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Water uptake and its impact on the texture of lentils (*Lens culinaris*)

Matina Joshi [a], Benu Adhikari [a,*], Joe Panozzo [b], Peter Aldred [a]

[a] School of Science and Engineering, University of Ballarat, Mount Helen, VIC 3353, Australia
[b] Department of Primary Industries, Horsham, VIC 3401, Australia

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ABSTRACT

Water uptake behavior of three cultivars of lentils (Boomer, French-green and Nugget) was studied at three different hydration temperature regimes (room temperature, 50 °C and 85 °C). Boomer had the highest amount of water uptake capacity (74.60 g water/100 g of seeds) at room temperature (20 °C) which can be linked with its pore properties. French-green lentils imbibed the largest amount of water at elevated soaking temperatures (50 °C and 85 °C) and can be attributed to its higher seed surface area to volume ratio, high protein content and relatively thinner seed coat. Water uptake at elevated temperatures (50 °C and 85 °C) were predicted by a two parameter Mitscherlich model ($R^2 > 0.99$, $\chi^2 < 0.5$) within 1.36–3.07% average absolute error. At room temperature, only the water uptake of Boomer was reasonably predicted by this model. The texture (hardness) of the soaked lentils was found to be related the amount of water uptake and soaking temperature used rather than seed size or seed mass alone. The hardness values of Boomer, French-green and Nugget at 85 °C after 75 min soaking were reduced to 5.66%, 3.53% and 6.77%, respectively compared to their respective initial seed hardness values. The water uptake capacity of the aged Boomer was found to be significantly reduced compared to the fresh seeds ($p < 0.01$) while French-green and Nugget do not exhibit significant change ($p < 0.05$). During 72 h of germination, hardness of all lentil cultivars showed a typical pattern which decreased in the first 24 h followed by an increase compared to the hydrated seeds. A peak hardness value was obtained within 36–48 h before finally declining in all types of lentils. Structural changes within the cotyledon, such as depletion of starch granules, new nuclei formation and development of tissues in vascular bundles and rupture of the seed coat were observed during germination.

1. Introduction

Lentil (*Lens culinaris* M.) is one of the prominent sources of plant protein after soybean in the world. Lentils are an excellent source of complex carbohydrates and dietary fiber as well as a good source of high quality protein, vitamins and minerals (Adsule et al., 1989). Despite being nutritious and healthy, legumes including lentils are underutilized in developed countries like Europe, North America and Australia (Schneider, 2002). The main factors limiting their utilization are their long hydration (up to 16 h) and cooking times (up to 1 h). The longer cooking time requires higher fuel energy input which is a constant impediment in lentil-consuming regions of the world. Furthermore, the longer hydration time also encourages proliferation of harmful microorganisms (Buckle and Sambudi, 1990).

Hard-to-cook (HTC) legumes are those which take longer time to soften during normal cooking procedures. The HTC characteristics have been noticed mostly in stored pulses and legumes as well as some freshly harvested seeds (El-Tabey Shehata, 1992). Traditionally, pulses are soaked 12–16 h beforehand to facilitate cooking and in the process, water penetrates through the seed coat to the cotyledons and distributes among starch and protein fractions. When water is uniformly distributed within the seed, the cotyledons become soft and uniform in texture. The water thus imbibed facilitates starch gelatinization and protein denaturation during cooking (Deshpande and Bal, 2001; Abu-Ghannam, 1998). Soaking also prevents the anisotropic heat transfer in dry seeds. Seed hardness is an important quality attribute because it reflects water uptake, seed coat permeability and overall texture and quality. The seed hardness is affected by water uptake, which in turn affects cookability of legumes (Chen et al., 1993). It has been reported that varieties with faster water uptake rate required less cooking time (Deshpande and Cheryan, 1986). However, the effects of soaking time and soaking temperature on the lentil hardness, so far, have not been reported.

Germination of pulses before consumption or cooking is known to bring important changes in biochemical, nutritional and sensory characteristics (Ahmed et al., 1995). Most of the published research on germination of pulses has focused on investigating its effect on

* Corresponding author. Tel.: +61 3 5327 9249; fax: +61 3 5327 9240.
E-mail address: b.adhikari@ballarat.edu.au (B. Adhikari).

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the nutritional and antinutritional factors (Alvarez and Guerra, 1985; El-Adawy, 2002; Ganesh and Venkataraman, 1975; Sathe et al., 1983). Previous studies indicated that during germination the reserved nutrients (carbohydrates, proteins and lipids) stored in the cotyledon are degraded by enzymes and used for the respiration and development of the embryo (Bryant, 1985).

The objectives of this study were two-fold. Firstly, we aimed at quantifying the effect of soaking temperature and time on the hardness of different cultivars of lentils. Secondly, we aimed to quantify the effect of germination on the textural hardness. Physicochemical properties as well as microscopic and mercury porosimetry studies were also carried out in order to explain the above mentioned effects.

2. Materials and methods

2.1. Materials

Three varieties of lentils viz., Boomer, French-green and Nugget were used in this study. The lentils were obtained from AWB Seeds Limited, Victoria, Australia. Prior to use, the samples were cleaned and immature and broken seeds were removed. The samples when received from supplier was analyzed as the "Fresh" samples, and the same samples were also stored for 18 months then reanalyzed to study the effect of ageing (storage) on the texture and water uptake characteristics. All samples were stored in plastic containers and kept at room temperature (20 ± 0.5 °C).

2.2. Methods

2.2.1. Physico-chemical analysis

2.2.1.1. Proximate analysis. The moisture content was determined by drying the pulverized sample in hot air oven (AOAC Method 925.09), and protein content was determined by a standard Kjeldahl digestion and distillation method (AOAC method 920.87). The lipid content was determined by petroleum ether extraction method (AOAC method 963.15) by using a Buchi Model 810 Soxhlet continuous extraction apparatus (Buchi, Flawil, Switzerland). All determinations were carried out in triplicate.

2.2.1.2. Seed volume, surface area and seed weight. A digital seed counting method (SeedCount™, Australia) was used to measure seed length, width and thickness and were subsequently used to calculate the volume and surface area of the lentil samples. Lentil seeds were placed on the special indented tray on narrow edge end and wide edge and scanned. The volume and the surface area of the seeds were calculated assuming that they resembled oblate spheroid (Firatligil-Durmus et al., 2008) using Eqs. (1) and (2), respectively

$$V = \frac{4}{3}\pi\, a^2 h \tag{1}$$

$$S = \pi(a^2 + h^2) \tag{2}$$

where, '*a*' is the mean radius, '*h*' is half of mean thickness of the lentil grains determined by seed count, '*V*' is the volume and '*S*' is surface area of the lentil.

The weight of 100 seeds was measured on randomly selected sub samples of all cultivars with three replicate measurements for each cultivar.

2.2.2. Water uptake tests

Randomly selected seeds (3 g) from each lentil variety were soaked in deionised water. The water:seed ratio was maintained at 5:1 by weight. After soaking for pre-defined time intervals, the water was drained and the soaked lentils were blotted dry with tissue paper to remove the surface water. The lentils were subsequently weighed and the increase in mass was taken as the amount of water absorbed. The water uptake experiments were carried out at room temperature (20 ± 2 °C) and two elevated temperatures, 50 ± 0.5 °C and 85 ± 0.5 °C. All determinations were carried out in triplicate. This experiment was also carried out in aged seeds (stored for 18 months) at room temperature (20 ± 2 °C) for all varieties tested.

A two parameter Mitscherlich model given by Eq. (3) (Wood and Harden, 2006) was used to predict the water uptake data

$$W_t = \alpha(1 - \beta^t) \tag{3}$$

where W_t is water uptake (g/100 g seed) after soaking for time t (min). α is the asymptote of the curve as t tends to infinity and indicates the peak water uptake value if the seeds were allowed to hydrate for considerably long time. β is a curve parameter which can be linked with the rate of water uptake. The goodness of fit of the experimental data using Eq. (3) was assessed using coefficient of determination R^2 and reduced chi-square (χ^2) values as given by Eq. (4)

$$\chi^2 = \frac{1}{N-n}\sum_{i=1}^{N}(E-P)^2 \tag{4}$$

where, N is the number of observations and n is parametric constant. E and P are experimental and predicted values, respectively.

2.2.3. Germination

Grains were soaked for 12 h maintaining the water:seed ratio of 5:1 (v/w) and the excess water was drained at the end of the soaking period. The soaked grains were placed on sterile plastic petri dishes layered with moistened filter paper. The petri dishes with soaked lentils were then kept in a temperature and humidity controlled cabinet (Thermoline Scientific, TRISLH-495-1-SD) at 20 ± 0.5 °C, 90% relative humidity and dark condition for germination. During germination, lentils were sprayed with deionised water every 12 h to compensate for the evaporated water. The samples were drawn at different time intervals for the texture analysis. The time when the soaked samples were placed into the germination chamber was taken as zero time for germination.

2.2.4. Texture evaluation

The textural property (hardness) of dry, soaked (as a function of time and temperature) and germinating seeds were measured using a texture analyzer (TA.XT Plus™, Stable Microsystems, UK). The texture analyzer was calibrated for force (2 kg) and probe height (6 mm) before commencing the tests. A stainless steel cylindrical probe with 5 mm diameter was used throughout. The load cell had a maximum capacity of 50 kg. The cross head speed was maintained 0.50 mm/s, and pre-test and post-test speeds were 1 mm/s and speed 5 mm/s, respectively. A deformation strain of 80% of the original length was applied.

The seed hardness was defined as the peak force of the texture profile curve and corresponded to the force required to deform or crush the seed. The measured force was expressed as force per unit area (MPa) by normalizing the force with the cross sectional area of the probe.

During germination, samples were drawn periodically for texture analysis. Twenty-five seeds were chosen as a representative for each experiment as variation in texture in individual grain is usually substantial (Gowen et al., 2007). During texture analysis, the orientation of each lentil was kept uniform on the platform of the texture analyzer.