ARTICLE IN PRESS
Journal of the Saudi Society of Agricultural Sciences (2016) **xxx**, xxx–xxx

King Saud University
Journal of the Saudi Society of Agricultural Sciences
www.ksu.edu.sa
www.sciencedirect.com

FULL LENGTH ARTICLE

Evaluation of physical properties and hydration kinetics of red lentil (*Lens culinaris*) at different processed levels and soaking temperatures

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Received 14 April 2016; accepted 28 July 2016

KEYWORDS
Physical properties;
Hydration;
Red lentil;
Soaking temperature;
Mathematical modeling

Abstract Hydration kinetics of red lentil seeds were carried out for whole, dehusked and splits at different temperatures (15 to 45 °C). Several physical properties were evaluated as function of soaking temperatures. Henderson and Pabis, Page, two term exponential and Peleg models were fitted to the obtained hydration kinetics data. To assess the adequacy of models three statistical parameters, coefficient of multiple determinations (R^2), root mean square error (RMSE) and chi-square (χ^2) were employed. Peleg model ($R^2 > 0.990$; RMSE < 0.018; $\chi^2 < 0.001$) was found to be adequate in describing the hydration behavior of red lentil seeds. Effective diffusivity of water over a temperature range of (15–45 °C) for whole, dehusked and splits varied from 6.890×10^{-11} to 1.142×10^{-10}, 1.030×10^{-10} to 1.584×10^{-10} and 1.231×10^{-10} to 1.927×10^{-10} with the activation energy of 12.239, 11.145 and 10.741, respectively. Soaking temperatures pose significant effect on water absorption capacities and all the evaluated physical properties of red lentil seeds.

1. Introduction

Lentil is an important high protein pulse crop, botanically classified as *Lens culinaris* (Adsule et al., 1989). Lentils are most common in the regions of Middle East and Asia and form the basis of the diet for the people living in these areas. India, the 2nd largest producer of lentils following Canada, accounts total production of 1.31 MMT (FAO, 2013).

Lentils contain high protein content about 25% and provide particularly the essential amino acids lysine and leucine (Roy et al., 2010). The high protein content recommends that it could assist in overcoming the malnutrition in undernourished regions. Lentil is generally marketed as whole seed, but the majority of red lentil is dehulled before it is processed. Dehulling is a crucial step in processing of lentils and it has various uses. Dehulled lentil is widely consumed in whole form

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jssas.2016.07.004

(footballs) or split form. Dehulled lentil is most commonly consumed as soup in the Mediterranean region or as dhal - a thick sauce in which spices are used as flavoring in South Asia.

Soaking of lentils is an important part of processing operations such as germination, cooking, fermentation and preparing a product from it. It aids in shortening of cooking time and results in more evenly textured products. Inadequacy in digestion is due to non-nutritional factors such as phytic acid and tannins. In order to increase the nutrition profile of these proteins, suitable soaking and cooking are essential (De Leone et al., 1992).

The knowledge of physical properties of lentils is required for the design of equipment for handling, harvesting, processing and storing (Prasad et al., 2010). The information regarding physical properties is not only relevant to engineers but also to food scientists, processors, and other scientists who may exploit these resources. The size and shape are important in designing of separating, harvesting, sizing and grinding machines. Size, surface area and volume are required in different handling and processing operations and are also needed as input parameters for the prediction of transport properties and drying rates of grains through simulation models. In particular, the estimation of the effective diffusion coefficient of water is affected by the geometry assumed to approximate the grain shape (Gasto et al., 2002). Bulk density, true density and porosity play a significant role in many applications such as design of silos and storage bins. It also helps in separation of undesirable materials, sorting and grading, and maturity evaluation (Tavakoli et al., 2009). The angle of repose is critical in designing an appropriate hopper or silo to store the material, or to size a conveyor belt for transporting the material. The coefficient of friction between seed and wall is an important parameter in the prediction of seed pressure on walls (Gumble and Maina, 1990).

Several researchers determined the physical properties of pulses and seeds such as Chick pea splits (Ghadge et al., 2008; Johnny et al., 2015), Melon seeds and kernals (Mansouri et al., 2015), red lentil seeds (Gharibzahedi et al., 2011), lentil splits (Bhatia et al., 2009b), whole lentil and split cotyledon (Bhattacharya et al., 2005) lentil (Amin et al., 2004), paddy and rice (Bhatia et al., 2009a; Singh and Prasad, 2013 , 2014). Hydration kinetics of various grains such as Andean lupin (Miano et al., 2015), lentis (Oroian, 2015), sorghum (Patero and Augusto, 2015), bean and chick pea (Shafaei et al., 2016), navy beans (Ghafoora et al., 2013), adzuki beans (Oliveira et al., 2013), common bean (Piergiovanni, 2011), chick pea splits (Prasad et al., 2010), sesame seeds (Khazaei et al., 2009) and rice was also studied (Kashaninejad et al., 2007). However, there is general scarcity in the published data that have been carried out on the dependency of soaking temperature on the physical properties of red lentils and its desired effects at different processed levels.

Red lentil is the source for various processed foods and is hydrated before consumption. Thus, modeling of grain-liquid water function is of significant value. The objective of the present work was to study the water uptake kinetics and to evaluate the physical properties of red lentil seeds at different processed levels before and after soaking at various soaking temperatures from 15 to 45 °C at an interval of 10 °C. The data leading from this work would significantly assist the engineering endeavors and will provide worthful inputs for processing, cooking and formulating food products using red lentil.

2. Materials and methods

2.1. Sample preparation

The lentil (*Lens culinaris*) variety PUSA 4076 (SHIVALIK), employed in this research was procured from Regional Research Station of Punjab Agricultural University, Ludhiana. They were cleaned manually to remove lighter foreign matter such as dust, dirt, chaff, immature, damage and shrink seeds. The initial moisture content (MC) of the whole, dehusked and split was determined using hot air oven method (Amin et al., 2004; Bhattacharya et al., 2005). It was found to be 8.6 ± 1.6, 10.0 ± 1.2 and 10.2 ± 1.3 (% db) for whole, dehusked and split PUSA 4076 lentil variety, respectively.

2.2. Determination of physical properties

Some physical properties such as dimensional characteristics (length, width and thickness), geometric mean diameter, sphericity and surface area, and gravimetric properties (thousand grain mass, bulk density, true density and porosity) were evaluated for different fractions of red lentil seeds. Frictional properties such as angle of repose, static coefficient of friction against surfaces glass, steel and wood (in perpendicular and parallel alignment) for lentil seeds were also determined. The evaluated physical properties in the study were also determined separately before and after soaking for different soaking temperatures (15, 25, 35 and 45 °C).

The physical dimensions were determined randomly measuring the length, width and thickness of 100 whole, dehusked and split using dial type vernier caliper (Mitutoyo Corporation, Japan) having least count of 0.02 mm.

The geometric mean dimension (D_e) of lentil was calculated using the relationship (Eq. (1)) given by Mohsenin (1986) as follows:

$$D_e = (LWT)^{1/3} \tag{1}$$

The criterion used to describe the shape of the lentil is the sphericity. Thus, the sphericity (S_p) was accordingly computed (Mohsenin, 1986) using Eq. (2).

$$S_p = \frac{(LWT)^{1/3}}{L} \times 100 \tag{2}$$

The surface area, S was calculated using the following relationship (Eq. (3)) given by Karababa and Coskuner (2013)

$$S = \frac{\pi B L^2}{2L - B} \tag{3}$$

where $B = (WT)^{0.5}$

where L is length, W is width and T is thickness

The true density was determined using liquid displacement technique using toluene (Nazmi, 2015). The bulk density is the ratio of the mass of a sample of a seed to its total volume. The porosity (ε) of bulk seed was computed from the values of true density (ρ_t) and bulk density (ρ_b) using the relationship (Eq. (4)) given by Mohsenin (1986):

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \tag{4}$$

The mass of 1000 seeds of lentil was determined by taking 100 seeds randomly and measured mass of seeds at different

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