Reprinted from Food Technology, Vol. 23, No. 11, Page

Sorption and Diffusion of Water in Dry Soybeans

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SUMMARY

The water sorption isotherms of dry soybeans at 30°C were determined with a vacuum sorption apparatus. The apparent diffusivity of water was estimated from measurements of the sorption rates and it was found to increase significantly at higher moisture contents. Defatted soybeans sorbed more water and at a faster rate than full-fat beans. The sorption characteristics are important in the processing, storage and use of dehydrated soybean products.

INTRODUCTION

Dry soybeans are a large volume crop which is utilized in the U. S. mainly for the extraction of oil and the production of soybean meal. Considerable interest has arisen during recent years in the utilization of soybeans in human nutrition because of their high protein content. New products have been developed such as textured protein products, extruded meal and soy milk.

Most of the manufacturing processes involve absorption of water by the dry soybeans which facilitates further processing. The absorption of water and the conditions required for optimum hydration have not been investigated in detail. Some empirical observations have been reported in the literature. Smith et al. (1961) observed that the seed coat is an important barrier to the absorption of water and that the absorption rate decreases at lower moisture contents. The physical and chemical structure of the soybeans has an important effect on the absorption of water. Some "hard" beans absorb water very slowly and, since they are usually smaller in size, they can be separated by volume either as dry beans or after absorption of water (Bourne, 1967).

The storage conditions and time may have an important effect on the absorption of water by soybeans and other dry beans. Burr et al. (1968) found that the cooking time of several varieties of dry beans increased after extended storage at moisture contents higher than 10% and temperatures higher than 50°F. Dry soybeans normally contain less than 10% moisture and, therefore, extended storage at ambient temperatures should not have any significant effect on their water-absorption capacity.

A number of processes have been proposed in the last few years for the development of quick-cooking dry beans. The aim of these methods is to reduce the long cooking time which is needed for most beans. The suggested processes include precooking followed by air-drying (Steinkraus et al., 1964), explosive puff-drying of partially hydrated beans (Adler, 1964) and vacuum treatment in a solution of inorganic salts followed by air-drying (Rockland et al., 1967). The last method was applied to several dry beans including soybeans. Mustakas et al. (1964) developed an extrusion process at high temperature for preparing a quick-cooking soybean flour.

Very little work has been reported on the sorption of water vapor by dry beans or dehydrated bean products. Weston et al. (1954) measured the equilibrium isotherms of seven varieties of beans other than soybeans. They reported that variety had no effect on the moisture equilibria but it influenced the rate of sorption of water.

The present study was intended to obtain fundamental data on the water sorption properties of dry soybeans. This information is needed for understanding the mechanism of water absorption and evaluating the storage and rehydration characteristics of dry soybean products.

EXPERIMENTAL

Commercial samples of two varieties of dry soybeans, Clark and Harasoy, were used in this study. The soybeans contained 6 to 8% moisture and were stored at room temperature 6 to 12 months before they were used in the sorption experiments. Soybeans of normal size were used and the small-sized beans of each sample were rejected because of their slow absorption of water. The seed coats of about 5 g of soybeans were removed and the separated cotyledons were stored at 75% Relative Humidity for one week. Two main types of experimental samples were used, 1) the separated cotyledons and 2) thin slices of uniform thickness (1 mm) cut with a blade from the middle of the moisture-equilibrated cotyledons. Additional experiments were performed with intact whole beans and freeze-dried whole beans. The latter were prepared by hydrating dry whole soybeans in water at room temperature and vacuum freeze-drying in a conventional laboratory apparatus to a moisture content of 2%.

Defatted soybean samples were prepared by extraction of the oil from dehydrated thin slices with n-hexane. The soybeans used in this work contained 20% oil and other hexane-extractable materials. The defatted slices were vacuum-dried to remove all the solvent before the water sorption measurements were made.

The moisture equilibria and the sorption rates were measured in a McBain vacuum sorption apparatus similar to that described by Saravacos (1967). The quartz spring extension (3.3 mg/min) was measured with a cathetometer which had an accuracy of ±0.1 mm. All measurements were made in vacuum (absolute pressure, 0.1 mm Hg) and at a constant temperature of 30°C. The constant relative humidities were maintained with saturated salt solutions.

Each sorption isotherm was determined on a sample of approximately 500 mg dry weight. The sample was first equilibrated at 75% R. H. and the desorption isotherm was determined first, followed by the adsorption isotherm. Finally the dry weight of the sample was determined by vacuum-drying in the same apparatus at 60°C until a constant weight was reached. All determinations were made in duplicate on two separate samples and the average values are reported.

RESULTS AND DISCUSSION

Sorption isotherms. Figure 1 shows the equilibrium sorption isotherms of Clark soybeans at 30°C. The same isotherms were obtained with thin slices, cotyledons and whole beans. With thin slices, equilibrium was reached in 12 to 24 hr, while cotyledons required 2 to 6 days. Whole soybeans required 1 to 3 weeks to reach equilibrium. A similar isotherm was obtained with freeze-dried whole Clark soybeans and equilibrium was reached within 2 days. The presence of the seed coat did not have any effect on the equilibrium moisture content.

No significant difference was noticed between the sorption isotherms of the two varieties of soybeans. Figure 2 shows the isotherms of normal and de-

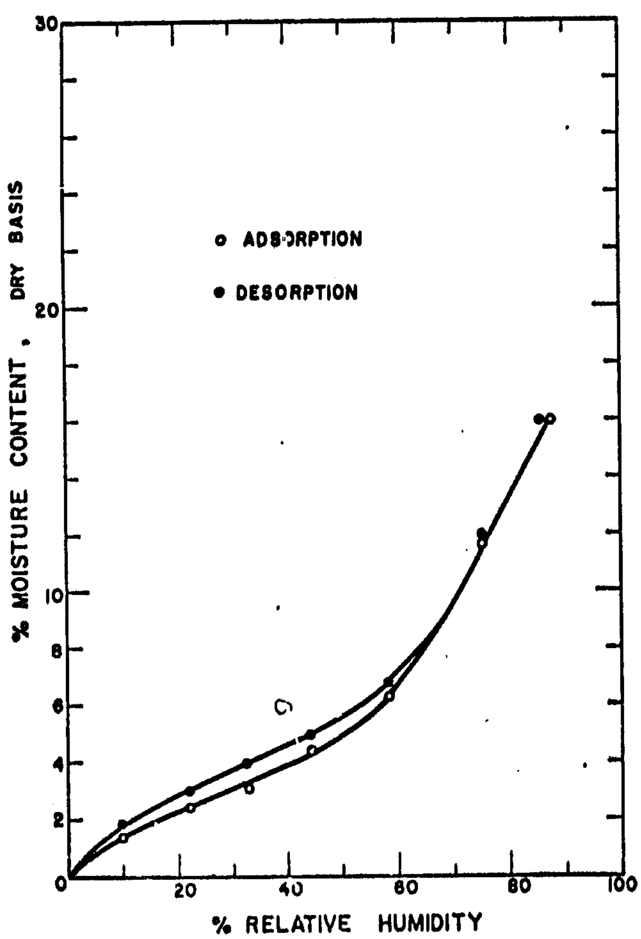

Fig. 1. Equilibrium sorption isotherms of Clark soybeans at 30°C.

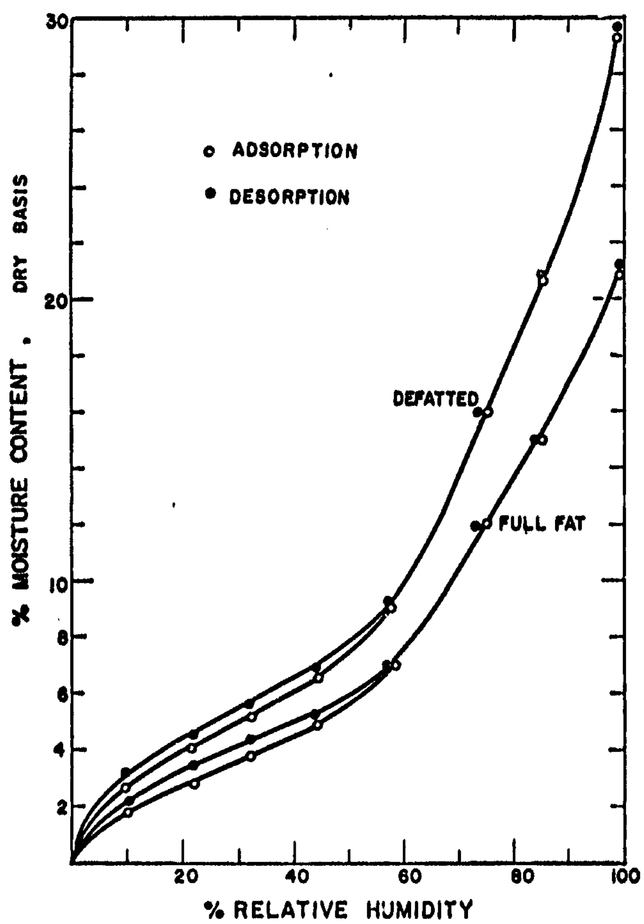

Fig. 2. Equilibrium sorption isotherms of full-fat and defatted Harasoy soybeans at 30°C.

fatted Harasoy soybeans. Defatted soybeans sorbed higher amounts of water over the entire relative humidity span. The removal of oil and other hydrophobic materials increases the percentage of protein and polysaccharides which have a higher sorption capacity. The percent increase in sorption capacity is greater than the percent of fat removed (20%, which suggests that polar water-holding sites may be uncovered during defatting. At the same time, the extraction of oil increases significantly the rates of sorption, as discussed later in this paper.

The sorption isotherms shown in Figures 1 and 2 form definite hysteresis loops below 60% R. H., i.e. the desorption isotherm lies above the adsorption isotherm in this region of water activity. The phenomenon of hysteresis has been found in several foods and it may be caused by the physical structure of the polymeric food materials (Labuza, 1968).

Diffusivity of water. Kinetic data of the sorption of water vapor by thin slices of soybeans were used for the calculation of the apparent diffusivity. The circular slices used in these measurements were 1 mm thick and 7 mm in diameter. It was assumed that diffusion of water was one-dimensional, i.e. the side effect was neglected. It was also assumed that the rate-controlling process was the diffusion of water within the mass of the soybean slices and that the resistances in the vapor phase and the vapor-solid interface were negligible. Under these conditions, the apparent diffusivity of water can be estimated from adsorption and desorption data using a simplified solution of the differential equation for unsteady state diffusion (Saravacos, 1967).

Figure 3 shows the apparent diffusivity of water in Harasoy soybeans at various relative humidities (at 30°C). The diffusivity in full-fat beans increased significantly as the relative humidity (or the moisture content of the sample) was increased. In the defatted soybeans, the diffusivity of water was much higher and it was not affected by the relative humidity.

The full-fat soybean samples expanded significantly as their moisture content was increased. This expansion, due to adsorption of water, is analogous to the expansion of various beans during hydration in water. The volume increase of dry beans by absorption of water may be similar to the volume changes of cereal grains, which have been found to follow a diffusion-like mechanism (Fan et al., 1962).

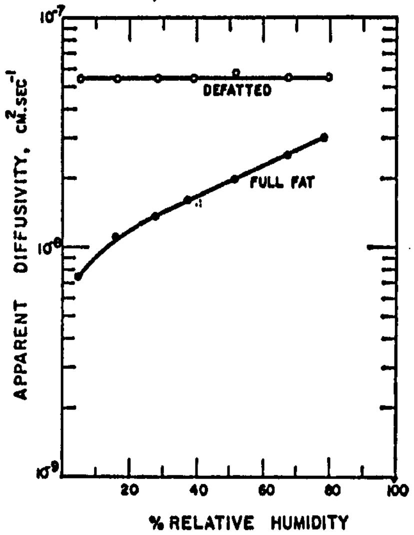

Fig. 3. Apparent diffusivities of water vapor in Harasoy soybeans at 30°C (air pressure, 0.1 mm Hg).

The higher apparent diffusivity of water in the defatted soybeans is evidently due to the porous structure of the samples, which was caused by the solvent extraction of the oil and the other lipid compounds. The defatted samples were more bulky than the full-fat soybean samples of the same moisture content. Their appearance and sorption characteristics were analogous to those of puff-dried potato, while the full-fat soybeans resembled the air-dried potato (Saravacos, 1967). The sorption rates in freeze-dried, full-fat soybeans were similar to the corresponding defatted beans, due, evidently, to the highly porous structure created by freeze-drying.

The seed coat of whole soybeans was found to decrease the rates of water sorption. However, it was not clear that this reduction is caused by the resistance to moisture transfer through the seed coat. It was noticed that when the seed coats were removed from the whole beans, the cotyledons tended to separate during the sorption processes, facilitating the transfer of water. On the other hand, seed coats held the cotyledons tightly together, increasing the path of diffusion of water within each bean.

The difference in sorption rates between full-fat and defatted soybeans can be explained on the basis of the mechanisms of heat and mass transfer (King, 1968). Depending on the external and internal conditions of a water sorption system, the transfer of water or the transfer of the heat of sorption may be the controlling factors. In the experimental arrangement used in our work, external transfer of water vapor to or from the sample surface was very fast because of the high vacuum in the apparatus.

In full-fat soybeans, the rate limiting factor was internal mass transfer because of the low porosity of the material. Increasing the moisture content expanded the volume of the sample and diffusion was accelerated. In defatted soybeans, the high apparent diffusivity of water and its independence from the moisture content suggest that external heat transfer was the rate controlling factor.

In applying the sorption data of this report to soybean products, it must be recognized that while pressure has no effect on the moisture equilibria, the sorption rates may be affected adversely at atmospheric pressure, particularly in porous products. It is also obvious that further studies of the sorption characteristics of special dry bean products are needed.

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Ms. received 5/12/69; revised 6/6/69; accepted 7/31/69.

New York State Agricultural Experiment Station Journal No. 1708.