the drying temperature and rehydration condition is studied to model the rehydration time as a function of processing conditions. The absorption data in the form of water content verses time have been fitted and interpreted by different mathematical models based on hydration diffusion.

Materials and methods

One of the rice varieties of ‘komal chawal’ or ‘soft rice’ of Assam called ‘chokua’ was taken for analysis. The quantity of raw paddy required for the study was collected as a single lot from the granary of farmers of nearby area, and is stored in gunny bags in a place away from heat and moisture for the period of study. Experiments were carried out in the Food Engineering Laboratory of the Department of Food Engineering and Technology, Tezpur University.

Experimental methodology

The experimental setup consisted of a tray dryer made by LABOTECH (model BDI-51), water bath and weighing

balance. Paddy (around 3 kg) was soaked in water for 18 h at room temperature followed by steaming in a closed vessel for 15 min and then drying in a tray dryer at three different temperatures (40, 50, 60 °C). Parboiled rice thus obtained was then dehusked and rehydrated by immersing in water filled beaker kept in a water bath at different temperatures (30, 40 and 50 °C). The samples were taken from the bath at different immersion times with the help of forcep and weighed after being blotted with a tissue paper to remove the excess water. Rehydration was carried out until rice became edible. Emc was determined by continuously soaking the parboiled rice at given hydration temperatures for 6 h. The dry matter, and the moisture content of the rehydrated samples were determined gravimetrically by the oven-drying method at 103 °C for 24 h.

Analysis of rehydration kinetics

Data corresponding to changes in mass of the rice during water uptake were quantified in terms of a rehydration ratio (RR), which was expressed as a ratio of the actual sample mass to the mass of the rice samples before rehydration. Three semi-empirical models, namely the Peleg (1988), Exponential (Krokida and Marinos-Kouris 2003), and Weibull (Machado et al. 1999; Krokida and Marinos-Kouris 2003), equations, commonly used to represent the rehydration of several foods, were selected for fitting the experimental data of water uptake kinetics of parboiled paddy.

$$\text{Peleg's equation} \quad RR = \left(RR_e - \frac{1}{k_2} \right) + \frac{t}{k_1} + \frac{k_2}{t} \quad (1)$$

$$\text{Exponential equation} \quad RR = RR_e - (RR_e - 1)e^{-kt} \quad (2)$$

$$\text{Weibull model} \quad RR = RR_e + (1 - RR_e)e^{-\left(\frac{t}{\beta}\right)^\alpha} \quad (3)$$

where RR – rehydration ratio, RR_e – rehydration ratio at saturation, k_1 – Peleg rate constant (min), k_2 – Peleg capacity

Fig. 1 Water absorption curves of parboiled rice (dried at 40, 50 and 60 °C) during rehydration at temperatures of 30, 50 and 70 °C

Table 1 Model parameters and statistical parameters of models

Samples	Peleg's Equation						
	k (min)	k ₂	R ²	SEE	Measured EMC	Predicted EMC	% Error
TI at 30 °C (RT)	0.0113	1.0695	0.9767	0.4742	1.0939	1.0706	−2.1
TI at 40 °C (RT)	0.0118	1.1759	0.9713	1.002	1.1809	0.9860	−16.5
TI at 50 °C (RT)	0.0204	0.7124	0.9272	1.9475	1.5546	1.5393	−1.0
TII at 30 °C (RT)	0.0258	1.1318	0.9553	0.6478	0.9204	0.9640	−1.7
TII at 40 °C (RT)	0.0185	1.1101	0.9555	1.1796	1.1345	0.9813	−13
TII at 50 °C (RT)	0.0089	0.6804	0.9797	1.3870	1.5320	1.5502	0.4
TIH at 30 °C (RT)	0.0173	1.3124	0.9771	0.3736	0.8413	0.8510	4.7
TIH at 40 °C (RT)	0.0205	1.1682	0.9571	0.5009	0.9019	0.9451	−13.5
TIH at 50 °C (RT)	0.0111	0.7848	0.9628	0.6003	1.1134	1.3633	1.2

where TI,TII,TIH are samples dried at 40,50 & 60°, RT- rehydration temp and SEE is standard error of estimation

constant (dimensionless), t -time in hour for Peleg's equation, k- exponential equation rate parameter), t-time in min for Exponential equation, α is the shape parameter of the Weibull model (dimensionless) and β is the scale parameter, with dimension of time.

Peleg's equation is a simplified equation proposed by Peleg (1988) to fit sorption data. For determining predicted emc below equation was used

$$M_e = M_0 + 1/k_2 \quad (4)$$

where M_t -moisture content at any time, M_0 -initial moisture content, M_e – equilibrium moisture content, k_2 - Peleg capacity constant (dimensionless).

The exponential equation represents a first order kinetic semi empirical model, the probabilistic Weibull model has

been employed to describe the behaviour of systems or events that have some degree of variability, such as the rehydration kinetics of food particulates. It can be expressed as follows

Analysis of diffusivities of water

Diffusivity of water in food products is important process which is controlled by properties of material. Analytical solutions of Fick's second law were often used to explain water diffusion inside the material. Bello et al. (2004) used various mathematical models (Lewis model, Page model, Modified Page model, Henderson and Pabis model) to describe the water absorption based on Fick's law of diffusion. Several investigators have successfully predicted moisture content using Fick's second law on various food such as paddy, soyabean, milled rice etc. For cylindrical geometry, with assuming that size and diffusivity remains constant, this

Table 2 Model parameters and statistical parameters of models

Samples	Exponential Equation			Weibull Equation			
	k (min ^{−1})	R ²	SEE	α	β	R ²	SEE
T I at 30 °C (RT)	−0.0113	0.9814	4.1640	0.6210	68.62	0.9790	0.0266
T I at 40 °C (RT)	−0.0039	0.9691	1.2130	0.6280	141.80	0.9898	0.1900
T I at 50 °C (RT)	−0.0064	0.9765	2.3150	0.7955	165.19	0.9888	0.0320
T II at 30 °C (RT)	−0.0076	0.9844	1.8600	0.7840	129.05	0.9879	0.0220
T II at 40 °C (RT)	−0.0037	0.9735	1.2323	0.6510	163.07	0.9898	0.1940
T II at 50 °C (RT)	−0.0183	0.9554	2.0070	0.8340	52.78	0.9791	0.0360
TIH at 30 °C (RT)	−0.0098	0.9838	2.5550	0.6680	87.99	0.9870	0.0170
TIH at 40 °C (RT)	−0.0042	0.9789	1.2650	0.6140	118.57	0.9973	0.2090
TIH at 50 °C (RT)	−0.0242	0.7997	1.3400	0.8930	48.45	0.9217	0.0521

where TI,TII,TIH are samples dried at 40,50 & 60°, RT- rehydration temp and SEE is standard error of estimation

model can be expressed in terms of the fraction of total absorption, M_t/M_∞ as stated in Crank (1975).

$$\frac{M_t}{M_\infty} = 1 - \sum_{n=1}^{\infty} \frac{4}{a^2 \alpha_n^2} \exp(-D \alpha_n^2 t). \quad (5)$$

where M_t is the mean moisture content, M_∞ is the saturation or equilibrium moisture content, a is the radius, ∞ is the root of Bessel functions of first kind and of zero order t the time and D the diffusion coefficient.

Results and discussion

Samples after putting in water were checked for water gain first after 5, 10 min and then after every 30 min interval. The increase in weight was noted down and used for further calculation.

Hydration was completed after 3.5 h after which all samples reach the saturation conditions. Gain in moisture content with time is given in Fig. 1.

The coefficient of determination, R^2 (Meda and Ratti 2005; Solomon 2007) and the standard error of estimation, SEE (Witrowa-Rajchert and Lewicki 2006) were used as statistical criteria for selecting the most suitable equation to predict the rehydration kinetics of the parboiled rice are given in Tables 1 and 2.

R^2 and SEE was calculated as follows

$$R^2 = 1 - \frac{\sum_{i=1}^N (MR_{per,i} - MR_{exp,i})^2}{\sum_{i=1}^N (\overline{MR}_{per} - MR_{exp,i})^2} \quad (6)$$

$$SSE = \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pre,i})^2}{N} \quad (7)$$

where MR_{pre} is the predicted moisture content, $MR_{pre,i}$ is the i th predicted moisture ratio, $MR_{exp,i}$ is the i th experimental moisture ratio, N is number of observations

The average Peleg's constant values were 0.01569 (k_1), 0.9869 (k_2), average R^2 value of fit was 0.963 for Peleg's equation and 0.973 for exponential and 0.986 for Weibull equation. The Peleg's constants determined were used in equation for determination of predicted equilibrium moisture content and percent error was determined. The Peleg's constant k_2 which indicates maximum rehydration ratio was found to be higher for sample which

was dried at 60 °C and rehydrated at 30 °C in a tray dryer. it was found that samples dried in tray dryer at 40 °C and rehydrated at 30 °C showed higher water uptake in both early and late stages of hydration and the samples dried at 60 °C and rehydrated at 50 °C shows lesser water uptake at early stages and higher water uptake at late stages.

Conclusions

Based on model and statistical parameters it was concluded that the samples dried in tray dryer at 40 °C and rehydrated at 30 °C showed higher water uptake in both early and late stages of hydration and the samples dried at 60 °C and rehydrated at 50 °C shows lesser water uptake at early stages and higher water uptake at late stages. The samples dried at higher temperature and rehydrated at low temperatures shows maximum water uptake.

Acknowledgments In the completion of this project, firstly, I am thankful to ALMIGHTY ALLAH and to my parents. I am also thankful to my advisor for his constant support, endurance and encouragement.

References

- Asaoka M, Okuno K, Hara K, Oba M, Fuwa H (1989) Effects of environmental temperature at the early developmental stage of seeds on the characteristics of endosperm starches of rice (*Oryza sativa* L.). *Denpun Kagaku* 36:1–8
- Asaoka M, Okuno K, Yano M, Fuwa H (1993) Effects of shrunken and other mutations on the properties of rice endosperm starch. *Starch* 45:383–387
- Bello M, Tolaba MP, Suarez C (2004) Factors affecting water uptake of rice grain during soaking. *Lebensm Wiss Technol* 37:811–816
- Eliasson AC (1986) Viscoelastic behaviour during the gelatinization of starch. *J Texture Stud* 17:253–265
- Helbig E, Dias A, Tavares R, Schirmer M, Elias M (2008) The effect of parboiled rice on glycemia in Wistar rats. *Arch Lat Nutri* 58(2):149–155
- Hermansson AM, Svegmarm K (1996) Developments in the understanding of starch functionality. *Trends Food Sci Tech* 7:345–353
- Krokida M, Marinos-Kouris D (2003) Rehydration kinetics of dehydrated products. *J Food Eng* 57:1–7
- Kuno M, Kainuma K, Takahashi S (2000) Physicochemical characteristics of low-amylose rice starches. (Japanese) *Oyo Toshitsu*. Kagaku 47:319–326
- Kyritsi A, Tzia C, Karathanos V (2011) Vitamin fortified rice grain using spraying and soaking methods. *Lwt-Food Sci Technol* 44(1):312–320
- Machado MF, Oliveira FAR, Cunha LM (1999) Effect of milk fat and total solids concentration on the kinetics of moisture uptake by ready-to-eat breakfast cereal. *Int J Food Sci Tech* 34: 47–57
- Meda L, Ratti C (2005) Rehydration of freeze-dried strawberries at varying temperatures. *J Food Process Eng* 28:233–246

- Miah M, Haque A, Douglass M, Clarke B (2002) Parboiling of rice. Part II: effect of hot soaking time on the degree of starch gelatinization. *Int J Food Sci Tech* 37(5):539–545
- Okuno K, Fuwa H, Yano M (1983) A new mutant gene lowering amylose content in endosperm starch of rice. *Oryza sativa* L. *Japan J Breed* 33:387–394
- Peleg M (1988) An empirical model for description of moisture sorption curves. *J Food Sci* 53:1216–1218
- Pillaiyar P (1981) Household parboiling of parboiled rice. *Kishan World* 8:20–21
- Solomon WK (2007) Hydration kinetics of lupin (*lupinus albus*) seeds. *J Food Process Eng* 30:119–130
- Witrowa-Rajchert D, Lewicki PP (2006) Rehydration properties of dried plant tissues. *Int J Food Sci Tech* 41:1040–1046