Factors Affecting Water Uptake of Soybeans During Soaking[1,2]

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ABSTRACT

Water uptake of soybeans during soaking was determined by recording the weight increase in beans with respect to time. Temperature was found to influence the rate of water uptake, with higher rates associated with higher temperatures. Up to one percent sodium bicarbonate showed little effect on the rate of water absorption; however, a slower rate was observed at higher concentrations. The rate and maximum amount of absorption showed little correlation with the protein content, density, and size of the bean. Preextraction of beans with methanol increased the water-uptake rate of slow-absorbing beans. A diffusion model was used to describe the absorption of water by the soybeans. Diffusivity was found to be dependent upon the water content in beans.

Oilseeds and legumes, which are rich in protein, are an important staple to people in many parts of the world. These crops are generally harvested and stored in dry forms. They may be processed directly for their oils and meals or, more often than not, they may be hydrated first and then processed into various types of foods and beverages for direct human consumption. Various workers have reported on the effects of hydration on the cooking time, appearance, and palatability of various dry beans, and they generally agreed that hydration is one of the most important factors in producing good-quality products (Jackson and Varriano-Marston 1981, Kilgore and Sistrunk 1981, Kon 1979, Molina et al 1975, Quast and daSilva 1977, Sefa-Dedeh et al 1978, Silva et al 1981, Wang et al 1979). Hydration of dry beans, therefore, is a subject of practical interest.

Smith and Nash (1961) studied the water absorption of U.S. and Japanese soybeans. They reported that the principal controlling factor in absorption of water is the seed coat. They also found that the rate of water absorption of sound whole beans is influenced by the initial moisture content in the beans. Shull (1920) showed that the water-intake curve of xanthium seeds is complex but can be represented by logarithmic equations. He further reported that, although temperature affects the rate of water intake, it does not follow the theory of Brown and Worley (1912), which states that the rate of intake is an exponential function of temperature. Leopold (1980), however, in studying imbibition and leakage of soybean cotyledons, found that the effect of temperature on the rate of water uptake during the early stage of imbibition can be described by an Arrhenius plot.

Powers (1959) reported that the rate of water imbibition of black-eyed peas and pinto beans was affected by the pH of the soaking solution, but he did not specify how the rate was influenced. Snyder (1936) observed that, for Great Northern beans, imbibition was slower in weak acid solution. The rate of water imbibition was also found to be conversely related to the pectic content of dry beans and peas (Hamad and Powers 1965). Effects of other compositional variations and processing variables on the rate of water uptake in beans, such as solute concentration of the soaking solution, had not been clearly established previously.

From a processing and engineering point of view, one is interested not only in knowing how fast the absorption of water can be accomplished, but how it will be affected by processing variables, and how one can predict the soaking time under given conditions. Quantitative analysis of water absorption had been performed for wheat, corn, and sorghum (Becker 1960, Chung et al 1961, Fan et al 1962). The suitability of applying those models to describe the absorption in legumes remains to be determined.

The objectives of this study, thus, were to study the effects of processing variables on the rate of water absorption in legumes and to develop a means to quantitatively describe and predict water absorption in legumes.

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MATERIALS AND METHODS

Beans

Because they were readily available, soybeans were used throughout this experiment. Amsoy 71 cultivar, produced as certified seed from the 1974 crop, was used. For correlation work, soybeans with various protein contents were supplied by Walter Fehr of the agronomy department at Iowa State University.

Water Uptake

Water uptake data were obtained by placing 10 g of soybeans, after equilibration to the desired temperature, in a strainer, and immersing into a temperature-controlled, deionized water bath. After each preset time period, beans were removed from water, superficially dried with facial tissues, and weighed. The weight gain was then calculated as the difference between the measured weight at a given time and the original weight.

Soaking Solutions

To study the effect of salt on soaking, sodium bicarbonate solutions of 0.25, 0.5, 1, and 5% concentrations were used.

Density

Average density of each variety was calculated by dividing the average weight by the average volume. Average weight of each soybean variety was determined by weighing approximately 10 g of beans and dividing the weight by the number of beans. Average volume was determined based on the average diameter, which was the arithmetic mean of the longest and shortest dimensions of the beans. Beans were assumed to be spherical.

Protein Content

Protein content of soybeans was determined by the micro-Kjeldahl method (AACC 1976).

RESULTS AND DISCUSSION

Figure 1 summarizes the results of absorption measurements at various temperatures. The weight gains are expressed as a fraction of total amount of water absorbed at time t, M_t/M_∞. Temperature drastically affected the water uptake. At 20°C, the beans took about 10.5 hr to reach 90% of the total absorption; at 30°C this same level of absorption took approximately 6 hr; at 50°C it took only 2.5 hr. At the lowest temperature (20°C), a rapid initial water uptake was observed. This indicated a different absorption mechanism for this period as compared to that for the rest of the curve. This rapid initial uptake was probably due to the filling of capillaries on the surface of seed coats and at the hilums. The phenomenon became less obvious at higher temperatures, due largely to the increased diffusion rate at these temperatures.

Salts are often added to the soaking water to induce certain features in the products. For instance, sodium bicarbonate is used to reduce cooking time of beans (Rockland and Metzler 1967), and ethylenediamine tetraacetic acid and citrate are used to aid in the retention of color and flavor (Junek et al 1980, Luh et al 1975). Bicarbonate is also used in the Illinois Process for making soy milk. The effect of this additive on the rate of water absorption of soybeans is depicted in Fig. 2. Bicarbonate concentration up to 0.5% did not cause significant changes in the rate of water absorption from that of deionized water. At 1% concentration (pH 8.8), a slightly lower absorption rate was observed, and at 5% concentration (pH 9.5), this slower water-uptake rate was even more pronounced. This observation did not agree with results reported by Snyder (1936), which showed that lower pH slows water uptake. Because soy protein is quite soluble between pH 7 and 9, a faster rate of water uptake rather than a slower one can be expected at this range. Other factors must have contributed toward the slower rate observed. These factors might include the higher viscosities and lower water activities associated with the more concentrated bicarbonate solutions.

Studies on the rate of water penetration into wheat kernels have indicated that high protein content, compact endosperm structure, and greater kernel hardness hinder the rate of absorption (Stenvert and Kingswood 1976, 1977). Whether these or other physical factors of soybean affect the rate of water absorption is an interesting question. An experiment was thus designed to correlate the total water absorption and absorption rate with the protein content, size, and density of the soybeans. Total absorbed water ranged from 120 to 140% of the original weight of the beans, depending on variety. Figure 3 shows that no correlation between total absorption and protein content was observed. Likewise, similar plots of total absorption vs soybean size and density did not result in any meaningful correlations. A linear correlation between absorption rate and kernel size is depicted in Fig. 4. Rate of absorption was expressed in terms of fraction of total water absorbed after 3 hr of soaking. A significant correlation was found at $P = 0.10$, with the correlation coefficient being −0.53. The negative correlation between absorption rate and kernel size is reasonable because smaller kernel size tends to provide a larger surface area per unit mass for mass transfer. Figure 5 shows the linear correlation between the rate of absorption and bean density ($r = 0.59$). This correlation was significant at $P = 0.05$. Higher density generally was associated with smaller kernel size. Because smaller bean kernels provide more surface area per unit mass for transfer, the correlation between the rate of absorption and density becomes understandable. No correlation was found between the rate of absorption and the protein content of soybean.

Because the color of the seed coat has also been implicated in reducing the water absorption of beans (Saio 1976, Smith and Nash 1961), a separate study, involving the water uptake of brown (T125

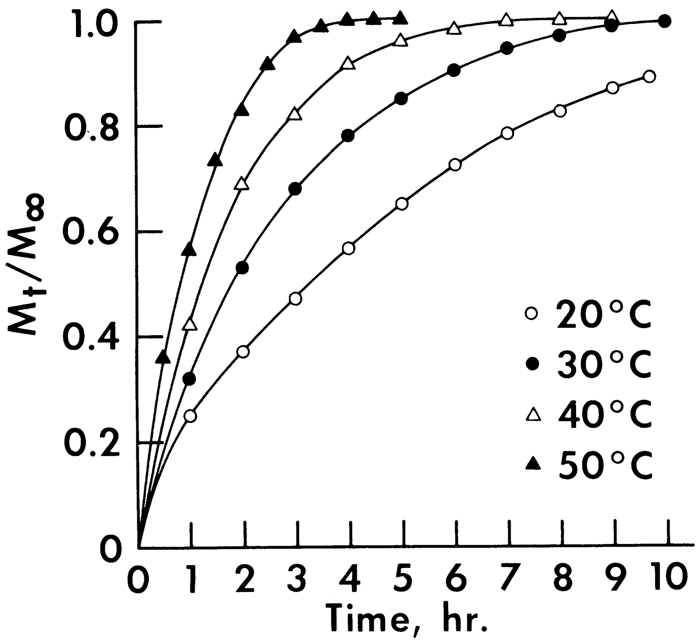

Fig. 1. Influence of temperature on the water uptake of soybean.

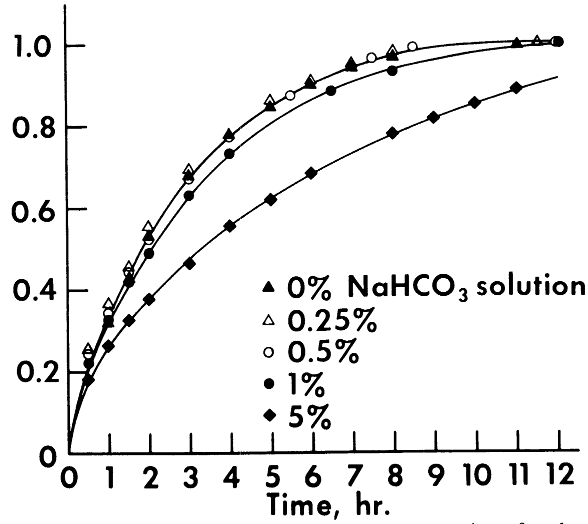

Fig. 2. Effect of sodium biocarbonate on the water absorption of soybean.

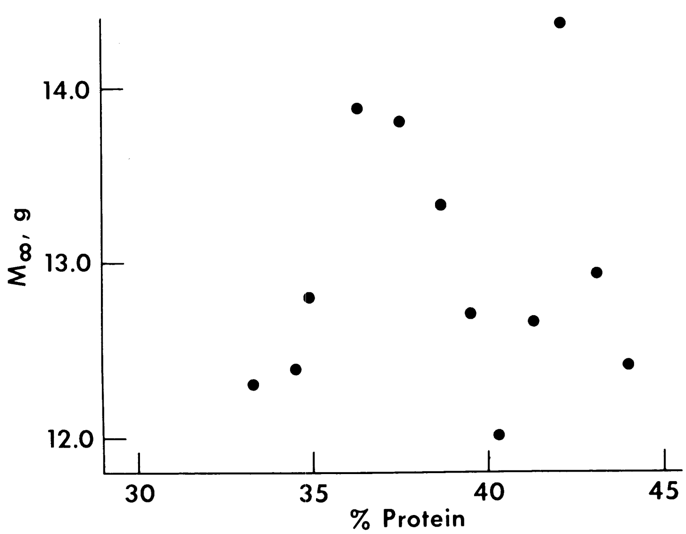

Fig. 3. Relationship between total water absorption and protein content of soybean.

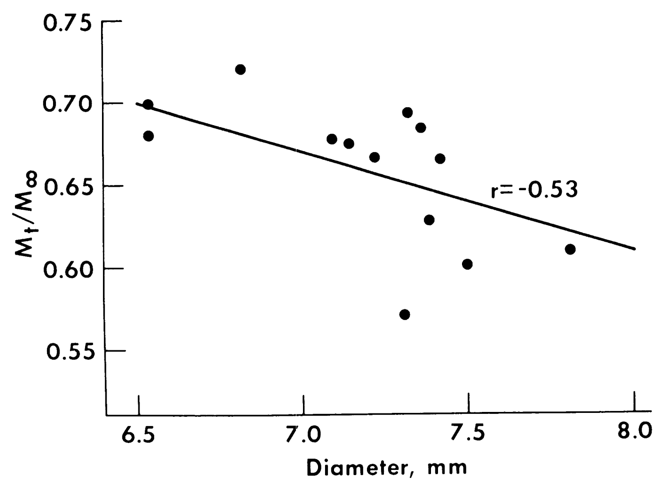

Fig. 4. Linear correlation between fraction of water absorbed after 3 hr of soaking and the diameter of soybean.

cone mot.) and black (PI82.278, PI291.320A, T143, Kingwa) soybean varieties, was initiated. Four of the black varieties (PI82.278, PI291.320A, PI424001, Kingwa) exhibited the hardshell phenomenon—low water imbibition after 16 hr of soaking (Fig. 6). This is of particular interest, because soybeans are not commonly known to have hardshell problems. However, Arechavaleta-Medina and Snyder (1981) were able to isolate a small number of hardshell beans from Amsoy 71 (a nonhardshell variety), and they reported that presoaking with methanol or ethanol alleviated the hardshell problem.

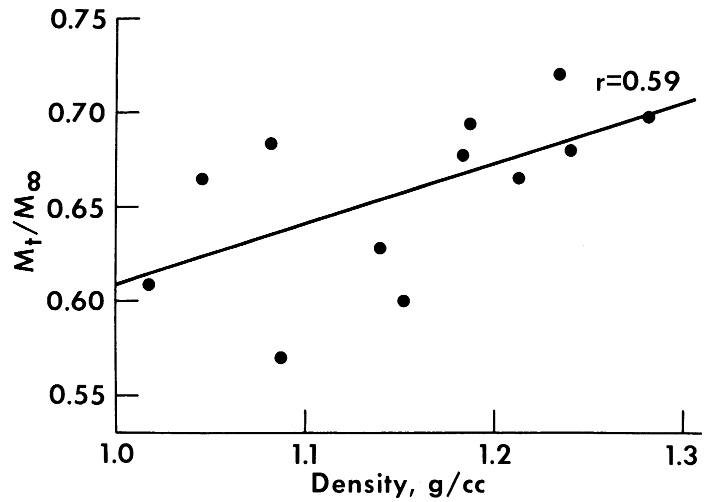

Fig. 5. Linear correlation between fraction of water absorbed after 3 hr of soaking and the density of soybean.

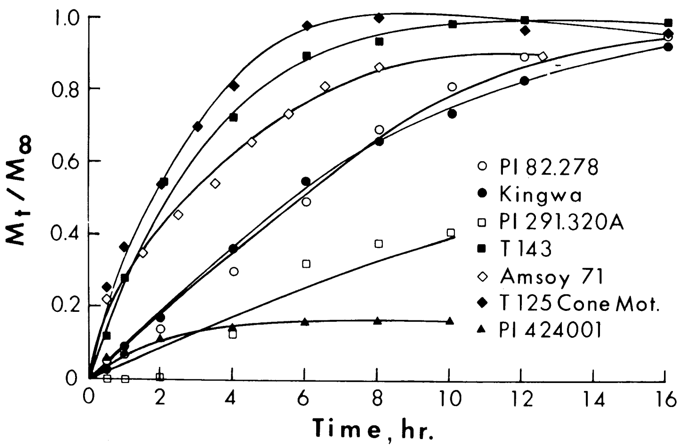

Fig. 6. Water absorption curves showing some soybeans with hardshell condition.

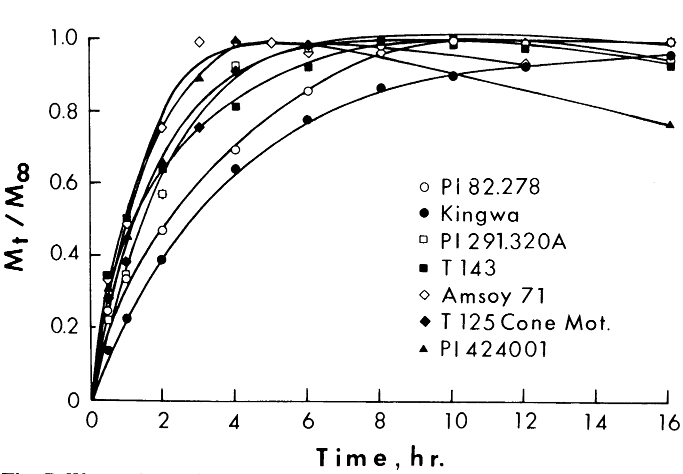

Fig. 7. Water absorption curves of soybeans treated with methanol.

All the bean varieties were treated with methanol for 24 hr, air-dried at room temperature, and then tested for their water-absorption ability. We found that the rate of water uptake increased for all varieties and that the hardshell condition no longer existed (Fig. 7). The hardshell condition appeared to be due mainly to the impermeability of the seed coat; methanol-soluble substances on or in the seed coat and hilum were responsible for this phenomenon. Further work is in progress and will be reported subsequently.

A major objective of this study was to develop a means of predicting water uptake during soaking. This can be approached by the application of Fick's law of diffusion. If soybeans are assumed to be spherical bodies, the diffusion equation can be expressed as (Crank 1975):

$$\frac{\partial C}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 D \frac{\partial C}{\partial r}\right), \quad (1)$$

where C = concentration of moisture, r = radial distance, t = time, and D = diffusion coefficient. By making appropriate assumptions, a solution to this differential equation can be obtained analytically or numerically.

One of the most widely known analytical solutions was developed by making the following assumptions (Crank 1975): the diffusion coefficient, D, is constant; effect of volume change is negligible; surface concentration reached that of saturation instantaneously upon immersion in water; and water concentration is evenly distributed before immersion. The result, in terms of fraction of total absorption, M_t/M_∞, is then expressed as

$$\frac{M_t}{M_\infty} = 1 - \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp(-Dn^2\pi^2 t/R^2) \quad (2)$$

where R = average radius of the beans. Thus, if D and R are known, the fraction of absorption at any time, t, can be determined.

Applicability of such an equation in describing the water uptake in beans must first be verified. To do so, we first assume that equation (2) is valid, and by substituting experimentally determined M_t/M_∞, t, and R values, we can calculate a diffusion coefficient, D. This estimated D is then utilized in the equation to simulate M_t/M_∞ by varying time, t. If equation (2) were truly descriptive of the absorption, the simulated curve should closely duplicate the experimentally measured curve.

From data collected at 30°C, we found that the beans must be

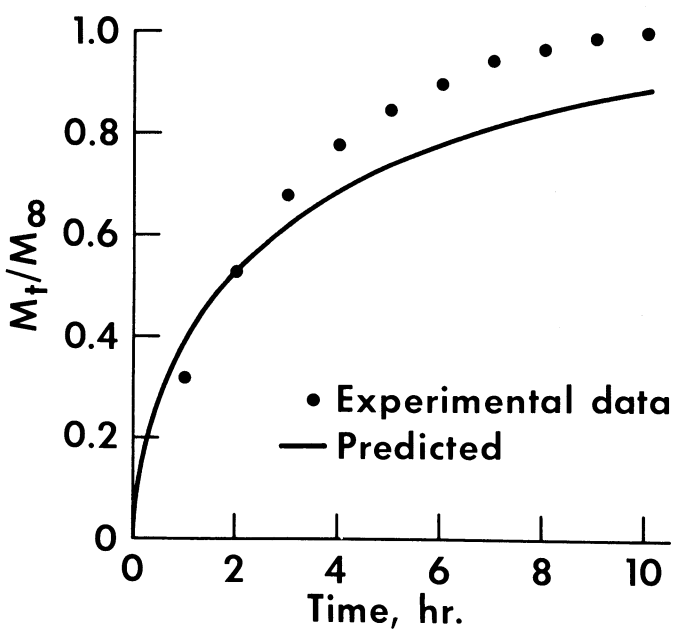

Fig. 8. Comparison of experimental absorption curve of Amsoy 71 cultivar with that predicted by equation (2) at 30°C.

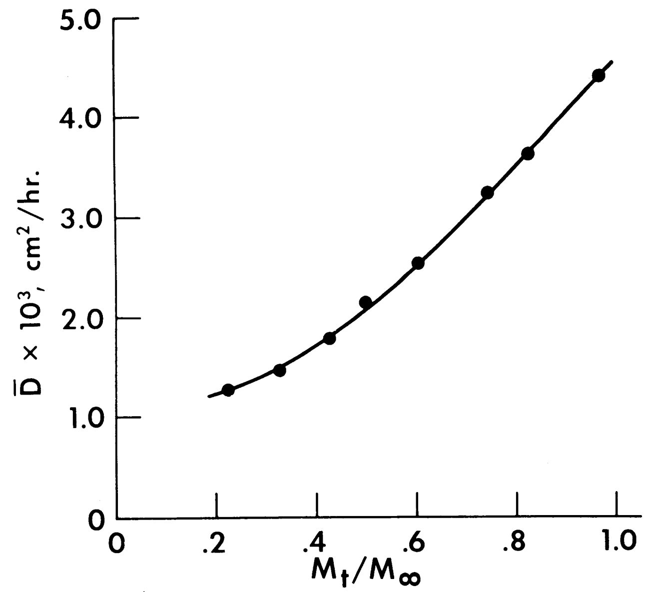

Fig. 9. Values of diffusion coefficient calculated by using data from various points on the 30°C absorption curve of Fig. 1.

soaked for 1.8 hr to reach an uptake level of 50% ($M_t/M_\infty = 0.5$). These values, as well as the measured R value, were substituted into equation (2), and the diffusion coefficient was determined to be 6.03×10^{-7} cm^2/sec. This figure compared favorably with that reported previously.[4] When this calculated value was used in equation (2) to simulate M_t/M_∞ at various t values, we found that the result of simulation did not fit the absorption curve very well (Fig. 8). Equation (2), thus, is not descriptive of the actual absorption. Evidently, some of the assumptions made during the derivation of the solution were not appropriate. The real volume of the beans increased during absorption, but this does not affect the adequacy of the model, because the frame of reference is fixed with respect to the moisture-free substances of the bean (Crank 1975). One of the assumptions, which we believe most likely contributed to the inadequacy of the model, is that of constant diffusion coefficient. If the diffusion coefficient were constant in this system, the D value calculated by using any point on the absorption curve should give a similar result. Figure 9 shows that this was not the case; the diffusion coefficient was strongly dependent upon the moisture content of the system. The figure also indicates that the dependence of D on moisture content may be exponential in nature.

CONCLUSIONS

The rate of water absorption by soybeans was highly dependent upon the process parameters such as temperature and solute concentration.

The rate of water absorption by soybeans varied with variety but did not correlate with protein content. It did correlate with the size and density of the beans studied, even though the correlations were relatively low.

Pretreatment of the soybeans with methanol improved the rate of water uptake and eliminated hardshell conditions.

Diffusion of water in soybeans was quite unlike those in cereal grains in that the diffusion coefficient was not constant. A diffusion model with a concentration-dependent diffusion coefficient is needed to accurately describe the water uptake of beans.

[4] K. Haghighi and L. J. Segerlind. 1978. Computer simulation of the stress cracking of soybeans. Paper No. 78-3560, presented at the ASAE meeting, Chicago, IL, 1978.

ACKNOWLEDGMENTS

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