EVALUATION OF DISPERSIBLE PROTEIN CONTENT DURING CONVECTIVE DRYING OF SOYBEANS UNDER DIFFERENT DRYING AIR TEMPERATURES

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***Abstract*—The present study assesses the effects of different drying conditions on dispersible protein content of soybeans. Experiments were conducted in a pilot-scale convective dryer operated at different air temperatures (60, 80 and 100°C) at a fixed velocity (1.0 m/s). Moisture and dispersible protein content were measured as a function of time. It was observed that drying air temperature influenced the dispersible protein content of the dried soybeans: when soybeans were submitted to air at 60, 80 and 100°C for 18 min, the dispersible protein content decreased from 33.0 kg of dispersible protein /100 kg of dry solids (d.s.) to 29.0, 20.5 and 12.0 kg /100 kg d.s., respectively. The temperature of 60°C proved to be a satisfactory condition for preserving the dispersible proteins of soybeans. However, using air at 100°C for short periods of time (< 6 min) was also a good option for minimizing protein denaturation during drying.**

***Keywords*—soybean, drying, moisture content, dispersible protein content.**

I. INTRODUCTION

Soybean is a grain rich in proteins used in human and animal food. This grain is well known and was early described in the study of Osborne and Mendel (1917) as a good food option. This study also stated a great need for better knowledge of the components and nutrients in soybeans to contribute to their broader use as food.

Through the processes used in industry, soybeans can be acquired and consumed in several forms, and also serve as an ingredient for the development of other food products. Among the many applications and methods of use for soy, some foods are of high importance: soybean flour, defatted soy flour, soy protein concentrate and soy protein isolate (Sgarbieri, 1996).

The Brazilian National Supply Company (Conab) confirmed in 2013 one more record insoybean production. The August 2013 survey data shows that the total harvest was 81.5 million tons of soybeans in the 2012/13 crop year, registering an increase of 22.7% from the previous cycle. For the 2013/14 cycle in Brazil, if there are no significant climate problems in such period of time, the production should range from 87 million tons to 90 million (Carvalho *et al.*, 2013).

The approximate composition of soybeans (dry basis) is 40% proteins, 30% carbohydrates, 20% oil, and 10% minerals. Its mineral composition is very rich, containing potassium, phosphorus, calcium, magnesium, iron, sodium, copper, among other elements (Sgarbieri, 1996).

The drying of food generally involves the application of heat in a controlled way in order to remove a given amount of water that is in the food. This process allows prolonging the shelf life of foods, since it reduces their water activities (Fellows, 2006).

However, the drying of foods not only affects the moisture content of the products, but also alters other physical, chemical and biological properties, such as enzymatic activity, microbiological contamination, viscosity, hardness, aroma, flavor and palatability (Sgarbieri, 1996). This disadvantage can be minimized by using the drying process in the optimizedconditions, so a thorough study of the process, equipment and parameters becomes necessary (Barbosa-Cánovas and Vega-Mercado, 1996).

The study of the drying process and the design of the necessary equipment need to take into consideration many issues such as fluid mechanical properties, surface chemistry and structure of the solids, as well as heat and mass transfer rates. In most situations, the dried product needs to maintain original features such as color and texture, and this requirement depends directly on the drying conditions it was submitted. The deficiency in the design of the drying process can establish large differences between the interior and the surface of the solid, thus resulting in events such as cracking, warping, and moisture gradients which may cause the formation of an impermeable coating on the surface of the solid. All of these events may damage the quality of the product, reducing its market value and even its shelf life. However, a well-based choice of conditions and drying equipment can avoid or minimize these events. Therefore, it is necessary to consider the effects of drying on the quality of the material to be dried, together with economic and operation issues (Heldman and Hartel, 2000).

The drying temperature is directly related to the drying rate, since the higher the temperature used, the higher the drying rate. When the process is in the constant-rate period, higher temperatures act to increase the heat transfer from air to the surface of the solid. In the falling-rate period, the temperature acts in the migration of internal moisture of the solid, which is facilitated with the application of high temperatures (Foust *et al*., 1980).

Soybean drying is a well-known process when the objective is the soybean oil production; the concern about keeping the dispersible protein content of the grain is almost nonexistent.

Proteins are very important nutrients in human and animal organisms. However, its nutritional value will depend on its composition, digestibility, essential amino acids' bioavailability and the lack of toxicity and/or antinutritional properties (Fennema *et al.*, 2010). In the study conducted by Martínez *et al.* (2013), the protein solubility was used to indicate the over-processing of soybean drying. In this study, there was significant change in protein solubility of soy beans that were submitted to heat treatment.

Heat treatments commonly applied to foods can cause modifications on amino acid side chains and hydrolysis of peptide bonds, as well as structural changes. However, these changes depend on the intensity at which the processing is applied, environmental conditions (e.g. moisture content, pH, ionic strength) and the nature of the protein. When food is subjected to a dehydration process, the non-aqueous components concentrate within the solid. This enables an increase in protein-protein interaction, particularly if the water removal is performed by applying elevated temperatures. The latter case can result in loss of solubility and reduction of surface-active properties of the protein (Pelczar Jr. *et al.*, 1993).

Heat treatment was considered a good alternative to inactivate antinutritional factors and improve the quality of soybean products in the study of Wiriyaumpaiwong *et al.* (2004). In their work, four different heat treatments (spouted bed, extruders, fluidized bed and infrared radiation) were applied to soybeans; the performance was evaluated in terms of moisture reduction, urease inactivation and proteins and lysine solubility. The results show that all techniques were capable of satisfactorily inactivating urease, but provide radical differences in the quantity of soluble proteins. The highest protein solubility was obtained by infrared treatment while the lowest one was produced by extrusion; the amounts of lysine remaining after treatments were similar.

The conventional convective drying process using hot air (adiabatic drying) can cause a negative effect in the form of protein denaturation. Denaturation occurs in the transformation of a protein originally formed under physiological conditions in a poorly defined structure under non-physiological conditions through the action of a denaturing agent. The sensitivity of a protein denaturation is dependent on connections that strengthen their compliance as well as the intensity and type of denaturing agent to which it was subjected (Ribeiro and Seravalli, 2007; Fennema *et al.*, 2010). The protein denaturation is caused by loss of immobilized water, especially the monomolecular layer. Commonly, the solubility of protein decreases with increasing time and temperature of heating (Wiriyaumpaiwong *et al.*, 2004).

The protein solubility is influenced by the hydrophilicity/hydrophobicity balance, which depends on the aminoacid composition, particularly on the protein surface. As the protein denaturation alters the hydrophilicity/hydrophobicity relationship, it affects the solubility of the protein (Araújo, 2011).

The solubility is different from dispersibility because a protein may be dispersed before being part of a solution. Dispersibility is the property of a powder that describes the uniform distribution of the particles in the aqueous medium, so this property is related to the ease with which particle aggregates disperse when in contact with water (Hall, 1996). The index of dispersible protein (PDI) is used to express the degree of protein dispersed in the aqueous medium (Hall, 1996). According to Nazareth *et al.* (2009), a high PDI is necessary to obtain an efficient protein extraction, allowing a high yield of products such as isolated soy protein.

Considering the issues discussed above, the aim of this study was to evaluate how the drying conditions influence the dispersible protein content of soybeans.

II. METHODS

The present study was conducted at the Department of Chemical Engineering of the Federal University of Rio Grande do Sul (Porto Alegre, RS, Brazil). The main raw material used was soybean (*Glycine max*) in the form of grains, which was provided by donation of a soybean processing company located in Esteio (RS, Brazil). The initial moisture content (X_0) of the raw material was 11.5 ± 0.1% on a dry basis.

The experiments were conducted in a pilot-scale dryer (Fig. 1), under the following conditions, alternating (for 60 s) the air flow direction (between upward and downward) crossing perpendicularly the grains bed:

- drying air velocity: 1.0 m/s;
- drying air temperature: 60, 80 and 100°C;
- sample layer height: 2.5 cm (approximately 800 g).

These experiments were based on results obtained in preliminary studies (not shown), setting the time needed, in each drying condition, for a 3% (dry basis) decrease (absolute) in moisture content, chosen according to common industrial practice. Due to low errors found at preliminary studies and the limited amount of sample from the same crop, drying experiments were performed in duplicates at temperatures of 60 to 80 ° C and in a single experiment at 100 °C. The experiments were carried out in batch-mode, that is, for each condi-

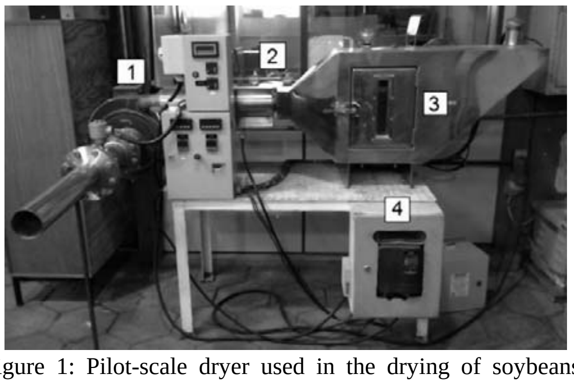

Figure 1: Pilot-scale dryer used in the drying of soybeans, where: (1) is centrifugal fan, (2) is electrical resistances, (3) is the sample basket and (4) is the frequency inverter (controller).

tion (i.e. temperature), the drying operation was conducted up to the desired end time, when subsequently the sample was collected for protein and moisture content analyses (performed both in triplicate). In each temperature, two intermediate data points (i.e. end times) were obtained besides the final one (with the expected decrease in moisture), evidencing 3 steps. For 100°C drying air, the desired decrease in moisture occurred rapidly (less than 6 minutes), so the total drying time was extended in order to better evaluate the protein denaturation, totaling 5 steps. Due to the experimental design, a complete statistical analysis, for the three temperatures studied, was not possible. However, it was done for the temperatures of 60 and 80 ° C: a One-way ANOVA analysis relating the reaction rate constant (k) obtained from the respective temperature was applied.

The percentage (dry basis) of proteins in the fresh soybean samples (total and dispersible) and in the dried grains (dispersible) was assessed to evaluate indirectly the protein denaturation. Analyses of dispersible protein content followed the methodology proposed by AOCS (1998) that describes how to obtain the PDI. However, the results of this work were presented in dispersible protein content to enhance visualization of the reduction of dispersible protein in each drying condition that the soybeans were submitted. The protein content analyses were performed in triplicate by the modified Kjeldahl method described by AOAC using dehydrated samples (AOAC, 1990).

To better evaluation of the decrease of the dispersible protein content, a multiple-factor ANOVA analysis with a significance level of 5%, with Tukey test, was applied. This analysis related the dispersible protein content with the step of drying in each temperature.

III. RESULTS AND DISCUSSION

The content of total proteins obtained for the soybeans was 38.0 ± 0.2 kg of total protein/100 kg d.s. (average of eight samples). This result is very similar to the one found in the literature: 40 kg total protein/100 kg d.s. (Sgarbieri, 1996).

As already mentioned, based on preliminary results, the drying times were established for each condition and are shown in Table 1 along with the corresponding (measured) moisture contents of the samples. This Table shows the standard deviations for moisture contents in the experiments conducted at 60 and 80°C and an average standard deviation for moisture contents at 100°C. The initial moisture content of soybeans (X_0) was 11.5 kg of water /100 kg d.s.

The coefficients obtained with One-way ANOVA analysis were 0.16 ± 0.02^b to 60°C and 0.70 ± 0.01^a to 80°C; this result evidences the significant difference in the soybean drying at these two temperatures in the studied conditions.

The Fig. 2 shows the dispersible protein content of soybeans obtained after drying with air at 60, 80 and 100°C in each step. The error bars correspond to ± the standard deviation of dispersible protein content analyses.

Table 1: Drying times and corresponding moisture contents obtained for each condition of the drying process in the pilot-scale dryer applied to soybeans.

Temperature (°C)	Steps	Drying time (min)	*X*(kg of water/ 100 kg of d.s.)
60	1	9	10.11±0.37
	2	18	9.73±0.08
	3	30	8.94±0.22
80	1	9	9.45±0.50
	2	12	8.96±0.19
	3	18	8.31±0.07
100	1	6	7.86±0.24
	2	12	6.62±0.24
	3	18	5.92±0.24
	4	60	1.78±0.24
	5	120	0.57±0.24

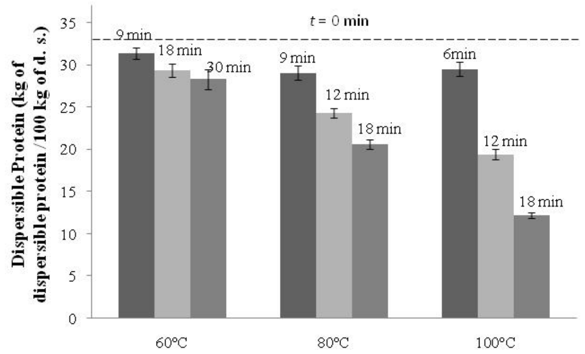

Figure 2: Dispersible protein content of soybeans subjected to drying at temperatures of 60, 80 and 100°C. Air velocity was fixed at 1.0 m/s.

It can be observed in Fig. 2 that there are considerable differences in the dispersible protein content of samples dried for the same period of time (18 min), but at different drying air temperatures. When drying at 60°C, there was a 13.6% final reduction in the dispersible protein content, which originally consisted of 33.0 kg of dispersible protein/100 kg d.s. and resulted in 28.5 kg of dispersible protein /100 kg d.s., with a simultaneous reduction in moisture content of only 2.56 kg of water /100 kg d.s. (see Table 1). When drying at 80°C, the reduction in dispersible protein content was 37.8% (final dispersible protein content equal to 20.5 kg/100 kg d.s.), giving a simultaneous reduction of 3.19 kg of water/100 kg d.s. Finally, soybean drying conducted at 100°C showed a final reduction of approximately 63.6% in dispersible protein content, resulting in only 12.0 kg of dispersible protein /100 kg d.s. at the end of the drying process (18 min), while achieving a reduction of 5.58 kg of water/100 kg d.s. in moisture content.

Figure 3 shows large reductions in dispersible protein content of soybeans subjected to long periods of drying with an inlet air stream at 100ºC. However, this does not mean that treatments with high temperatures cannot be used in the drying of soybeans.

It can be observed in Fig. 3 that when drying was applied for only 6 minutes, there was a reduction of only 10.6% in the soybean dispersible protein, so the percentage of dispersible proteins from soybeans went from 33.0% to 29.5% (dry basis) with a simultaneous

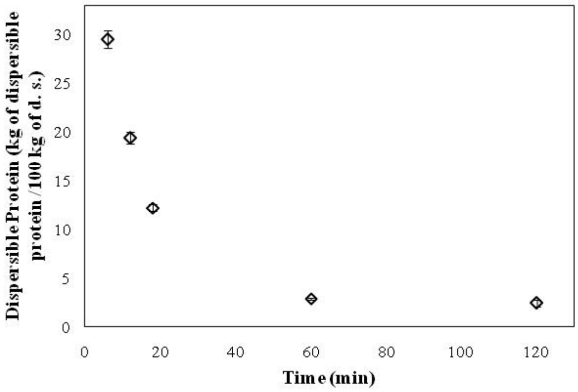

Figure 3: Dispersible protein content of soybeans subjected to drying at 100°C. Air velocity was fixed at 1.0 m/s.

Table 2: Difference significance evaluation of dispersible protein contents through Multiple-factor ANOVA analysis and Tukey test.

Temperature (°C)	Dispersible protein content (kg of dispersible protein/100 kg dry solids)					
	Start	Step 1	Step 2	Step 3	Step 4	Step 5
60	33.0± 0.5[a]	31.5± 0.5[b]	29.5± 1.0[c]	28.5± 1.0[c]		
80	33.0± 0.5[a]	29.0± 1.0[c]	24.5± 0.5[d]	20.5± 0.5[e]		
100	33.0± 0.5[a]	29.5± 1.0[c]	19.5± 0.5[f]	12.5± 0.5[g]	3.0± 0.1[h]	2.5± 0.5[h]

reduction of 3.64 kg of water/ 100 kg d.s. in moisture content. When using drying air at the temperature of 60°C, the percentage of dispersible proteins became 28.5% after 30 minutes of drying, with a simultaneous moisture reduction of only 2.56 kg of water/100 kg d.s.

Drying soybeans with higher temperatures and shorter times, also seeking the quality of soy protein, is discussed by Martínez *et al.* (2013). In this study, the authors seek to reduce treatment time and end-product quality losses and suggested that soybeans could be dried for 3.4 minutes with the air temperature of 136.5°C using a fluidized bed dryer. In this case, the soybeans had initial moisture content of 0.14 g/g (wb) and final moisture content of 0.086 g/g (wb).

Table 2 shows the dispersible protein contents with the statistic difference between each step.

Through Table 2 it is possible to observe that, at the temperature of 60 °C, there was statistically significant reduction in the dispersible protein content from soybeans *in natura* (Start) and the grains that were dried for 9 minutes (Step 1). Additionally, it can be observed that it has no significant difference in the reduction of the dispersible protein content in Steps 2 and 3 at 60°C, Step 1 at 80°C and Step 1 at 100°C. That is, a drying temperature of 60°C over 18 minutes produces a reduction in the dispersible protein content statistically similar to a drying process performed at 60°C, for 30 minutes, at 80°C, for 9 minutes and at 100°C, for 6 minutes.

Looking at Table 2 and Fig. 3, it can also be noted that long drying process times (60 and 120 min) at 100°C, did not significantly increase the reduction of the dispersible protein content (Steps 4 and 5).

Since the moisture content reduction of soybeans proposed by this study was around 3% (11,5% to 8,5% on a dry basis), it was required 30 min at 60°C (step 3), 18 min at 80°C (step 3) and 6 min at 100°C (step 1) to be possible to achieve the proposed moisture content reduction. Between these three conditions, the temperature that generated a larger reduction in the dispersible protein content was 80°C (33 to 20.5±0.5%), followed by the temperatures of 60°C (33 to 28.5±1.0%) and 100°C (33 to 29.5±1.0%) that did not have statistically significant difference between them.

Therefore, the choice of the optimal point for the application of this drying process needs to consider the technical-economic costs and the available time for the process. If there is the possibility to use more time to dry the soybeans, the temperature of 60°C is a good choice to keep a high dispersible protein content; if it is economically viable to work with air at 100°C, it may be a good choice, because it reduce drastically (by about five times) the process time.

IV. CONCLUSIONS

The results showed that to reduce the moisture content of the soybean samples by the same amount (approximately), there was a greater reduction in dispersible protein content for convective drying carried out at 80°C than at 60°C. However, for the same moisture content reduction, the drying carried out at 100°C showed higher dispersible protein content (and therefore lower protein denaturation) than at 80°C and did not present statistically significant difference with the process at 60°C. Nevertheless, an air temperature of 100°C showed a large reduction in dispersible protein content when applied to a greater drying time.

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