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Mass transfer dynamics in soaking of chickpea

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ABSTRACT

Chickpea (*Cicer arietinum* L.) is a widely-used pulse in industrial production of foods and home cooking with soaking being the most used operation in its processing. Insight into its mass transfer behavior enables the design of optimum processing conditions to achieve maximum quality and nutrient content.

In this work, water gain and solids loss were modeled assuming ordinary diffusion. Water diffusivities vary between 1.12×10^{-10} m^2/s at 25 °C to 3.83×10^{-10} m^2/s at 100 °C. Solids diffusivities vary between 9.77×10^{-11} m^2/s and 4.07×10^{-10} m^2/s at 75 °C and 50 °C, respectively. Activation energies were calculated, assuming an Arrhenius model.

Three periods of mass transfer have been identified, with the first characterized by a density increase and a solids loss until 5%. Hydrodynamic flow and diffusion occur simultaneously, both for water and solids transfer. The new insights gained with this work can support the development of more rigorous modeling of chickpea soaking, based on more accurate mass transfer mechanisms.

1. Introduction

Chickpea (*Cicer arietinum* L.) belongs to Leguminosae botanical family, also called Fabaceae or Papilionaceae (Stace, 1991). The legume family has been divided into three subfamilies: Caesalpinieae, Mimosoideae, and Papilionoideae. The grain legumes are included in the later subfamily, which represents the group most economically important family of flowering plants, since the legumes are constituents of the human and animal diet (Doyle and Luckow, 2003). Chickpea is the third most consumed legume, after soya and bean and the fifth most cultivated all over the world, after soya, arachnid, beans and green peas. The largest producers in the world are India, Australia, Pakistan, Turkey, Iran and Mexico. India is responsible for 64.1% of the global chickpea production. The largest exporters are Australia, Mexico, Turkey, Canada, Iran and USA (FAO and WHO, 2006).

Chickpea is served in many ways, with cooking after soaking being the most used, particularly in the main meal, either as hummus or boiled. Soaking is the most important step in dry legumes processing, needed for leaching of antinutritional factors (Kon, 1979), and for water uptake that will enable starch gelatinization during the boiling (Köksel et al., 1998). This operation is performed in a variety of conditions, such as soaking at ambient temperature, usually during an entire day, and simultaneous cooking and soaking at temperatures up to 100 °C. During soaking, water uptake is the main change in the chickpea, and if the temperature is above 55 °C, starch gelatinization also occurs (Turhan and Sagol, 2004), and may also lead to significant solids loss (Frias et al., 2000). These changes enable the softening of the chickpea after which it can be eaten.

Understanding the kinetics of chemical and physical changes during soaking of chickpea, and of its mechanisms leads to an accurate mathematical modeling of this processes, which is essential to further optimize the operation regarding maximum quality, waste and energy consumption reduction. The kinetics of soaking of chickpea have been studied mainly for water transfer, starch gelatinization and texture changes. To our knowledge, no mathematical modeling of solids loss and identification of mass transfer periods during soaking of chickpea has been done. The present work aims to study mass transfer changes during soaking of chickpea at different temperatures, estimating the mass transfer diffusivities and defining mass transfer patterns.

2. Materials and methods

2.1. Chickpeas

Chickpeas of kabuli type were obtained from the distribution company MEPS (Fafe, Portugal). The medium weight of 100 seeds was 66.3 g, with an initial water content of 7.8% (total basis) and an

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Nomenclature

$C_{w,\infty}$	Water content per solids content at infinite time (g/100 g)
D	Apparent diffusion coefficient (m^2/s)
f_s	Fraction of solids loss during soaking until time t (g/100 g)
M	Mass at time t (g)
M^n	Normalized mass at time t (g/g)
r	Radius of the chickpea (mm)
t	Soaking time (s)
T	Soaking temperature (°C)
V	Volume at time t (cm^3)
V^n	Normalized volume at time t (g/g)
ρ	Density (mass/volume) of the chickpea (g/cm^3)
Subscripts	
i	at the initial time
s	solids
w	water
∞	at infinite time

individual weight in the range 0.55–0.70 g.

2.2. Soaking kinetics

Soaking in deionized water was performed at 25 °C and 50 °C to study the kinetics at temperatures where starch gelatinization is not expected to occur, and at 75 °C and 100 °C to study the kinetics at temperatures at which gelatinization of starch is expected to be complete.

For water and solids kinetics, time intervals were defined to follow weight changes until constant weight, using 5 replicates for each time and temperature combination. At least eight different sampling times were considered for each temperature.

Each chickpea was weighted individually, placed in a closed 25 mL Duran flasks (Wertheim, Germany) with 15 mL of water and left for the specified time-temperature in a thermal water bath (Precisterm Selecta, Barcelona). After the specified time elapsed, the excess of water was drained off, and the chickpea was weighed again.

For water uptake and solids loss kinetics, the variables considered were the total mass of the chickpea (M), the mass of water in the chickpea (M_w), and the mass of solids of the chickpea (M_s). At any time (t):

$$M = M_w + M_s \tag{1}$$

The study of the changes of these two components (water and solids) with time was done comparing the mass, per chickpea, at each sampling instant, normalized using the initial mass according to:

$$M_w^n = \frac{M_w}{M_i} \tag{2}$$

$$M_s^n = \frac{M_s}{M_i} \tag{3}$$

$$M^n = \frac{M}{M_i} \tag{4}$$

where M_i is the initial mass of the chickpea (g). The water and solids masses were normalized with the initial mass of the chickpea in order to decrease the variability of results due to the differences in the chickpeas' initial mass, since a heavier chickpea will also have a larger volume and will thus absorb more water and loose more solids.

For volume change kinetics, additional chickpeas were subjected to the same soaking temperatures, for five different times. The chickpeas were weighed before and after soaking, and its volume after soaking was measured. For comparison purposes, the normalized volume ratio was calculated as:

$$V^n = \frac{V}{V_i} \tag{5}$$

where V is the volume at time t (cm^3) and V_i is the initial volume of the chickpea (cm^3).

2.3. Physical and chemical analyses

2.3.1. Observation of the seed coat-cotyledons interface

Several raw seeds were broken and observed with a stereo microscope (Leica EZ4D, Leica Microsystems, Germany) at 35 magnification to study the separation between the seed coat and the cotyledons.

2.3.2. Porosity

Porosity is the ratio of void volume inside a seed per the apparent volume of the seed (Sahin and Sumnu, 2006). Porosity was determined by mercury porosimetry using Micrometrics' AutoPore IV 9500 (Norcross, USA). To account for the different possible porosities of chickpeas of different sizes, a batch of 5 seeds with an average weight 0.6002 g and a batch of 9 seeds with an average weight of 0.2898 were analyzed.

2.3.3. Volume

The apparent volume of the chickpea was measured by pycnometry (Boyle method): a 25 mL in volume pycnometer was used and filled with toluene (99.5%, PANREAC).

2.3.4. Water and solids contents

Each chickpea was smashed (to increase the superficial area) and put in a small pottery flask. The water and solids contents were determined by drying the chickpea at 105 °C until constant weight.

2.4. Estimation of diffusion coefficients

Water transfer in the soaking of chickpea has been modeled by empirical models such as Peleg, Wang, Mitscherlich, Weibull and exponential empirical models (Gowen et al., 2007; Turhan et al., 2002; Wood and Harden, 2006) and mechanistic models, such as the ordinary diffusion (Seyan-Gürtaş et al., 2001; Yildirim et al., 2011) or simultaneous water transfer and starch gelatinization (Sayar et al., 2001), but none modeled solids loss.

In this work, the water uptake and solids loss were modeled according to Fick's second law (equation (6)). For the purpose of mass transfer modeling, the chickpeas were considered to have the shape of a sphere, with a mean radius of 5 mm. Considering constant properties (dimensions and mass transfer coefficients) and an isotropic material, during soaking, without external resistance (infinite Biot) at the surface of the chickpea, an analytical solution