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Hydration kinetics of soybeans: Transgenic and conventional cultivars

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ABSTRACT

Hydration processes of soybeans influence the physiological characteristics of the grain in order to facilitate milling and extraction operations. Moreover, it can improve the soy digestibility and eliminate anti-nutritional factors. The knowledge about hydration kinetics is essential for the proper industrial equipment dimensioning. In the context of increasing production and use of genetically modified soybeans, and the scarcity of physico-chemical and thermal studies regarding this product, the current analysis consists in studying the hydration process kinetics of conventional and transgenic varieties. Experimental tests were performed in five temperatures (25, 35, 45, 55 and 65 °C) using two cultivars of transgenic soybeans (A7321 and CD231) and two conventional cultivars (CD206 and BRS232). Mathematical models presented in the literature (Peleg and concentrated parameters models) were fitted to the experimental data. Both models adequately represented the hydration process. The process rate showed a strong dependence on temperature, but no clear difference towards hydration rate or equilibrium moisture content was observed between conventional and transgenic cultivars.

1. Introduction

Soy (*Glycine max (L.) Merrill*) is one of the most commonly grain grown worldwide. Soybeans are widely used in the food industry as they are rich in proteins, lipids and carbohydrates. The soybean production is in continued and accelerated expansion. Brazil is the second largest producer, with an estimated production of 82.1 million tons in 2012/2013, a volume that is 23.6 million tons higher than the one produced in the 2011/2012 season (Embrapa, 2013). Transgenic soybeans are used in various food products around the world as a result of interesting agricultural characteristics such as yield, cost of production and resistance to infestations (Dinon et al., 2010; Elsanhoty et al., 2013). In view of the increased planting of genetically modified soy, the knowledge about the properties of conventional and transgenic cultivars is important. There are several types of transgenic soybeans currently being developed. The best known and commercially grown is a plant that received a gene from another organism able to make it tolerant to the use of a herbicide commonly used for this culture, glyphosate. When inserted into the soybean genome, the plant became more resistant to the herbicide application and more productive (Embrapa, 2013).

The hydration process influences the physiological characteristics of cereals in order to facilitate milling and extraction of constituents of interest. Moreover, a cooking operation is often used in the food industry to benefit other stages of the process, improving the digestibility and eliminating anti-nutritional factors of soybeans (Coutinho et al., 2010; Maskan, 2002; Turhan et al., 2002). Due to the importance of grain hydration, the kinetic study is crucial for the proper industrial equipment dimensioning. The absorption of water by the soybeans during hydration depends mainly on the binomial time-temperature. Models that represent the hydration process have been developed to predict the time required to obtain the desired moisture content at a given temperature. These models can be either empirical or phenomenological (Coutinho et al., 2010). The empirical models are derived from simple mathematical correlations of experimental data, therefore they are not based on physical laws or mass transfer theories (Gowen et al., 2007; Jideani and Mpotokwana, 2009; Peleg, 1988), while the phenomenological models mathematically represent the phenomenon of mass transfer by diffusion and/or convection (Coutinho et al., 2010; Hsu, 1983). The latter can be classified into concentrated or distributed parameters and usually

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represent the main trends of the process, even outside the range of experimental conditions in which they were validated, which makes their use very attractive .

Studies found in the literature regarding transgenic soybeans deal with the detection of modified organisms in foods (Dinon et al., 2010; Elsanhoty et al., 2013; Kodama et al., 2009; Toyota et al., 2006), the protein quality (Daleprane et al., 2009) and the impact on consumer' health (Daleprane et al., 2009; Marrelli et al., 2013). However, there is no study with respect to the behavior of transgenic soybeans during soaking. The aim of the current analysis is to evaluate the influence of temperature on the hydration process of conventional and transgenic soybeans by applying the models of Peleg and concentrated parameters, and to evaluate the influence of transgenesis on the water absorption.

2. Material and methods

2.1. Hydration tests

Samples of transgenic (A7321 and CD231) and conventional (CD206 and BRS232) soy cultivars were used in the hydration tests. The grains, harvested in 2009, were produced in Paraná, Brazil, and were donated by the Cooperative Coopagrícola Ponta Grossa. The equipment used for hydration is a Dubnoff thermostatic bath with temperature control (Q226M2 model, brand Quimis).

Samples of 200 g were placed in 400 mL beakers containing a solution of sodium benzoate in distilled water at a concentration of 1 g/L. The beakers were placed in a thermostatic bath at constant temperatures of 25, 35, 45, 55 and 65 °C. Sample portions of approximately 15 g were removed from the bath at the following times: 0, 5, 10, 20, 30, 50, 70, 100, 120, 180, 270, 360 and 450 min.

After removal of the surface water, the grains were weighed and volume and moisture content were analyzed. The volume was determined by water displacement in a test tube according to the methodology described by Omoto et al. (2009). Moisture content was measured by oven drying at 105 °C for 24 h or until constant weight (AOAC, 1995) and was calculated by Equation (1):

$$X_{\mathrm{bu}} = 100 \times \frac{MU}{MS} \tag{1}$$

where X_{bu} is the soybean moisture content w.b. [%] and MU [g] and MS [g] are the sample mass before and after drying, respectively.

The water mass concentration in the soybean (ρ_A) was obtained by Equation (2):

$$\rho_A = X_{\mathrm{bs}} \times \rho_{\mathrm{soy}} \tag{2}$$

where ρ_A is the water mass concentration in the soybean [kg m^{-3}], X_{bs} is the moisture content d.b. of the grain [kg kg^{-1}] and ρ_{soy} is the soybean density [kg m^{-3}].

The hydration rate was calculated by:

$$W = \frac{X_{\mathrm{bsf}} - X_{\mathrm{bs0}}}{\Delta t} \tag{3}$$

where W is the hydration rate [h^{-1}], t is time [h] and X_{bs0} [kg kg^{-1}] and X_{bsf} [kg kg^{-1}] are the moisture contents d.b. before and after the hydration process [kg kg^{-1}], respectively.

2.2. Mathematical modeling

The moisture content of the soybeans in function of time was predicted by the empirical model of Peleg (Peleg, 1988) and the phenomenological model proposed by Omoto et al. (2009).

The Peleg model is described by Equation (4):

$$X_{\mathrm{bs}}(t) = X_{\mathrm{bs0}} + \frac{t}{K_1 + K_2 t} \tag{4}$$

where K_1 and K_2 are dimensionless constants and $X_{\mathrm{bs}}(t)$ [kg kg^{-1}] and X_{bs0} [kg kg^{-1}] are the average moisture contents of soy d.b. in a process time t [s] and in the beginning of hydration, respectively.

The concentrated parameter model proposed by Omoto et al. (2009) was developed from a mass balance in transient state for the water within the grain. Considering the average water content inside the soybean, Equation (5) was obtained.

$$\frac{\mathrm{d}(\rho_A V)}{\mathrm{d}t} = -N_A A \tag{5}$$

where V is the soybean volume [m^3], N_A is the water mass flux [kg m^{-2} s^{-1}] and A is the external area of the grain [m^2].

Considering that the grain has a spherical geometry, with a radius r_o, and constant volume, and that the mass flux can be defined as $N_A = K_S(\rho_{Aeq} - \rho_A)$, one can obtain the concentrated parameter model, described by Equation (6):

$$\frac{\mathrm{d}(\rho A)}{\mathrm{d}t} = \frac{-3K_S(\rho_{Aeq} - \rho_A)}{T_0} \tag{6}$$

where K_S is the apparent mass transfer coefficient [m s^{-1}] and ρ_{Aeq} is the water mass concentration within the grain at equilibrium [kg m^{-3}].

Integrating Equation (6), considering that ρ_A and K_S are constant for a given hydration temperature, one can obtain Equation (7):

$$\ln\left(\frac{\rho_{Aeq} - \rho_A}{\rho_{Aeq} - \rho_{A0}}\right) = \frac{-3K_{sx}t}{T_0} \tag{7}$$

The parameters K_S and ρ_{Aeq} can be obtained by fitting Equation (7) to the experimental data by linear regression.

3. Results and discussion

3.1. Hydration tests

During hydration, the variation of moisture content of transgenic and conventional soybeans in function of time was determined experimentally. Fig. 1 shows the evolution of moisture on a dry basis with time for three of the five temperatures studied. At all temperatures, the water absorption is higher in the initial stages of hydration and decreases as the moisture content approaches saturation. In addition, the hydration curves showed an asymptotic behavior, indicating the maximum moisture content attained, according to the findings of Hsu (1983) with respect to hydration of beans, which may be ascribed to the capillary transport mechanism.

The soybeans, with initial moisture of 0.14 ± 0.02 kg/kg, reached equilibrium at an average moisture content of 1.47 ± 0.04 kg/kg, considering all cultivars and hydration temperatures. A significant temperature effect ($p < 0.05$) on the hydration rate of all cultivars was observed: the higher the temperature, the higher the process rate (Fig. 1). To render this figure clearer, only the results for the temperatures of 25, 45 and 65 °C are presented. Several studies have shown that increasing the temperature of the immersion medium is an excellent way to accelerate the water absorption of various seeds, shortening the immersion time (Abu-Ghannam and McKenna, 1997; Hsu et al., 1983; Kon, 1979; Maskan, 2002; Quast and da Silva, 1977; Seyhan-Gürtas et al., 2001; Sopade and Obekpa, 1990; Tang et al., 1994). According to Coutinho et al. (2010), the hydration rate of cereals at a given temperature is directly proportional to the difference between the concentration