Study of softening and/or hardening of beans, and controlling the hardness of beans during cooking

Abstract

In general, mature dry legumes are soaked to allow water absorption before cooking or processing. The main purposes of soaking are to shorten the length of the subsequent heating time and to achieve evenly softened bean tissue. The water absorption rate of dried beans depends on the soaking temperature. Soaking at a temperature higher than room temperature facilitates water absorption. The rate of softening is affected not only by the water temperature and soaking time, but also by additive substances such as metal ions. Dry legumes are an excellent preservation, however, storage at high temperatures and high humidity can lead to a hardening phenomenon in which the beans soften less easily during cooking. Therefore, the cooking time of dried beans depends on the storage conditions and as well as the soaking conditions. The softening process during the cooking of beans is complex, and both the water absorption and the heating conditions are thought to affect the hardness of dry beans during cooking. Nevertheless, no previous studies have focused on the continuous softening behavior of dry beans to reach a degree of softness suitable for eating by simultaneously analyzing the different reactions of "water absorption" and "softening" during cooking.

Here, I aimed to understand the distinct phenomena of “softening due to water absorption" and "softening due to heating" during cooking by analyzing each process kinetically. Furthermore, I aimed to predict the precise cooking time from dry beans to an optimal edible state by determining the rate constants from a wide temperature range and by calculating complex changes in hardness during cooking from a first-order rate equation. As samples, I used soybeans and red kidney beans, which differ in their chemical composition. This allowed me to focus on the relationships between their characteristics and their softening behavior.

First, I focused on the hardening phenomenon related to storage and/or soaking by analyzing the composition of dried stored beans and by observing their tissues in detail. These analyses suggested that changes occurring in tissues during storage, such as protein degeneration, proceed further during preliminary soaking, and this greatly suppresses softening during heating.

Next, I conducted a kinetic analysis of the softening behavior of dry beans soaked and then heated at 10–99.5°C or heated without preliminarily soaking. I used a first-order rate equation to determine quantitatively "softening due to water absorption" and "softening

due to heating". Based on the slope of the line from a first-order reaction plot, softening of dry beans to reach an optimal edible state could be separated into the two reactions of “softening due to water absorption” and “hardening/softening due to heating.” The precise cooking time from dry beans to the optimal edible state was predicted by determining rate constants.

Next, the beans were soaked in various salt solutions containing monovalent and divalent metal ions (NaCl, KCl, $CaCl_2$, $MgCl_2$), and the softening susceptibility during subsequent heating was compared with the rate constant. The promoting effect of NaCl on softening was during the "softening by heating" stage, regardless of whether the beans were pre-soaked or not. The inhibitory effect of $CaCl_2$ on softening was greater in red kidney beans than in soybeans. To explore the influence of endogenous divalent metal ions on hardness after heating, the beans were also heated with EDTA and EGTA. These analyses suggested that factors other than metal ions strongly affect the hardness that develops during storage.

I proposed an "intermittent heating" cooking method for beans, which uses residual heat during cooking. This cooking method is simple and saves energy compared with the conventional cooking method. The cooking time using the intermittent heating method was predicted using the softening rate constant, and agreed with the measured value, which validated the prediction method. The actual heating time by intermittent heating was approximately 20 min for soybeans and 10 min for red kidney beans, much shorter than the heating times in the conventional cooking method.

Last, the effects of storage and soaking on the cooking times of various beans other than soybean and red kidney bean were examined by comparing the softening rate constants. All the beans that were soaked after storage at high temperature and high humidity showed remarkably suppressed softening during subsequent heating and a prolonged heating time. From this result, I concluded that it is desirable to cook stored beans without preliminary soaking.

By combining several equations representing the different processes, I constructed a softening model that included "softening by water absorption" and "softening by heating" in the softening process during the cooking of dried beans. This model was applied to determine the softening rate constant, the effect of storage, and the influence of metal ions on cooking for various beans, allowing a quantitative comparison of different beans. There is a widely held belief that in the normal cooking of dried beans, the heating time will be shorter if the beans are soaked first. However, for beans stored at high temperature and high humidity, a soaking treatment exacerbates hardening and suppresses softening by heating. The softening model developed in this study can be used to predict cooking times, which provides important information for food processing. Analyses using the model will be useful for controlling hardness and saving energy during the cooking of dried beans.