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PHYSICAL AND CHEMICAL CHANGES DURING
PREPARATION AND COOKING OF DRY EDIBLE BEANS

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PHYSICAL AND CHEMICAL CHANGES DURING PREPARATION AND COOKING OF DRY EDIBLE BEANS

By

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ABSTRACT

PHYSICAL AND CHEMICAL CHANGES DURING
PREPARATION AND COOKING OF DRY EDIBLE BEANS

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The effects of soaking and cooking treatments as well as cooking temperature on physical and chemical characteristics of navy and kidney beans were investigated in two studies.

Study I evaluated soaking methods (hot soak, two minutes boiled and one hour held; cold soak, 2 to 16 hours at room temperature) and cooking at 190 $^{\circ}$F (87.8 $^{\circ}$C). Hot-soaking resulted in greater chemical changes than cold-soaking. Hot-soaked and cooked beans were generally softer than corresponding cold-soaked beans. Beans became softer as the cook time increased. Greater losses of solids, ash, minerals, and sugars occurred during cooking than during soaking. Protein contents did not show significant changes.

Study II evaluated four cooking temperatures 181.3 $^{\circ}$F, 190.7 $^{\circ}$F, 200.0 $^{\circ}$F, and 207.5 $^{\circ}$F (82.9 $^{\circ}$C, 88.1 $^{\circ}$C, 93.3 $^{\circ}$C, and 97.5 $^{\circ}$C). The effects of soak time and cook time were also considered. Elevated temperatures as well as prolonged soaking and cooking produced softer beans and a greater loss of solids from beans into the cook water.

To Daddy, Mommy, Grandmas, Uncle, On,
and Dhanes

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INTRODUCTION

The food legumes, of which dry edible beans (*Phaseolus vulgaris* L.) are an example, are important sources of essential protein, calorie, vitamins, and minerals. They are foods of choice worldwide and are a major source of protein in diets of people in developing countries and vegetarians who eat primarily food from cereal and root crops.

Dry edible beans may be prepared in several ways. In households, they are cooked, fried, or baked to be used in soups, eaten as a vegetable, or combined with other protein foods to make a main dish. Commercially, they are procesed in cans to produce a number of bean-based foods. However, several problems are encountered in bean utilization which include long soaking and cooking time necessary to adequately soften the beans, loss of valuable nutrients during bean preparation, flatulence, and antinutritional factors. Many studies have been devoted to investigating factors affecting cooking quality of beans in the attempt to reduce the preparation time. Researchers have also tried to eliminate flatus-causing components and antinutritional factors from beans.

This study was undertaken to evaluate the physical and chemical changes occurring in dry edible beans during cooking preparation. The experiment was divided into two studies. In Study I, two soaking methods (hot soak, two minutes boiled and one hour held; cold soak, 2 to 16 hours at room temperature) were examined. Soaked beans were then cooked separately in a blancher at 190 ^{o}F (87.8 ^{o}C). In the second part, only cold-soaking was applied and all bean samples were cooked together in a steam kettle at 190 ^{o}F (87.8 ^{o}C). Both physical and chemical changes in beans were evaluated in Study I.

The effect of cooking temperature was examined in Study II, in which beans were cold-soaked and cooked at four different temperatures, 181.3 ^{o}F, 190.7 ^{o}F, 200.0 ^{o}F, and 207.5 ^{o}F (82.9 ^{o}C, 88.1 ^{o}C, 93.3 ^{o}C, and 97.5 ^{o}C). Only the physical changes in beans were investigated in this study.

REVIEW OF LITERATURE

Food legumes belong to the genus *Phaseolus* and include such beans as common, kidney, field, garden, or haricot The majority of legumes grown in the United States belong to *Phaseolus vulgaris* species which include Great Northern, pinto, black, small white or navy, red, and yellow eye beans (Deschamps, 1958).

Dry Bean Composition

Seed Composition

Seed Coat. The capacity of beans to imbibe water is determined by the structure and composition of seed coat, as well as the environmental conditions during harvesting and storage. The seed coat, which constitutes 7.7% of dry matter of mature beans (Powrie et al., 1960), is found to be the primary barrier for water to pass into the bean. Ott and Ball (1943) studied the relation between cell wall pectic substances, which are the polyuronide and "true pentosans" and constitute about 40% of the dry weight, and water retention of the seed coats. Reeve (1946) studied the relationship between histological characteristics and texture in the seed coats of peas and stated that during maturation there is the formation of a highly specialized, epidermal structure composed of macrosclerid cells as well as development of a pentosan-cellulosic compound, which causes remarkable thickening and hardness of the cell wall. Protein content of the seed coat is reported to be 5.07% of the seed coat dry weight (Ott and Ball, 1943), which is in agreement with the protein content of 4.8% as found by Powrie et al. (1960). Snyder (1936) also reported the protein content in seed coats of "soft" and "hard" Michigan pea beans to be 5.6 and 6.8% respectively. Snyder (1936) mentioned that the amount of protein in the seed coats of beans may be related to hardshell character, but Ott and Ball (1943) did not find any correlation between water retention and protein content.

Cotyledon. Cotyledons are the most important components of the bean seed with respect to weight and volume as well as for contributing to texture and nutritive value of processed beans. According to Powrie et al. (1960), the cotyledons constitute 90.5% of dry bean matter. Epidermal cells are the outermost layer of the cotyledon. The cell contents are microscopically granular and this granular structure is presumed to be of proteinaceous nature. Starch granules are not found in this layer. The next inner layer of the cotyledon is the hypodermis. The cells of this layer are elliptical in shape and are larger than epidermal cells. The cell contents are granular and composed of protein but no starch. The remaining tissues of cotyledons are parenchyma cells and vascular bundles. Starch granules are found to be imbedded in a protein matrix of each parenchyma cell. The secondary walls of parenchyma cells are observed to be very thick as compared to the primary wall and contain numerous small cavities and pits which facilitate the migration of water during the soaking period. However, Snyder (1936) noted that the major areas through which water passes into beans are the micropyle and germinal areas.

Protein Content

Dry beans are good sources of protein. Many researchers (Watt and Merrill, 1963; Meiners el al., 1976a; Tobin and Carpenter, 1978; and Koehler and Burke, 1981) have reported the protein content of common beans (white beans, navy beans, pink beans, and red kidney beans) to be in the range of 21% to 25.5% on dry weight basis. However, Koehler and Burke (1981) found the protein content of large dark red kidney beans to be as high as 32.8%. Several studies have been done on the loss of protein from beans during cooking. Meiners et al. (1976a) reported 50% to 60% protein loss after beans were cooked in excess water until tender, while Koehler and Burke (1981) reported only a 3% to 10% reduction. Haytowitz and Matthews (1983) showed that during cooking, protein is not destroyed but small amounts may leach into the cooking water, and that protein retention is 93% to 100%.

Ash and Minerals

According to the literature, the total ash content of raw beans is in the range of 2.9% to 4.9% on dry weight basis (Watt and Merrill, 1963; Fordham et al., 1975; Meiners et al., 1976a; Tobin and Carpenter, 1978; and Koehler and Burke, 1981). Considerable decrease of the ash content after cooking has been observed by many researchers due to the leaching of minerals into cooking water. Watt and Merrill (1963) reported a 10% decrease of the ash content, whereas Meiners et al. (1976a) and Koehler and Burke (1981) noted the losses of 55% to 70% and 20% respectively. The reported percentages of decreases vary in a wide range, possibly due to different methods of cooking. The ranges of specific mineral contents in mature, raw beans of *Phaseolus vulgaris*, which are reported by several researchers, are summarized in Table 1. Great variations are found in certain minerals because of the differences in the growing location, soil composition and varieties of beans. Atomic absorption spectrometry is used by many researchers to determine most minerals, except for Walker and Hymowitz (1972) who used emission spectroscopy in their analyses. Augustin et al. (1981) employed flame emission spectrometry to measure sodium and potassium. Phosphorus is determined colorimetrically by Meiners et al. (1976b) and Augustin et al. (1981). As seen in Table 1, beans contain relatively high

Table 1. Contents of selected minerals of raw, mature *Phaseolus vulgaris* classes.[1]

Reference	Ca	Cu	Fe	Mg	Mn	Na	P	Zn	K
Augustin et al. (1981)[2]	700-2100	5-14	33-80	1600-2300	10-20	40-210	3800-5700	19-65	13200-17800
Fordham et al. (1975)[3]	1030-1666	-	13-83	1620-2222	173-232	-	3650-5090	-	10850-15260
Koehler and Burke (1981)[4]	1380-2020	-	78-93	-	-	-	-	38-40	15570-17120
Meiners et al. (1976b)[5]	595-1812	7-8	53-75	1230-1783	10-15	17-36	3740-5100	21-25	8208-13007
Walker and Hymowitz (1972)[6]	1100-2600	8-12	69-135	1300-1800	6-20	-	2800-5000	17-29	11200-19400
Watt and Merrill (1963)[7]	1110-1440	-	64-78	-	-	100-190	4060-4570	-	9840-11960

1. All values are reported in parts per million.
2. Black, cranberry, Great Northern, navy, red kidney, pink, pinto, small red, and small white beans were analyzed.
3. Great Northern, navy, red kidney, and pinto beans were analyzed.
4. Small red, pink, pinto, and red kidney beans were analyzed.
5. Navy, Great Northern, pinto, and red kidney beans were analyzed.
6. Navy, black, white, and red kidney beans were analyzed.
7. White, red, pinto, calico, and red Mexican beans were analyzed.

amounts of calcium, iron, magnesium, phosphorus, and potassium. Mineral contents reported by all researchers are found to be in good agreement except for manganese and sodium. These variations may be due to the varietal differences, cooking methods, or methods of analysis.

Retention of various minerals during cooking of beans has been studied (Table 2). Meiners et al. (1976b) cooked until tender ten varieties of legumes in an excess amount of water and determined the contents of nine minerals in both raw and cooked samples. It was found that minerals in cooked legumes were about one-third to one-half of the values in raw legumes, and cooking water contained measurable amounts of all minerals, with relatively high amounts of magnesium, phosphorus, and potassium. Augustin et al. (1981) cooked beans of nine different commercial Phaseolus vulgaris classes in adjusted amounts of water such that no more than 50 ml of cooking water remained after cooking and with the experimental procedures designed to minimize mineral contamination from outside sources. Mineral values in cooked samples were higher than in the corresponding uncooked samples. Retention of minerals during cooking was in the range of 80% to 90% with the exception of 38.5% sodium retention and total calcium retention. Koehler and Burke (1981) looked at the calcium, iron, potassium, and zinc contents in raw and freeze-dried (following cooking) beans of seven cultivars and found close agreement in mineral retention with Augustin et al. (1981).

Table 2. Contents of selected minerals of raw and cooked *Phaseolus vulgaris* classes.[1]

		Reference		
		Augustin et al. (1981)	Koehler and Burke (1981)	Meiners et al. (1976b)
Calcium	Raw	1500	1758	1220
	Cooked	1500	1743	517
Copper	Raw	9.5	-	7.5
	Cooked	7.1	-	2.8
Iron	Raw	58.4	84.0	66.8
	Cooked	58.4	72.7	30.7
Magnesium	Raw	2000	-	1587
	Cooked	1700	-	508
Manganese	Raw	14	-	14
	Cooked	15	-	6
Sodium	Raw	103	-	26
	Cooked	34	-	22
Phosphorus	Raw	4600	-	4490
	Cooked	4300	-	1550
Zinc	Raw	32	39	23
	Cooked	30	33	11
Potassium	Raw	15400	16300	10913
	Cooked	12900	10470	3898

1. All values are mean values and reported in parts per million.

Variabilities between and within classes of beans as well as the effect of growing locations have been investigated (Table 1). According to Augustin et al. (1981), calcium variabilities are high both between and within classes, although growing area has little effect. The data are in close agreement with those of Watt and Merrill (1963), Walker and Hymowitz (1972), and Meiners et al. (1976b). The variability of copper and iron are about the same between and within classes; the effect of growing area on iron content is noticeable only in navy beans. Copper levels are similar to those reported by Walker and Hymowitz (1972), Meiners et al. (1976b), and Rockland et al. (1979), whereas iron levels are lower than those reported by Walker and Hymowitz (1972), Meiners et al. (1976b), and Koehler and Burke (1981), but are in fair agreement with those of Fordham et al. (1975). Little variability and small location effect are found for magnesium and the data agree with the values from Watt and Merrill (1963), Fordham et al. (1975), and Meiners et al.(1976b). The variability of manganese is found to be high by both Fordham et al. (1975) and Augustin et al. (1981). The range of manganese appears to be wide which is presumed to result from different growing locations. Similarly, sodium variabilities between and within classes are very high. Augustin et al. (1981) suggested that this variability may be associated with the analysis method as a result of very low sodium concentration on beans. The data agree well with those of Watt and

Merrill (1963) but are dramatically lower than those of Meiners et al. (1976b). Both Meiners et al. (1976b) and Augustin et al. (1981) noted low variability of phosphorus and remarkable effect of growing area. All data in literature are in good agreement. Whereas Meiners et al. (1976b) observed the least variability for the zinc content, Augustin et al. (1981) found the overall variability of this element to be high. Potassium shows low variability between and within classes grown in the same location, but those grown in different areas show high variability within classes. All data from literature are reasonably in good agreement except the high potassium content observed by Koehler and Burke (1981). It may be presumed that variation in all minerals is due to differences in soil composition, growing location, and the method of analysis.

Relationship between mineral contents and proximate composition in twenty-eight varieties of Phaseolus vulgaris is studied by Walker and Hymowitz (1972). Significant negative correlations are found between fat content and contents of calcium, iron, and zinc. Significant correlation coefficients are also noted between raffinose content and contents of phosphorus and potassium. It is concluded that the relationships found are not directly proportional since the correlation coefficients are all less than 0.60, although they are statistically significant.

Carbohydrates

The total carbohydrates of dry legumes range from 24.0% in winged beans to 68.0% in cowpeas (Reddy et al., 1984). Starch constitutes the most abundant legume carbohydrate ranging between 24.0% to 56.5%. Other carbohydrates include monosaccharides, oligosaccharides, and polysaccharides. Total sugars (monosaccharides and oligosaccharides) represent only a small percentage of the total carbohydrates. Among the sugars, oligosaccharides of the raffinose family (raffinose, stachyose, verbascose, and ajugose) predominate in most legumes and account for 31.1% to 76.0% of the total sugars (Akpapunam and Markakis, 1979; Kon, 1979; Rockland et al., 1979; Ekpenjong and Borchers, 1980; Reddy and Salunkhe, 1980; Fleming, 1981; and Sathe and Salunkhe, 1981). The predominance of a particular oligosaccharide is likely to depend on the legume type. Stachyose represents the major oligosaccharide in most varieties of Phaseolus vulgaris (smooth and wrinkled peas, Great Northern beans, California Small White beans, red kidney beans, navy beans, pinto beans, pink beans, black eye beans, and cowpeas). Raffinose is present in moderate to low amounts in most legumes.

Legumes also contain appreciable amounts of crude fiber (1.2% to 13.5%, Reddy et al., 1984), with cellulose being the major component, followed by hemicellulose, lignin, pectic and cutin substances.

Oligosaccharides of the raffinose family (raffinose, stachyose, and verbascose) are reported to be, at least in part, responsible for the flatulence problem in humans and animals. Several studies have been done on flatus and flatus formation (Steggerda, 1968; Rockland et al., 1969; Sanchez et al., 1969; Levine, 1979; and Fleming, 1981). The sugars of the raffinose family cannot be absorbed through the intestinal wall and cannot be digested by humans because the intestinal tract does not contain the enzyme (α-1,6-galactosidase) necessary to split these oligosaccharides into simple sugars. These indigestible oligosaccharides pass through the small bowel and enter the colon where bacteria can readily utilize them as fermentation substrates and produce large amounts of carbon dioxide and hydrogen and a small quantity of methane (Levine, 1979; and Olson et al., 1981). The degree of flatulence produced is related to the level of oligosaccharides in beans. However, some studies (Fleming, 1981; Olson et al., 1975 and 1982; Wagner et al., 1976 and 1977) revealed that flatus-producing capacity of beans is not totally eliminated by removal of oligosaccharides, thus suggesting that there are other substances that contribute to flatulence. Olson et al. (1975) found that protein is not a significant cause of flatus. Reddy et al. (1984), in reviewing studies pertaining to this problem, mentioned that fiber, which is one major undigestible component in beans, may be involved in the fermentation by microorganisms and subsequent flatulence production, and that further research is needed to understand the role of fiber in this problem.

Various approaches have been studied and suggested in order to reduce the flatus-production capacity of beans. One of the possible methods is to genetically develop special varieties of beans with low levels of sugars of the raffinose family. Another method is to add antibiotics or bacteriostat to bean products in order to inhibit the activity of intestinal bacteria and subsequently eliminate flatulence-causing compounds. However, this method is not considered acceptable and may cause changes in organoleptic properties of the products (Steggerda, 1968). Substantial amounts of flatus-producing components in beans can also be eliminated by various common processes (soaking, cooking and discarding the cook water, germination, fermentation, or a combination of the aforementioned processes). Since the sugars of raffinose family are water-soluble, discarding the soak and cook waters will remove most of these sugars from beans. Ku et al. (1976) reported 33% to 59% decrease of sugars of raffinose family from soybeans when cooked in a one to ten bean to water ratio. Silva and Luh (1979) noted 90.6% and 88.1% reduction of these oligosaccharides from soaking of black eye and pink beans, respectively. Whereas Iyer et al. (1980) observed 32.8% to 51.0% reduction in Great Northern, kidney, and pinto beans after soak water is discarded. These beans are cooked at 100 ^{o}C for 90 minutes and the decrease of 70.3% to 80.2% is found when both soak and cook waters are discarded. Reddy and Salunkhe (1980) pointed out that the reduction of oligosaccharides from soaked and cooked beans is primarily due to leaching effect. A combination of various treatments can also be employed to remove oligosaccharides from beans. Recently Olson et al. (1981 and 1982) developed a boil-soak method in which beans are boiled for three to four minutes (in 1:5 to 1:10 bean to water ratios) and then allowed to stand at room temperature. These workers observed over 90% removal of sugars of raffinose family from various common beans (light red kidney, California Small White, pinto, and black eye). In addition, over 70% of oligosaccharides are depleted during germination (Reddy et al., 1984).

Bean Preparation

Soaking

During soaking, beans imbibe water which leads to softening of seed coats and thus decreases the cook time required to obtain desirable texture. The capacity of beans to absorb water depends greatly on their own physical-chemical composition and seed coat which is said to be the primary barrier to the migration of water into the bean. Snyder (1936) observed and found no beneficial effect of scarification or removal of seed coat on tenderness of beans. However, Kon et al. (1973) noted a reduction of cook time when seed coat was removed. The work by Kon et al. (1973) is supported by Varriano-Marston and de Omana (1979) who investigated the effects of accelerated storage on water absorption and cook time. However, Muneta (1964) found that the presence of a seed coat affects subjective evaluation of bean products.

Various additives in soak water have been employed by a number of researchers. Such additives include ethylene diamine tetracetic acid (EDTA), sodium bicarbonate, sodium hexametaphosphate, sodium chloride, sodium carbonate, sodium bisulfite, oxalic acid, ammonium oxalate, citric acid, malic acid, acetic acid, hydrochloric acid, sulphates and chlorides of calcium and magnesium.

Hoff and Nelson (1965) reported that EDTA has no significant effect on water imbibition of dry pea beans, nor does it affect the increase in firmness of navy, pinto and kidney beans as shown by Junek et al. (1980). However, EDTA is found to help preventing discoloration of canned dry lima beans (Luh et al., 1975) by its chelating action to immobilize metal ions. EDTA also reduces the chemical oxygen demand (COD) in wastewater by its chelating action with divalent metals in soak water (Neely and Sistrunk, 1979).

Addition of sodium bicarbonate tends to soften the seed coats of beans and can be used effectively in amounts which are not deleterious to appearance or flavor (Snyder, 1936). The same conclusion was made by Dawson et al.(1952) who found a 42% increase in water absorption of beans by adding $NaHCO_3$. Sodium salt solutions were used by Rockland and Metzler (1967) in quick-cooking of dry beans in which the beans were soaked in a solution containing NaCl, $Na_5P_3O_{10}$, $NaHCO_3$ and Na_2CO_3 and the resulting product was cooked in less than fifteen minutes. Work done by Varriano-Marston and de Omana (1979) also showed that black beans soaked in $Na_5P_3O_{10}$ and Na_2CO_3 solutions absorbed the most water. They suggested that the beneficial effect of adding sodium salts was a solubilization of pectic substances during soaking and cooking due to ion-exchange in which the sodium ions replace divalent ions.

Snyder (1936) reported that addition of hydrochloric acid and acetic acid of various concentrations tends to depress water absorption and harden the seed coats due to the presence of hydrogen ions (increased acidity), thereby reducing the rate of water imbibition. This researcher also mentioned that addition of ammonium salts of oxalic, citric and tartaric acid softens the seed coats of beans. Ammonium salts of oxalic acid are the most efficient. Nordstrom and Sistrunk (1977) observed an increase of shear press value when pinto, red kidney, and Dwarf Horticulture #4 were processed in the acidic medium, tomato sauce (pH 5.0 to 5.2). This work was supported later by Junek et al. (1980) who found that addition of citric and malic acids increases the firmness of navy beans as measured by shear force. The decrease in drained weight was observed as well. Luh et al. (1975) also noted a decrease in drained weight when higher concentration of citric acid was added. Varriano-Marston and de Omana (1979) observed an increase in acidity of soak water during the soaking process which resulted primarily from the loss of hydrogen ions from cellular components. It was proposed that starch is one of the physical-chemical barriers in water absorption and that an acidic environment leads to a decrease in starch swelling potential, thus decreasing the ability of beans to imbibe water. Lai and Varriano-Marston (1979) observed a direct positive increase in solubility with increased swelling power and noted that solubilization and starch swelling are restricted during cooking.

Phosphate solutions have also been employed in soaking by many researchers. Mattson (1946) observed the dephosphorylation of phytic acid due to inactivation of the enzyme phytase in the presence of heat. Consequently the phytic acid precipitates out calcium and magnesium ions and the tough metal-pectin cross-linked products are not formed. The use of polyphosphates by Hoff and Nelson (1965) resulted in a great increase in water imbibition, which may be due to the chelating mechanism of the polyphosphates with divalent metal ions, thus preventing the formation of tough metal cross-linked pectates. Later work by Lee (1979) showed an increase in water absorption and softness of beans when sodium hexametaphosphate (NaHMP) was added, but there was leaching of soluble solids as well. This worker also noted a decrease in drained weight when the combination of calcium ions and NaHMP was used.

Snyder (1936) looked at the effect of adding minerals to the soak water and reported that solutions of sulphates and chlorides of calcium and magnesium of 100 ppm depress water absorption and harden the seed coats. The hardness increases with corresponding increase of solution concentration. However, this researcher did not find deleterious effects on beans when chlorides of sodium and potassium were used. This was supported later by Luh et al. (1975) and Davis and Cockrell (1976) who noticed that the addition of calcium chloride to the brine resulted in firmer products, with the formation of firm calcium pectates. Both also found that the shear press values of canned lima beans increased with the increased concentrations of calcium chloride. Quenzer et al. (1978) also reported a positive correlation between shear press values and calcium content, and a negative correlation between water absorption capacity of beans and calcium content.

Cooking and Processing

Various factors that affect the cooking quality of dry beans include the composition of seed coats, storage conditions, soaking treatments, blanching treatments, and cooking conditions. A number of studies have been done in the attempt to decrease the cook time necessary to obtain a desirable and palatable product. Snyder (1936), in studying the cooking quality of Great Northern and pea beans from various states in the United States, found that differences in place of origin do not contribute marked differences in cooking quality of the beans studied, and that the size of beans had a negligible effect on cooking quality. This researcher also noted pronounced effect of storage conditions and concluded that beans should be best stored in tightly closed containers at a temperature around 45 ^{o}F. Studies by Burr et al. (1968) and Antunes and Sgarbieri (1979) revealed that as the storage temperature increased, the rate of hydration decreased and the cook time increased. Their observations also showed that cooking time decreases directly with the decrease in storage temperature and humidity. Studies on the effect of storage time have been conducted by Morris (1963 and 1964), Burr and Kon (1966), Burr et al. (1968), and Bedford (1972). Burr and Kon (1966) found that pinto beans, when subjected to prolonged storage for one year, needed 62 minutes at 121 ^{o}C to cook until tender while freshly harvested beans required only 23 minutes.

Relative humidity and bean moisture content also play important roles in the cooking ability of beans. During storage, high relative humidity and high bean moisture lead to mold growth, development of off-flavors, lipid oxidation, color darkening, and development of hardshell beans (Morris, 1963; Muneta, 1964; Burr et al., 1968; Bedford, 1972; and McCurdy et al., 1980). Gloyer (1928) reported an increase in percentage of hardshell beans with lower storage humidity, while Bourne (1967) noted that the hardshell beans tended to be smaller in size than non-hardshell beans. Kon

(1968) noted a very substantial increase in cook time for high moisture beans stored for four years. Molina et al. (1976) mentioned that the hard-to-cook phenomenon could be reduced if heat treatment was applied to beans prior to storage. He also observed the hardness of black beans stored at 25 °C and 70% relative humidity for nine months. Morris (1963) and Burr and Kon (1966) reported that storing beans at low moisture content was essential to preserve their cooking quality. An increase in cooking time was observed with high moisture stored beans (Burr et al., 1968). Pinto beans stored at 25 °C and 16% moisture required 60 minutes to cook as compared to 20 minutes for beans stored at the same temperature at 8.2% moisture. Rockland (1963) found that beans of 9.9% initial moisture content require one-fifth the cooking time of beans stored for five months at 32.2 °C with 13.3% initial moisture. However, Jackson and Varriano-Marston (1981) noted an inverse proportion between moisture content and cooking time in black beans.

Various cooking treatments have been investigated by a number of researchers. The Michigan Bean Commission developed a standard method of bean preparation, in which beans are soaked either by cold-soaking or hot-soaking. In cold-soaking, beans are soaked in six cups of cold water and two teaspoons of salt for every pound of beans. Hot-soaking is done by bringing a pound of beans and six to eight cups of water to boil, cooking for two minutes, removing the beans from the heat, and allowing to stand for one hour. After that the beans are cooked by simmering over medium-heat until tender for an approximate cooking time suggested for each particular bean type. For instance, for one cup of soaked beans, 1.5 hours are required for navy and pinto beans and two hours for black and kidney. Snyder (1936) recommended the optimum soaking temperature of 120 °F for Great Northern and pea beans in which the beans imbibe their own weight of water in five and six hours. She also added that a longer cooking time is required if soaking is done at a lower temperature. Quast and da Silva (1977) observed that by raising the cooking temperature by 10 °C for black beans, the cooking time is decreased by 3.36 fold. Kon (1979), studying the effect of soaking temperature, found that soaking beans at elevated temperatures increased the rate of water imbibition and decreased the time required for maximum water absorption. Junek et al. (1980) noted that when soaking temperature was raised from 15 °C to 35 °C, the shear peak height decreased.

A quick-cooking method was developed by Dawson et al. (1952) and Quast and da Silva (1977). Dawson et al. (1952) found that adding beans to boiling water for two minutes followed by soaking in hot water for one hour resulted in products of higher quality than those cooked by the standard method. The latter researchers found that cooking beans for nine minutes at 127 °C resulted in the same quality of products as those cooked at 98 °C for 260 minutes. However, both Dawson et al. (1952) and Quast and da Silva (1977) pointed out that a sufficient process time should be employed to ensure commercial sterility of the product. Rockland and Metzler (1967) and Rockland et al. (1979) also studied the quick-cooking method of beans. The method developed by Rockland and Metzler (1967) included loosening the seed coats by vacuum filtration in a solution containing NaCl, $Na_5P_3O_{10}$, $NaHCO_3$ and Na_2CO_3; soaking the beans in the same salt solutions; rinsing; drying; and cooking or freezing depending on their ultimate utilization. The resulting product cooked in less than fifteen minutes. Rockland et al. (1979) observed quick-cooking of winged beans by blanching in boiling water for two minutes; soaking 24 hours in soak water containing various salts; and cooking for 15 to 20 minutes in boiling water.

Effect of blanching was examined by Davis (1976), who concluded that beans absorbed more water and lost fewer solids when blanched below the boiling point of water than those blanched at the boiling point. He also found great effect of processing time on the firmness of pinto and red kidney beans and suggested that one should increase temperature rather than time when processing for the desired texture in navy beans. Brown and Kon (1970) observed a decrease of cooking time from 80 minutes to 30 minutes when seed coats were removed, thus supporting the theory that seed coat is the primary barrier to water absorption. Daoud et al. (1977) noted 5 to 8% losses of vitamin B_6 in steam-blanched beans while water-blanched beans showed 10% to 15% losses. Nordstrom and Sistrunk (1979) found that steam blanching resulted in firmer beans, but less leaching of starch and pectin, than hot water blanching. However, Davis et al. (1980) observed that steam-blanched beans were firmer than those being hot water-blanched.

MATERIALS AND METHODS

The present work consists of two separate studies. Study I evaluates physical and chemical changes of beans during cooking preparation. Study II examines the effect of cooking temperature on physical properties of beans. Navy beans (Seafarer) and red kidney beans (Montcalm) were used in both studies.

Material Preparations

Initial moisture of dry beans to be used in the experiment was measured and the fresh weight corresponding to 100 grams of bean solids was calculated. Bean samples were weighed according to the fresh weight obtained. They were then soaked and cooked according to the procedures described below.

Moisture

The initial moisture content (% by weight) of dry bean samples was measured by using the Motomco Moisture Meter (Model 919, Motomco Inc., Clark, NJ). All measurements were performed according to the manufacturer's instructions. The fresh weight of dry beans to yield the required solids was calculated as follows:

$$\% \text{ Solids at given moisture} = 100 - \%\text{Initial moisture content}$$

$$\text{Required fresh weight (g)} = \frac{\text{Solids required (g)}}{\% \text{ Solids at given moisture}} \times 100$$

Each bean sample was weighed to yield 100 grams of dry bean solids, which was the sample size used in both studies.

Soaking and Cooking

The soak water and cook water used in both studies were distilled water containing 100 ppm of calcium (see Appendix for calculation).

The following three different methods of cooking were employed in the two studies:

1. Blancher cooking at 190 $\pm$ 2 ^{o}F (87.8 $\pm$ 1.1 ^{o}C)
2. Kettle cooking at 190 $\pm$ 2 ^{o}F (87.8 $\pm$ 1.1 ^{o}C)
3. Temperature variation cooking

The first and second methods were incorporated into Study I, in which the physical and chemical changes in beans were investigated. The third cooking method was Study II, where the effect of cooking temperature was evaluated. Sample preparations for each cooking method are described in detail as follows.

Blancher Cooking. Two methods of soaking were investigated.

1. Cold soaking. Eight samples of beans were soaked in

plastic containers at room temperature for 2, 4, 6, 8, 10, 12, 14, and 16 hours respectively (1:4, bean:water).

2. Hot soaking. A sample of beans was added into boiling water (with the same bean to water ratio as above) and allowed to stand for two minutes, after which it was removed from heat and allowed to cool to room temperature for one hour.

When the desired soaking time was reached, each sample was drained on a No.8 standard sieve for two minutes. The weight gained after each soaking was measured and the hydration ratio was determined. Then the soak waters were stored frozen in plastic zip-lock bags for subsequent total solids determination. The soaked beans were weighed, dried in an air-oven dryer (Precision Scientific Co., Chicago, IL) at 80 ^{o}C for 24 hours, and reweighed to obtain the oven-dried weight. Dried beans were ground in a Cyclone Sample Mill (U.D.Y. Corporation, Fort Collins, CO) and bean flour samples were stored at room temperature in plastic zip-lock bags for chemical analyses.

The 16 hour cold-soaked and hot-soaked beans were cooked in the blancher at 190 ^{o}F (87.8 ^{o}C) for 30, 60, and 90 minutes respectively. Each soaked sample was placed into a 1000 ml flask and boiling cook water was added into each flask to yield bean to water ratio of 1:4. The flasks were covered with aluminum foil and immersed into the blancher containing water, which had been previously heated to reach the cooking temperature of 190 ^{o}F (87.8 ^{o}C). When the desired cooking time was reached, the flasks were removed from the blancher and the beans were drained on No.8 standard sieves for two minutes. The weight gained after cooking was measured and the hydration ratio was determined. Cook waters were stored frozen for further determination of total solids. Texture measurement was performed on all cooked samples. The shear residues were weighed and dried in an air-oven dryer (Precision Scientific Co., Chicago, IL) at 80 ^{o}C for 24 hours. The oven-dried weight was measured and the bean percent total solids was calculated. The dried residues were ground and stored as previously described.

Kettle Cooking. Beans were soaked at room temperature in plastic containers (1:4, bean:water). The soaking times were 0 (raw beans), 8, 12, and 16 hours. The time schedule was so arranged that the soaking processes terminated at the same time. Immediately after soaking, the beans were put into a steam kettle containing preboiled water. The bean to water ratio used for cooking was one to eight in order to prevent burning due to insufficient cook water. The beans were boiled for five minutes and the temperature was then brought down to 190 ^{o}F (87.8 ^{o}C). The cooking times applied were 30, 60, and 90 minutes respectively. When the desired cooking time was reached, bean samples for each soaking time were drawn from the kettle and the texture measurement was performed. The shear residues were dried, ground and stored as previously described.

Temperature Variation Cooking. Bean samples were soaked in the same manner as described in kettle cooking, except that the soak times were 0 (raw beans), 6, and 12 hours respectively. Each sample was placed in separate 1000 ml flasks and boiling water was added into each flask to obtain 1:4 bean to water ratio. The flasks were covered with aluminum foil and immersed into the blancher containing water, which was heated to get the nearest desired cooking temperature of 180 ^{o}F, 190 ^{o}F, 200 ^{o}F, and 210 ^{o}F (82.2 ^{o}C, 87.8 ^{o}C, 93.3 ^{o}C, and 98.9 ^{o}C) respectively. Cooking at each temperature was performed separately. The cooking times were 30, 60, and 90 minutes. When the desired cooking time was reached, bean samples of each soaking were drawn from the blancher and determination of hydration ratio and texture were conducted. The shear residues and cook waters were handled in the same manner as in Study I.

Raw navy and kidney beans were also prepared to serve as control samples in chemical analysis. They were ground in a Cyclone Sample Mill (U.D.Y. Corporation, Fort Collins, CO) and stored in plastic zip-lock bags.

Methods of Analysis

Texture

After cooking, the cooked beans were evaluated for texture using an Allo-Kramer Recording Shear Press (Model TR-1, Food Technology Corp., Reston, VA). The 3000 pound transducer and No. C-15 standard shear compression cell were used. The rate of shear compression blade travel was 0.52 cm/sec. A sample of 100 grams cooked beans was placed in the cell, evenly distributed, and sheared. The entire cell was cleaned and rinsed between each measurement. Duplicate readings were taken for each sample.

The typical Kramer shear peak is shown in Figure 1. A firm bean requires greater force to shear, as indicated by a higher peak height, than a soft bean. Certain bean varieties produce two peaks: a predominant shear peak (Type A) and a predominant compression peak (Type B) (Hosfield and Uebersax, 1980). For texture evaluation of samples in the current study, the compression peak height was recorded and the shear force (lbs/100 grams bean) was calculated as follows:

Shear force = Peak height X transducer force (3000 lbs) X instrument range (1/1 or 1/3)

Hydration Ratio

After soaking and cooking, beans were drained on No.8 standard sieves for two minutes and weighed. Hydration ratio was calculated as follows:

$$\text{Hydration Ratio} = \frac{\text{Weight after soaking/cooking (g)}}{\text{Bean fresh weight (g)}}$$

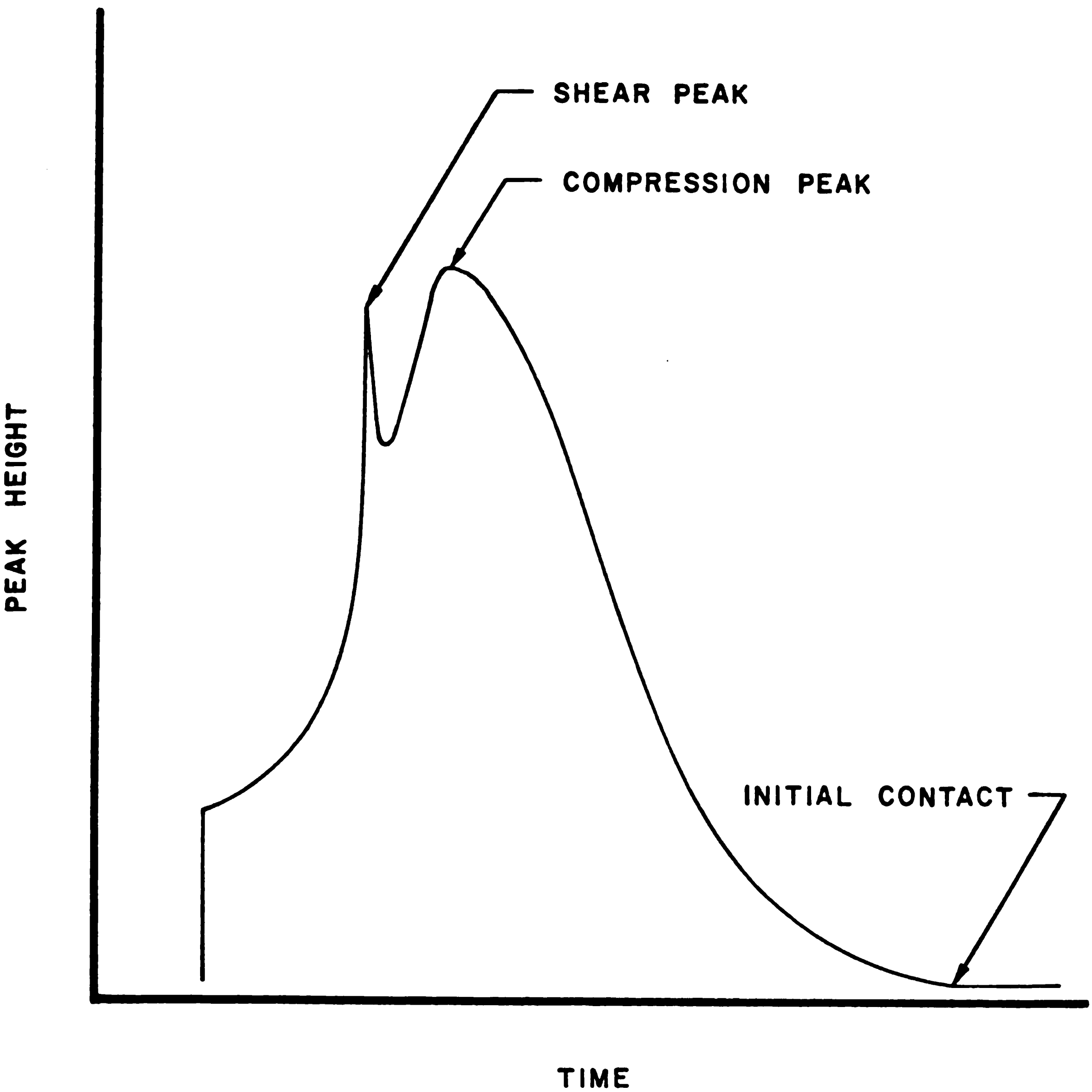

Figure 1. Typical Kramer shear peak for bean texture evaluation.

Total Solids in Soaked and Cooked Beans

Soaked beans and shear residues were weighed and dried at 80 ^{o}C in an air-oven dryer (Precision Scientific Co., Chicago, IL) for 24 hours. The oven-dried weight was measured and the percent total solids in beans was determined as follows:

$$\% \text{ Total Solids} = \frac{\text{Oven-dried weight (g)}}{\text{Initial weight (g)}} \times 100$$

Total Solids in Soak and Cook Waters

The frozen soak and cook waters were thawed at room temperature. A homogeneous sample of 100 grams was placed into a dry, preweighed aluminum pan and dried at 100 ^{o}C in a Proctor-Schwartz dryer (Proctor and Schwartz; Inc., Philadelphia, PA) to a constant weight. The sample pans were then allowed to cool and the final weights were measured. Total solids was determined as follows:

$$\% \text{ Total Solids} = \frac{\text{Pan final weight (g)}}{\text{Pan initial weight (g)}} \times 100$$

Ash Determination

Five gram samples were weighed into previously dried, cooled and weighed 50 ml porcelain crucibles. Samples were dried at 80 ^{o}C for 24 hours in an air-oven dryer (Precision Scientific Co., Chicago, IL). After being cooled in a desiccator, samples were burned on a Labconco micro-Kjeldahl burner unit (Labconco Corp., Kansas City, MO) until smoke disappeared; they were then incinerated at 525 ^{o}C for 24 hours in a Barber-Coleman muffle furnace (Model No.293 C, Thermolyne Corp., Dubuque, IA). The ash residue was allowed to cool to room temperature in a desiccator and weighed. The ash content was calculated as follows:

$$\% \text{ Ash (dry basis)} = \frac{\text{Residue weight (g)}}{\text{Sample weight (g)}} \times 100$$

Protein Determination

The protein content was determined by Micro-Kjeldahl method according to AACC method 46-13 (1983). Percentage of nitrogen and protein content were calculated as follows:

$$\%N = \frac{\text{(ml HCl-ml Blank) X Normality of HCl X Eq.Wt.of N}}{\text{Sample weight (mg)}} \times 100$$

$$\text{Protein content (\% dry basis)} = 6.25 \times \%N$$

Mineral Analysis

An inductively coupled plasma (ICP) emission spectrometer (Jarrell-Ash Model 955 Plasma Atomcomp; Fisher Scientific Co., Pittsburgh, PA) was used to determine Ca, Cu, Fe, Mg, Mn, Na, P, Zn, and K contents for each sample.

Equipment Handling. All crucibles, volumetric flasks, funnels, and culture tubes used in preparing samples were specially cleaned. After being washed with detergent and rinsed with distilled demineralized water, they were soaked overnight in a 3N Baker Instra-analyzed nitric acid solution, rinsed three times with distilled demineralized water, allowed to air dry and were stored separately from other laboratory glassware. Several samples of the distilled demineralized water were analyzed for mineral content and found to contain below detectable amounts of the minerals to be determined in this study. The muffle furnace was washed and thoroughly rinsed with the distilled demineralized water before each use.

Sample Preparation. One gram sample of previously dried flour was weighed into 50 ml porcelain crucibles and heated on a Labconco micro-Kjeldahl burner unit (Labconco Corp., Kansas City, MO) on a low setting for 20 to 30 minutes until all smoke dissipated and the samples appeared charred. Samples were then placed in a Barber-Coleman muffle furnace (Model No. 293C, Thermolyne Corp., Dubuque, IA) at room temperature. Samples were ashed at 500 ^{o}C for approximately 16 hours. When cool, the residue remaining in each crucible was dissolved in two ml concentrated Baker Instra-analyzed nitric acid for approximately one hour. The dissloved residues were transferred to 10 ml volumetric flasks, which contained one ml of 100 ppm Yttrium oxide solution (internal standard), and brought to volume with demineralized distilled water. The mineral solutions were transferred to labeled polypropylene culture tubes. The tubes were capped and refrigerated overnight. If the solutions contained visible sediment the next day, the solutions were decanted into clean culture tubes so that only clear solutions were used for mineral analysis. For approximately every 20 flour samples, a procedural blank, which contained no sample material, and a sample of standard reference material (SRM) #1572, which was citrus leaves (National Bureau of Standards, Washington, D.C.), were prepared. The procedural blank and the standard reference material received the same treatment as did flour samples. All flour samples, SRM, and procedural blank solutions were stored at -20 ^{o}F (-28.9 ^{o}C) until analyzed.

All samples were analyzed for the mineral content by a trained technician of the Department of Pharmacology and Toxicology at Michigan State University.

Sugar Analysis

Glucose, sucrose, raffinose and stachyose were analyzed using High Performance Liquid Chromatography (HPLC) according to the procedure developed by Agbo (1982). The procedural diagram is presented in Figure 2. One gram sample of bean flour was mixed with ten ml of 80%(v/v) ethanol, shaken in a water bath at 80 ^{o}C for 15 minutes, and centrifuged for three minutes at 2000 RPM. The supernatant was collected in a separate tube. This extraction was performed twice more, with five ml and ten ml of 80% ethanol respectively. The supernatant from all three extractions was collected in the

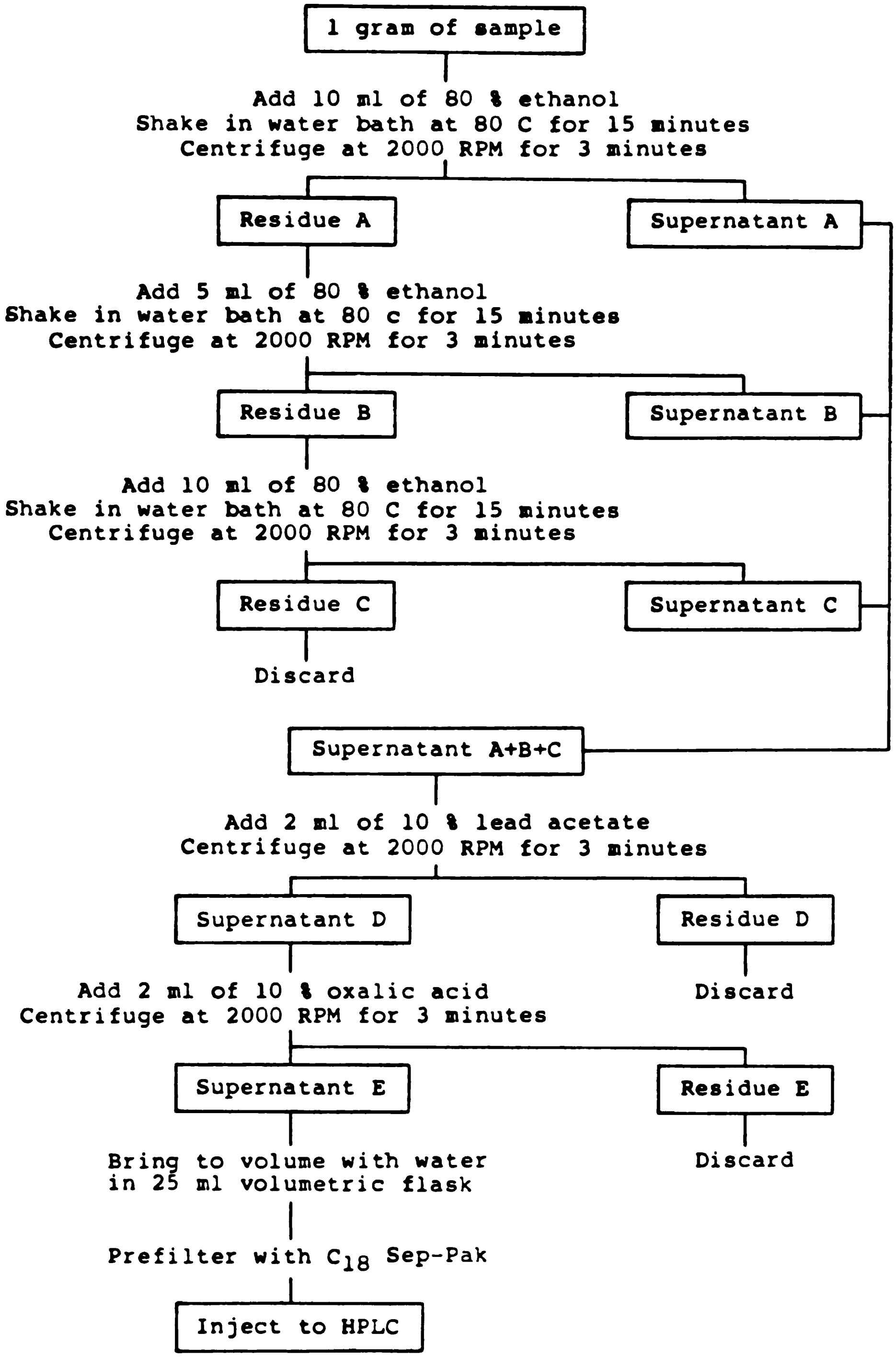

Figure 2. Sample preparation for sugar analysis by High Performance Liquid Chromatography.

same tube and the precipitate was discarded. Then two ml of 10% lead acetate were added. The extract mixture was shaken in the same manner and centrifuged at 2000 RPM for three minutes to precipitate proteins. The supernatant was removed and two ml of oxalic acid were added to it. The mixture was again shaken and centrifuged, and the final supernatant was brought to 25 ml with distilled water. The solution was then filtered through an HA filter (Millipore Corp., Bedford, MA) and Sep-Pak C_{18} cartridge (Waters Associates, Inc., Milford, MA) and injected into the HPLC. The chromatography system was composed of a Solvent Delivery System 6000 A, a Universal Chromatograph Injector U6K, a Differential Refractometer R401, and a Data Module 730 (Waters Associates, Inc., Milford, MA). The sample size was 25 microlitres and the solvent used was a mixture of 70% acetonitrile and 30% water (v/v) with a flow rate of one ml/min. Resolution of sugars from this extraction was accomplished by using a μ-Bondpak Carbohydrate Analysis column (Waters Associates, Inc., Milford, MA). An external standard method programmed into the Data Module was used to identify and quantitate the sugars.

Statistical Analysis

The "Statistical Package for the Social Sciences" (SPSS) computer programs described by Nie et al. (1975) for use on the CDC 6500 computer operated by Michigan State University Computer Laboratory was used to assist statistical analyses.

Multivariate analyses of variance and covariance were determined using subprogram ANOVA. Mean squares were reported after rounding. Single classification analyses of variance, Tukey mean separations and treatment trends were determined using subprogram ONEWAY.

Tukey separations were presented such that treatments which were not significantly different ($P \leq 0.05$) were indicated with like letters. Mean squares with significant F ratios were reported with probability levels of $P \leq 0.05$ (*), $P \leq 0.01$ (**), and $P \leq 0.001$ (***). Coefficient of Variation (CV) which expresses the standard deviation as a percent of the mean was calculated (Little and Hills, 1972).

RESULTS AND DISCUSSION

Two separate studies were undertaken in this research. Study I dealt with cooking preparation of beans at a fixed temperature of 190 °F (87.8 °C). Various soaking treatments were performed and cooking was done in two different ways:

a) Blancher cooking, in which each sample was cooked in a separate flask in a blancher.

b) Kettle cooking, in which all samples were cooked together in a steam kettle.

In the blancher cooking section, the effects of soak time, soaking method, and cook time on physical changes (hydration ratio, shear force, and total solids) and chemical changes (protein, ash, minerals, and sugars) were investigated. In the kettle cooking section, the effects of soak time and cook time on shear force, protein, ash, and minerals were examined.

Study II emphasized the effects of cooking temperature, as well as soak and cook time, on hydration ratio, shear force, and total solids in beans. Various soaking and cooking treatments were employed and the beans were cooked in separate flasks in the blancher. Four cooking temperatures; 181.3 °F, 190.7 °F, 200.0 °F, and 207.5 °F (82.9 °C, 88.1 °C, 93.3 °C, and 97.5 °C) were studied.

Physical and Chemical Changes During Preparation of Beans

Blancher Cooking

The effect of soak time, soaking method, and changes during the process of soaking and followed by cooking were investigated.

Mean values and Tukey mean separations for physical and chemical characteristics of cold-soaked, hot-soaked, and cooked beans are presented in Tables 3, 4, 7, 8, 11, and 12. Graphical presentation of the results are in Figures 3 to 36 and the analysis of variance of the data for cooked beans of two different soaking methods are summarized in Tables 5, 6, 9, and 10.

Hydration Ratio. For both navy and kidney beans, data showed insignificant increases in hydration ratio after 8 hours of cold soaking and after hot soaking (Figures 3 and 4). Hydration ratio increased more remarkably during the cooking period, with slightly higher ratios for 16-hour-soaked beans than for hot-soaked beans. Statistical analyses indicated the effect of soaking method and cook time as well as treatment interaction to be insignificant (Tables 3 to 6).

The values of hydration ratio indicate the ability of beans to imbibe water. Therefore the results illustrated that beans absorbed maximum amount of water after 8 hours of

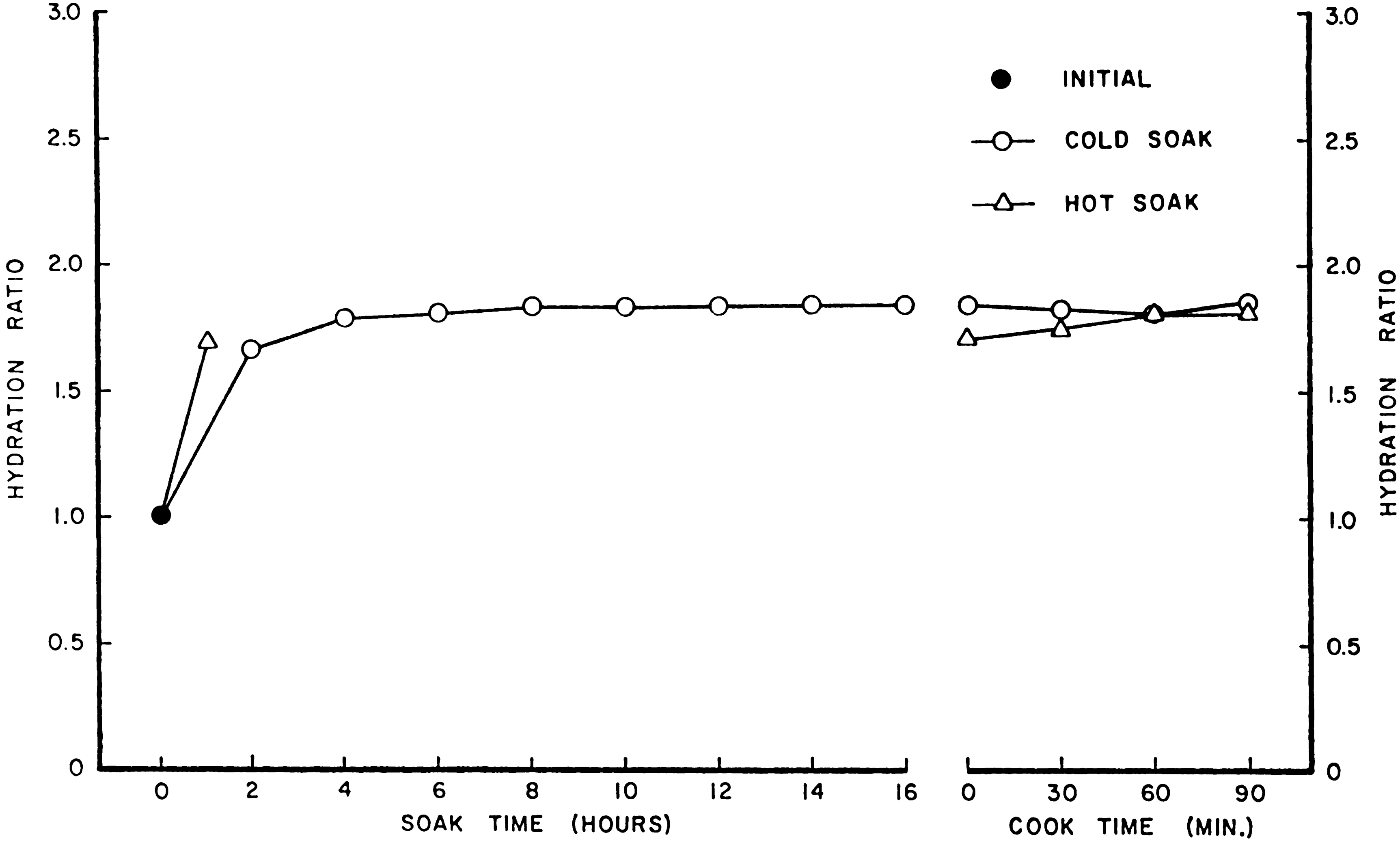

Figure 3. Changes of hydration ratio during preparation of navy beans.

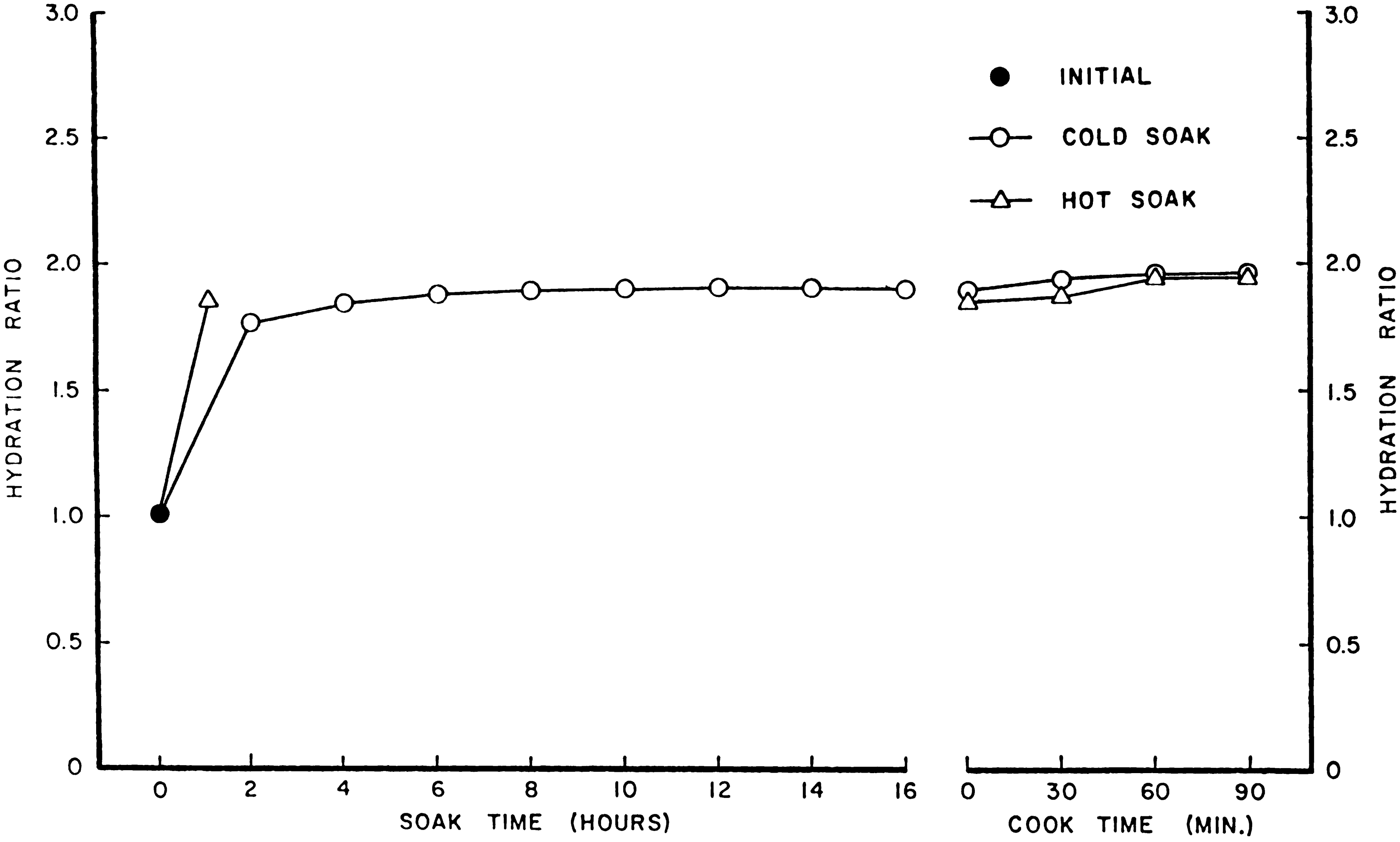

Figure 4. Changes of hydration ratio during preparation of kidney beans.

Table 3. Physical and chemical changes during preparation of navy beans.

	Physical changes[1]				Chemical changes[1]	
	Hydration ratio	Total solids in beans[2]	Total solids in water[2]	Shear force[3]	Protein[4]	Ash[4]
COLD SOAKING						
Raw beans	1.00	84.44	0.00	---[6]	23.3 a	4.13 b
Soak time						
2 hours	1.67	52.06	0.11 a	---	25.1 a	4.18 b
4 hours	1.79	48.37	0.14 a	---	25.4 a	4.05 b
6 hours	1.82	46.98	0.18 ab	---	25.4 a	4.02 ab
8 hours	1.81	46.48	0.25 b	---	25.4 a	4.00 ab
10 hours	1.84	46.57	0.36 c	---	25.3 a	3.81 ab
12 hours	1.84	46.38	0.39 cd	---	25.1 a	3.76 ab
14 hours	1.85	45.98	0.36 c	---	25.7 a	3.80 ab
16 hours	1.85	45.40	0.44 d	---	26.4 a	3.76 ab
Cook time (after 16 hours soak)[5]						
30 minutes	1.83	44.96 b	1.30 a	1090 b	25.2 a	2.95 b
60 minutes	1.82	43.78 a	1.29 a	1050 b	25.3 a	2.88 b
90 minutes	1.86	43.01 a	1.70 b	780 a	25.7 a	2.76 a
HOT SOAKING						
Raw beans	1.00	84.44	0.00	---	23.3 a	4.13 b
Hot-soaked beans	1.72	48.22	0.63 e	---	27.0 a	3.21 a
Cook time (after hot soak)[5]						
30 minutes	1.76	45.80 b	0.80 a	1155 b	25.5 a	2.71 b
60 minutes	1.82	43.23 a	1.05 b	795 a	25.8 a	2.52 a
90 minutes	1.83	42.57 a	0.99 b	705 a	26.3 a	2.49 a

1. Like letters within each column indicate no significant differences ($P \leq 0.05$).
2. Total solids in beans and water are expressed in per cent.
3. Shear force is expressed in pounds per 100 grams of bean.
4. Protein and ash are expressed in per cent (dry basis).
5. Tukey mean separation within this group was done separately.
6. Not analyzed.

Table 4. Physical and chemical changes during preparation of kidney beans.

	Physical changes[1]				Chemical changes[1]	
	Hydration ratio	Total solids in beans[2]	Total solids in water[2]	Shear force[3]	Protein[4]	Ash[4]
COLD SOAKING						
Raw beans	1.00	83.21	0.00	---[6]	29.9 a	4.11 a
Soak time						
2 hours	1.77	48.04	0.10 a	---	32.3 a	4.02 a
4 hours	1.84	46.08	0.18 b	---	32.3 a	3.94 a
6 hours	1.89	44.59	0.25 c	---	32.2 a	3.97 a
8 hours	1.90	43.82	0.27 c	---	32.5 a	3.93 a
10 hours	1.91	44.03	0.32 d	---	32.2 a	3.94 a
12 hours	1.92	43.53	0.35 d	---	32.0 a	3.91 a
14 hours	1.91	43.57	0.40 e	---	32.2 a	3.87 a
16 hours	1.90	43.22	0.46 f	---	32.6 a	3.85 a
Cook time (after 16 hours soak)[5]						
30 minutes	1.95	42.32 b	1.18 a	1110 c	32.2 a	3.49 b
60 minutes	1.96	40.96 a	1.38 a	990 b	33.0 a	3.19 a
90 minutes	1.97	40.31 a	1.61 b	705 a	32.7 a	3.17 a
HOT SOAKING						
Raw beans	1.00	83.21	0.00	---	29.9 a	4.11 a
Hot-soaked beans	1.85	45.26	1.14 g	---	32.3 a	3.67 a
Cook time (after hot soak)[5]						
30 minutes	1.88	43.21 b	1.14 a	1230 b	32.4 a	3.09 a
60 minutes	1.95	41.18 a	1.17 a	975 a	33.2 a	2.99 a
90 minutes	1.95	40.36 a	1.30 a	940 a	32.2 a	2.97 a

1. Like letters within each column indicate no significant differences ($P \leq 0.05$).
2. Total solids in beans and water are expressed in per cent.
3. Shear force is expressed in pounds per 100 grams of bean.
4. Protein and ash are expressed in per cent (dry basis).
5. Tukey mean separation within this group was done separately.
6. Not analyzed.

Table 5. Analysis of variance for physical and chemical changes during preparation of navy beans.

Source of variation	df	Mean Squares					
		Hydration ratio	Total solids in beans	Total solids in water	Shear force	Protein	Ash
Main effects	3	0.003	4.786 ***[1]	0.290 ***	104158.3 ***	0.512	0.113 ***
Soak method (SM)	1	0.003	0.008	0.696 ***	23408.3 **	0.695	0.253 ***
Cook time (CT)	2	0.002	7.175 ***	0.087 ***	144533.3 ***	0.420	0.044 ***
Two-way							
SM x CT	2	0.001	0.599 **	0.055 ***	25733.3 **	0.026	0.004
Residual	6	0	0.051	0.001	1125.0	0.575	0.001
%CV		0	0.515	2.657	3.6	2.957	1.163

1. Indicate probability level of significance:
   * $P \leq 0.05$
   ** $P \leq 0.01$
   *** $P \leq 0.001$

Table 6. Analysis of variance for physical and chemical changes during preparation of kidney beans.

Source of variation	df	Mean Squares					
		Hydration ratio	Total solids in beans	Total solids in water	Shear force	Protein	Ash
Main effects	3	0.003	4.278 ***[1]	0.094 ***	93516.7 ***	0.483	0.111 ***
Soak method (SM)	1	0.004	0.445	0.104 ***	38533.3 **	0.009	0.217 ***
Cook time (CT)	2	0.002	6.195 ***	0.088 ***	121008.3 ***	0.720	0.059 ***
Two-way							
SM x CT	2	0.001	0.199	0.019 *	15658.3 *	0.137	0.014 *
Residual	6	0	0.087	0.003	2183.3	0.300	0.002
%CV		0	0.713	4.213	4.7	1.678	1.420

1. Indicate probability level of significance:
   - * $P \leq 0.05$
   - ** $P \leq 0.01$
   - *** $P \leq 0.001$

cold-soaking and that soaking longer than 8 hours might not be necessary. In fact, soaking of more than 16 hours leads to microbial growth.

Total Solids in Soaked and Cooked Beans. During the first 8 hours of cold soaking, the total solids in beans decreased dramatically but after that the rate of decrease slowed down until the end of the cold-soak period (Figures 5 and 6). A significant decrease after hot-soaking was also illustrated. The losses occurred more during cooking, with 16-hour-soaked beans showing greater losses than hot-soaked beans. The amount of total solids after 60 minutes of cooking was significantly lower than that after 30 minutes for both hot-soaked and 16-hour-soaked beans (Tables 3 and 4). Analysis of variance indicated the significance of treatment effects and interaction between soaking method and cook time for both bean types (Tables 5 and 6).

Total Solids in Soak and Cook Waters. Total solids in soak water increased gradually over the cold-soaking period, but increased drastically after hot-soaking (Figures 7 and 8). Hot-soaked kidney beans lost more solids into the soak water than did hot-soaked navy beans. Total solids in cook waters were found to be much higher than those in soak waters (Tables 3 and 4). In addition, 16-hour-soaked beans lost more solids than hot-soaked beans during cooking. Analysis of variance showed significant effects of both soaking method and cook time. Treatment interaction effect

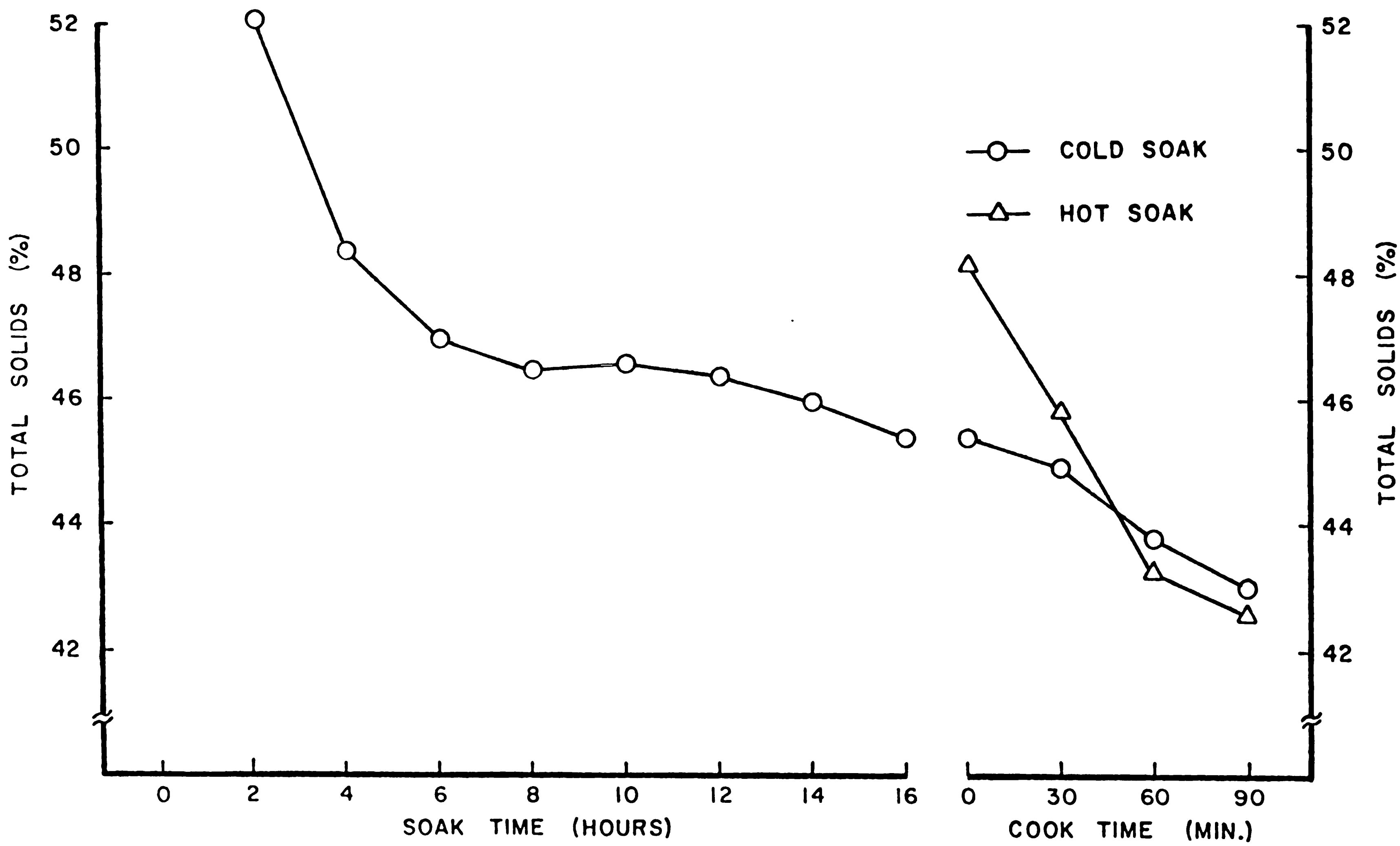

Figure 5. Changes of total solids in soaked and cooked navy beans during preparation (Initial total solids = 84.44%).

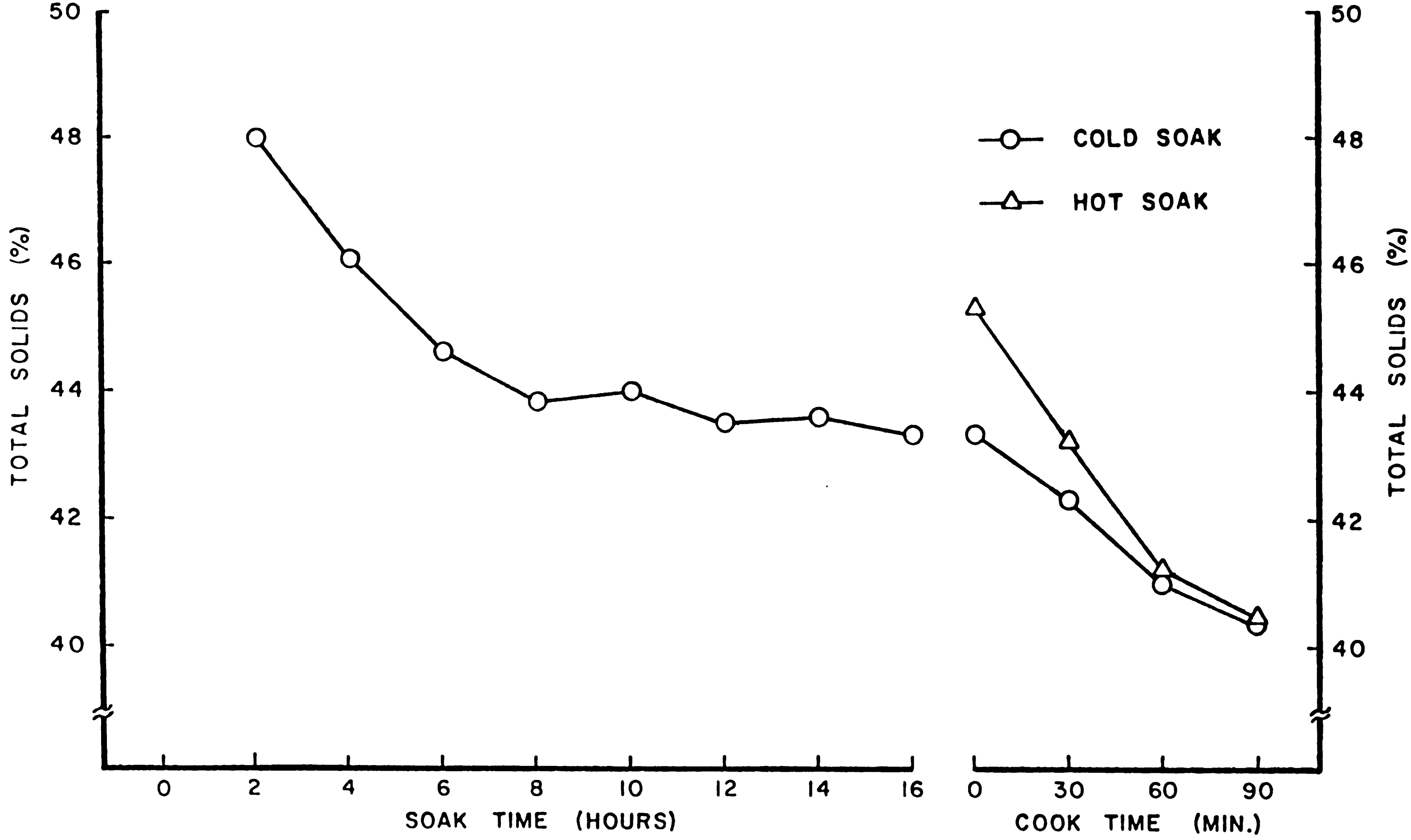

Figure 6. Changes of total solids in soaked and cooked kidney beans during preparation (Initial total solids = 83.21%).

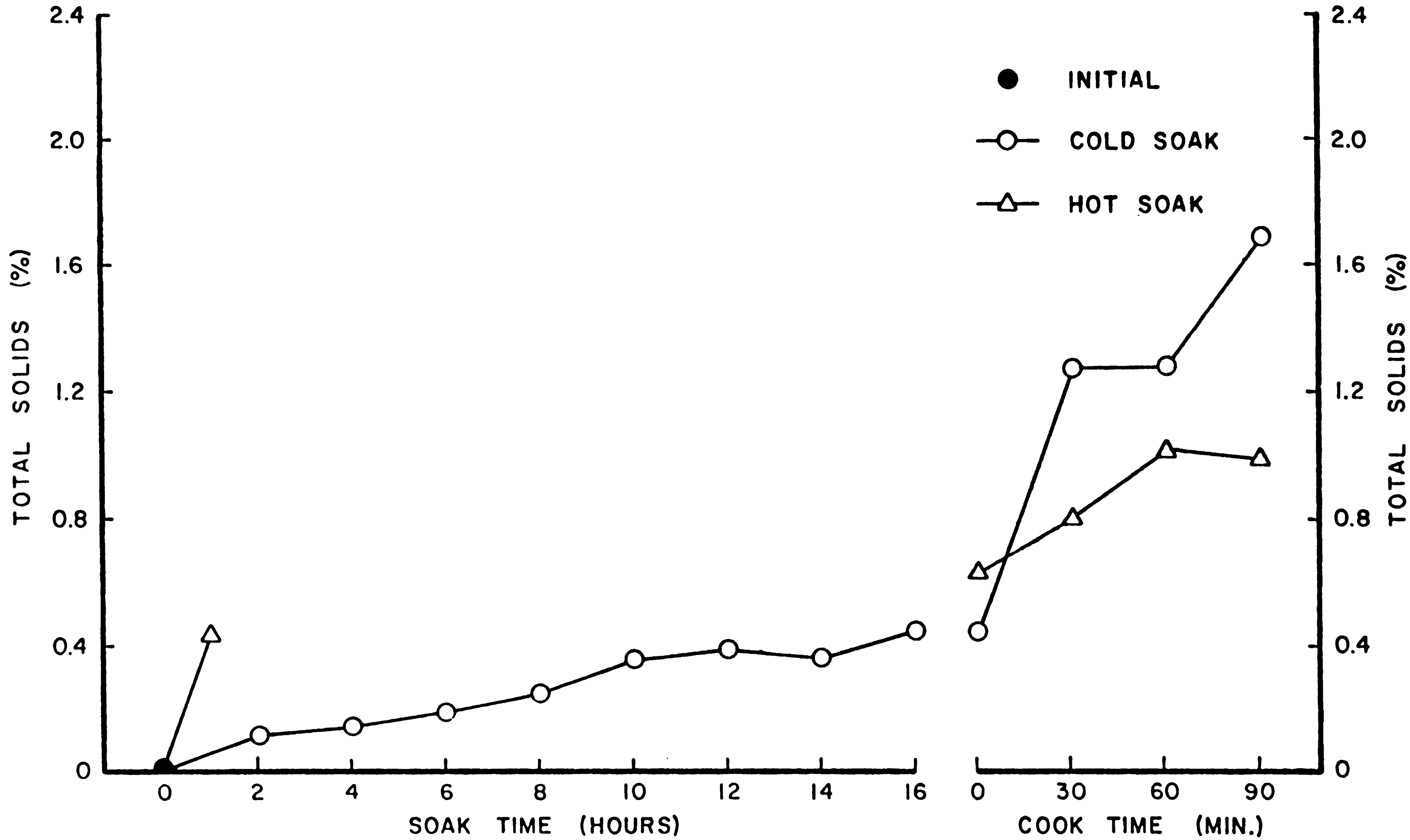

Figure 7. Changes of total solids in soak and cook waters during preparation of navy beans.

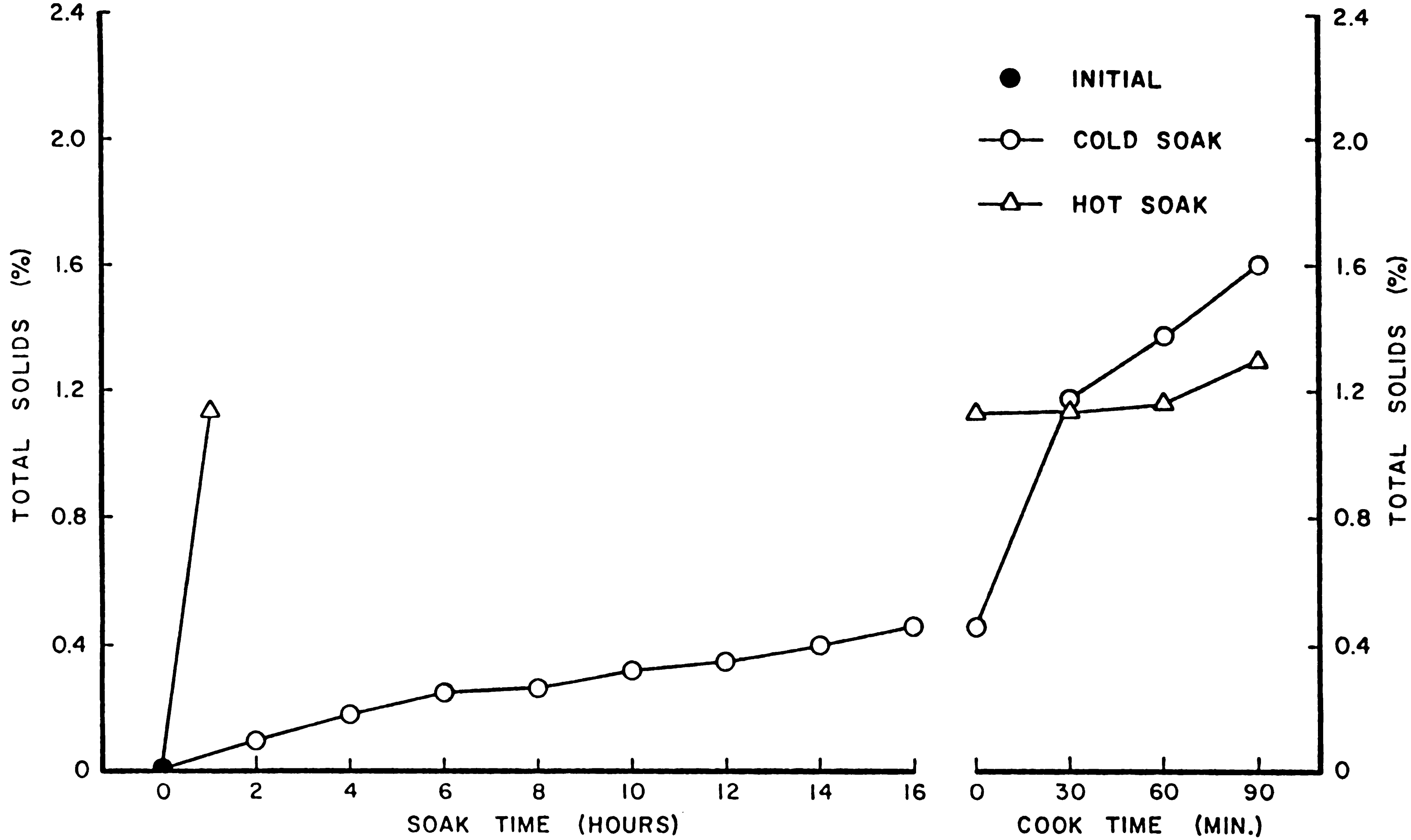

Figure 8. Changes of total solids in soak and cook waters during preparation of kidney beans.

in kidney beans was less than in navy beans (Tables 5 and 6).

Shear Force. Significant effects of soaking method and cook time as well as their interaction were illustrated in both bean types (Tables 5 and 6). The beans were softer as the cook time increased (Tables 3 and 4) and hot-soaked beans were generally softer than 16-hour-soaked beans which were cooked for the same period of time (Figures 9 and 10).

Protein Content. The protein content of raw navy beans was 23.3% (dry basis), which was slightly higher than the values in the literature of 21.4% (Watt and Merrill, 1963; and Meiners et al., 1976a). The protein of raw kidney beans was 29.9% (dry basis). This value was lower than the value reported by Koehler and Burke (1981) of 32.8%; but was much higher than the values of Watt and Merrill (1963) or Meiners et al. (1976a), which was 21.4%.

Oneway analysis of variance showed that protein content did not change significantly during the soaking or cooking periods (Tables 3 and 4), although changes were observed in graphical presentation (Figures 11 and 12). There was a large increase of protein content after 2 hours of cold soaking. Actually this increase was due to the dry basis used in the determination of protein in soaked beans, in which dried bean flour samples were analyzed. All water was evaporated from the beans thus resulting in higher concentration of solids in them. The effects of both soaking

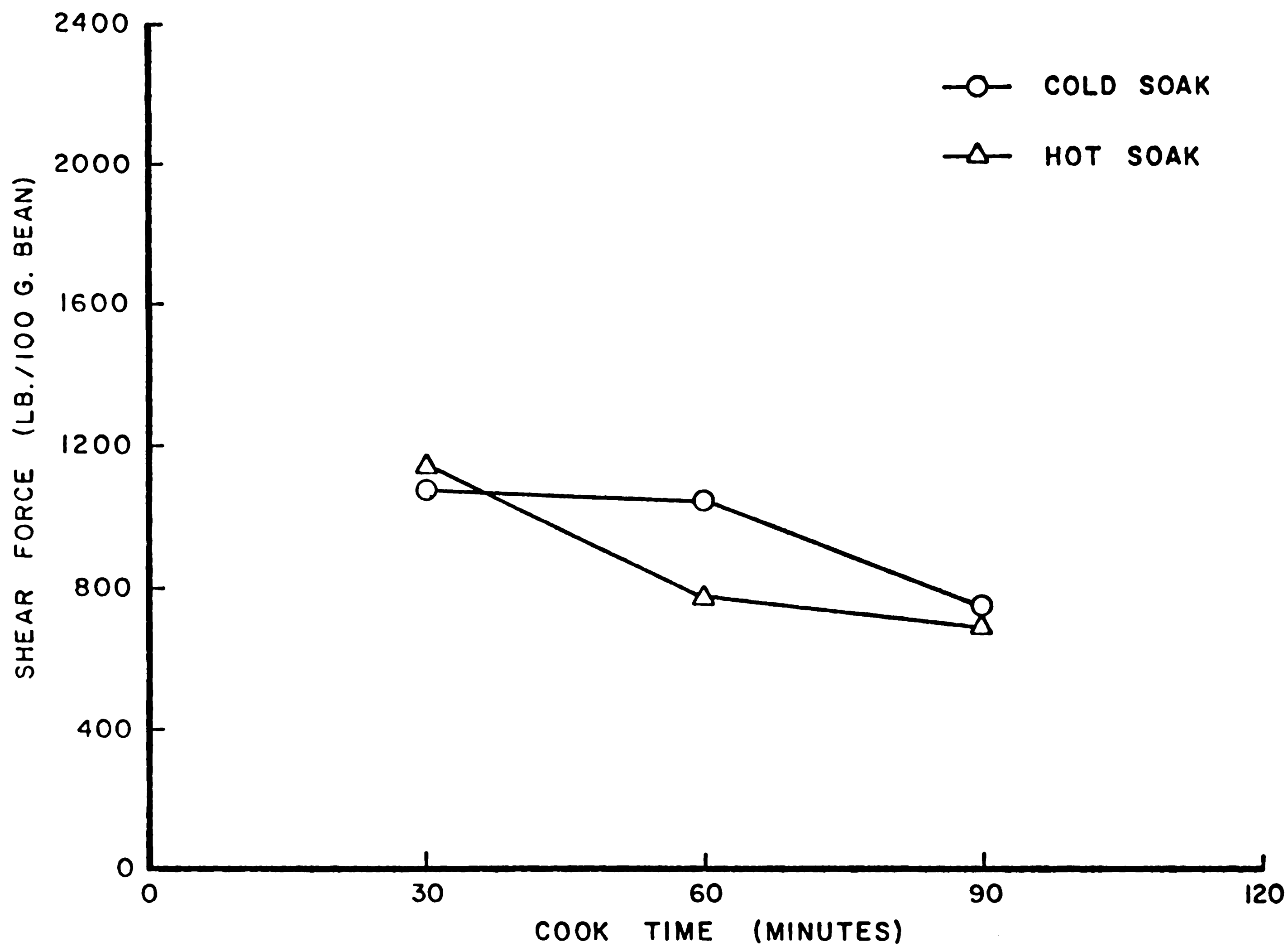

Figure 9. Changes of shear force during preparation of navy beans.

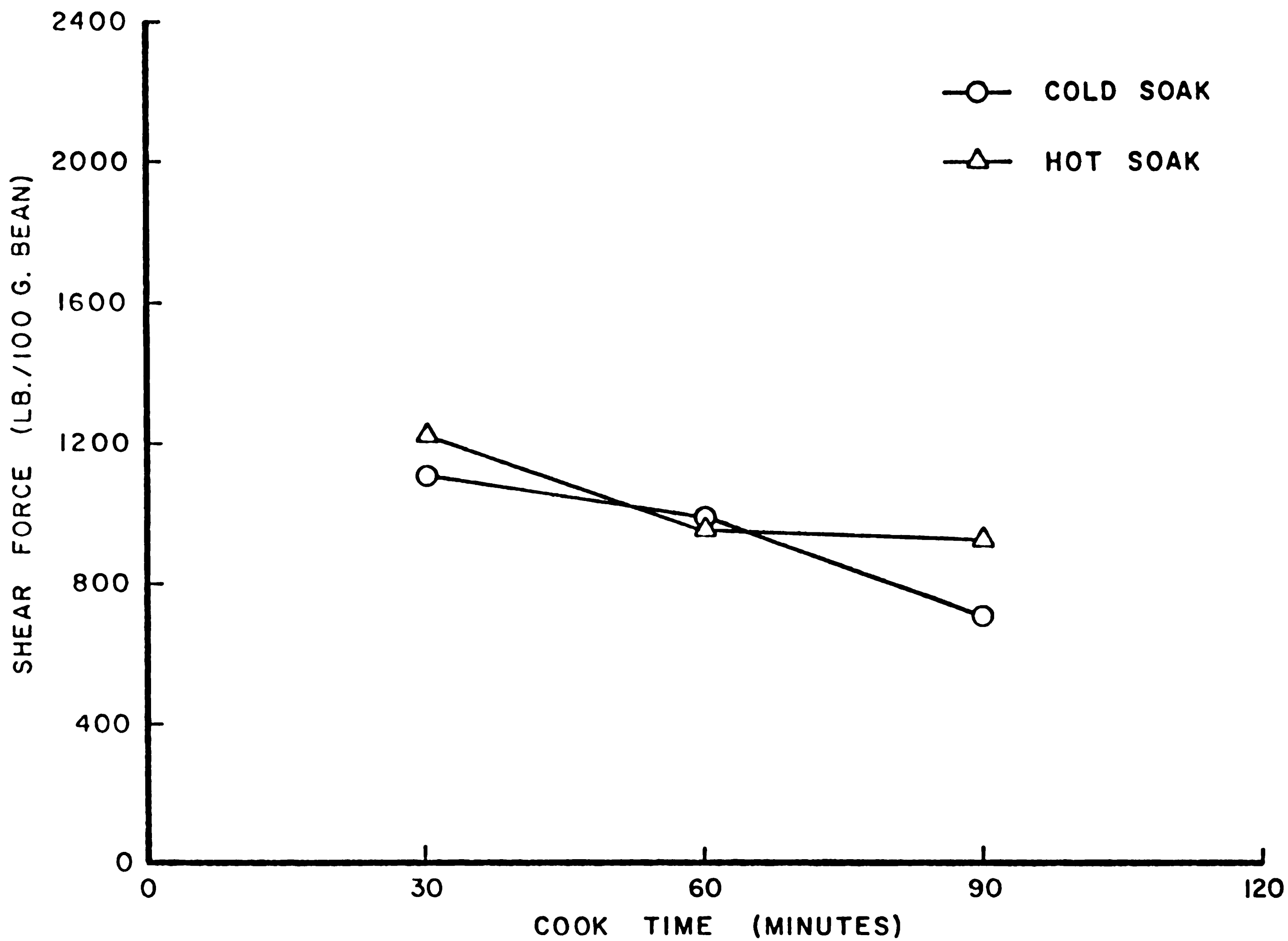

Figure 10. Changes of shear force during preparation of kidney beans.

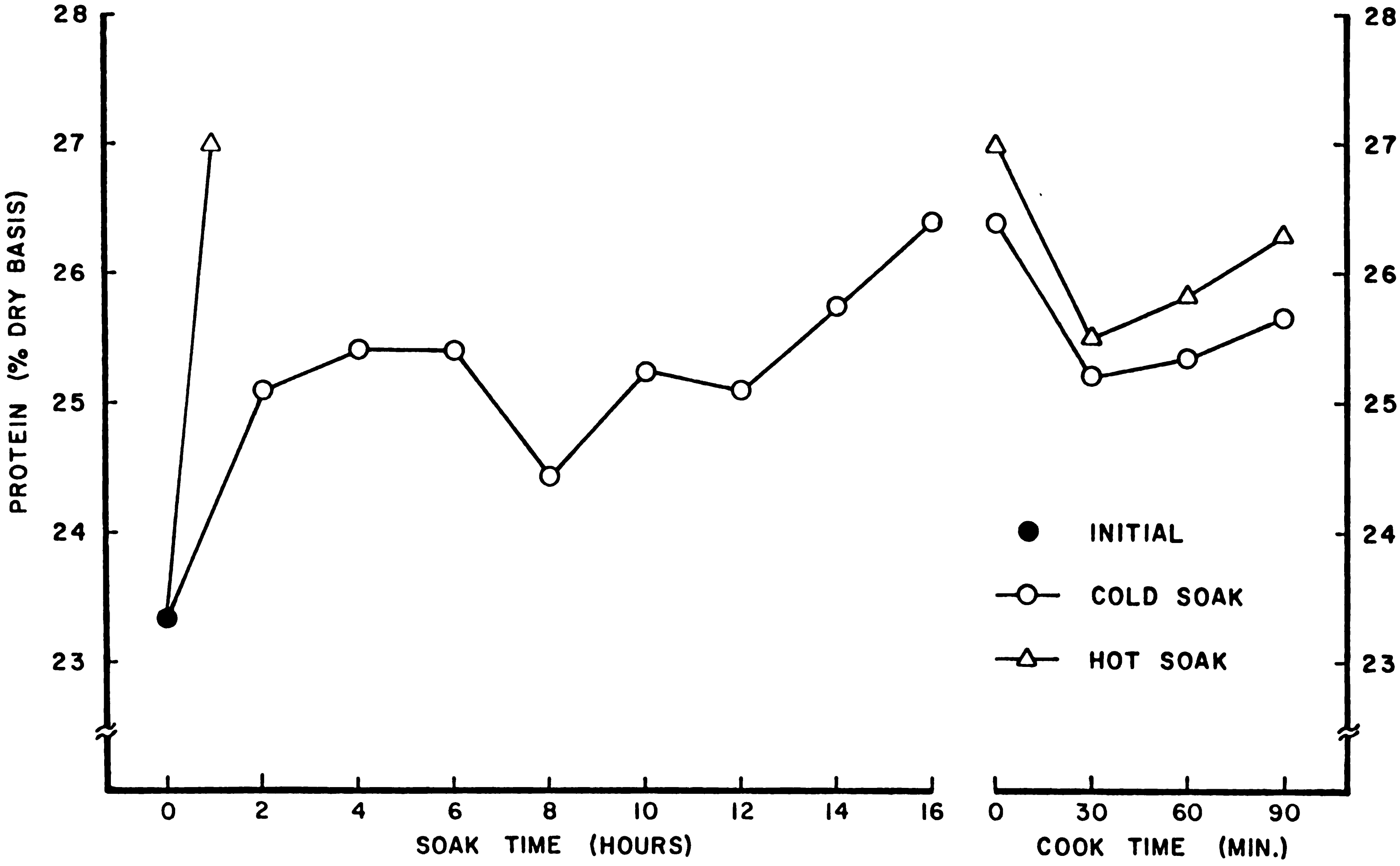

Figure 11. Changes of protein content during preparation of navy beans.

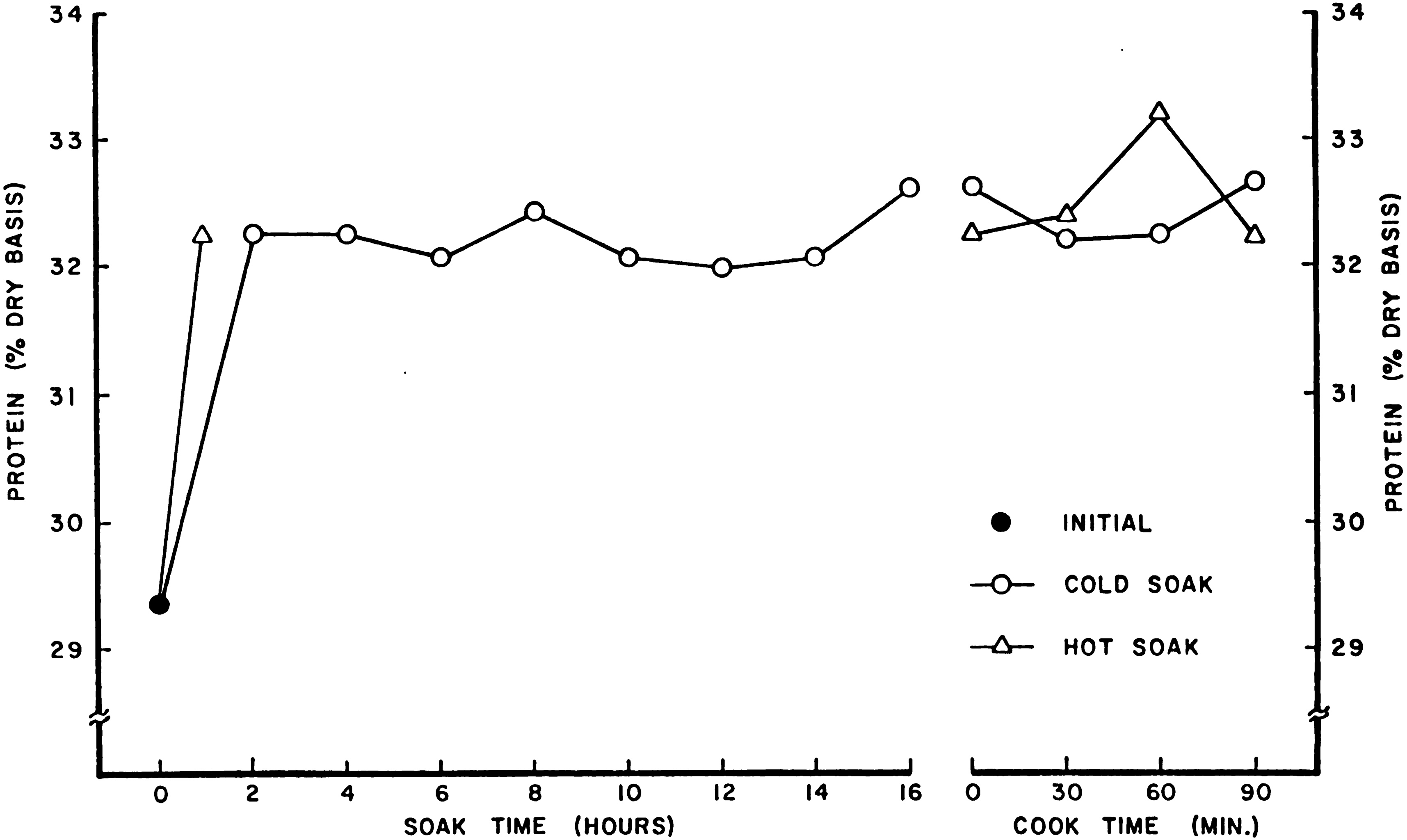

Figure 12. Changes of protein content during preparation of kidney beans.

method and cook time were insignificant according to the analysis of variance (Tables 5 and 6). The results are in good agreement with those of Koehler and Burke (1981) and Haytowitz and Matthews (1983) who reported 93% to 100% retention of protein after cooking. However, they did not agree with those of Meiners et al. (1976a) who reported 50% to 60% loss of protein after cooking.

Ash and Minerals. The ash contents of both raw navy and kidney beans were 4.1% (dry basis), which were in the range reported in literature of 3.9% to 4.8% (Watt and Merrill, 1963; Meiners et al., 1976a; and Koehler and Burke, 1981).

Hot-soaking resulted in a greater decrease in ash content than did cold-soaking (Figures 13 and 14). Oneway analysis (Tables 3 and 4) showed greater loss of ash from cooking than from soaking, and hot-soaked beans lost more ash than did 16-hour-soaked beans. This was confirmed by significance of treatments and treatment interaction from the analysis of variance (Tables 5 and 6). The results were in accord with studies conducted by Watt and Merrill (1963), Meiners et al. (1976a), and Koehler and Burke (1981). The decrease in ash content is due to the leaching of minerals from beans into soak and cook waters.

The values of nine minerals (Tables 7 and 8) in raw navy and kidney beans were reasonably consistent with values from previous studies (Table 1).

The calcium content increased during both soaking and

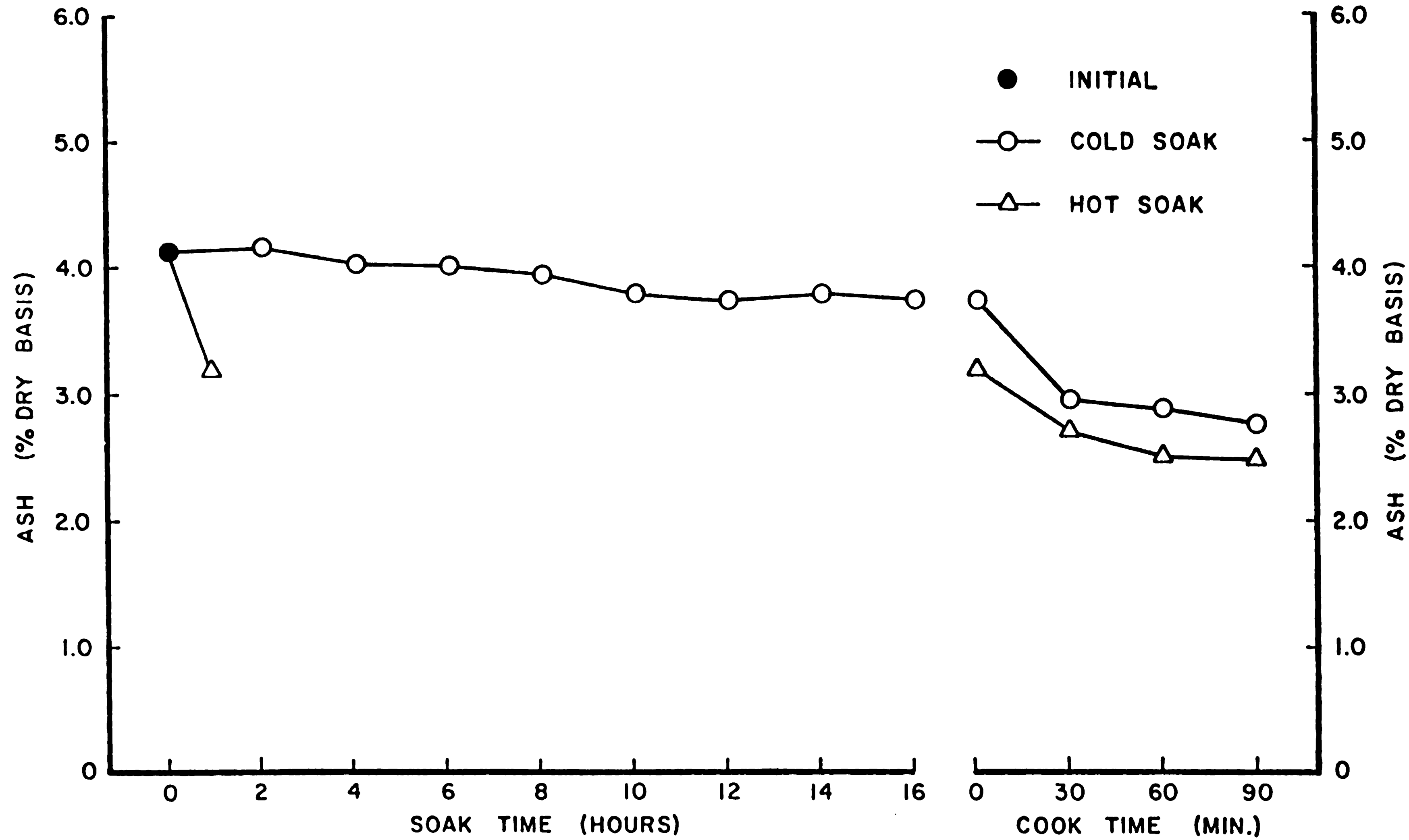

Figure 13. Changes of ash content during preparation of navy beans.

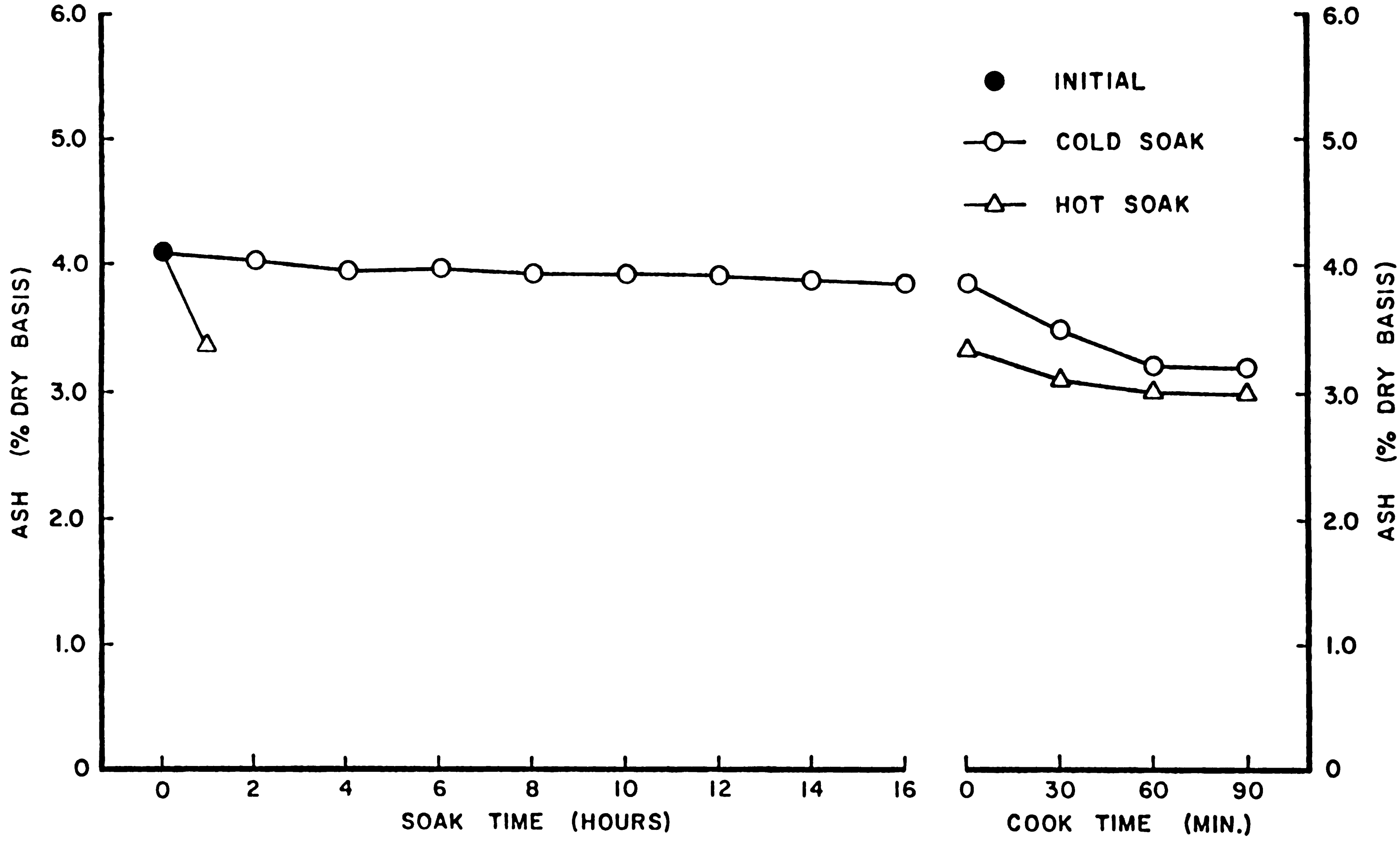

Figure 14. Changes of ash content during preparation of kidney beans.

cooking since beans absorbed water which contained 100 ppm calcium (Figures 15 and 16). In kidney beans, hot-soaked samples gained more calcium during cooking than did 16-hour-soaked samples. Both oneway analysis (Table 7) and analysis of variance for navy beans (Table 9) showed significance of soaking method and treatment interaction, but not for cook time alone. For kidney beans, the effect of cook time was more significant than soaking method and treatment interaction was not significant at all (Tables 8 and 10).

Marked change in the copper content was not found in the entire process of preparation (Tables 7 and 8; Figures 17 and 18). From analysis of variance (Tables 9 and 10), cook time did not produce significant effect but the soaking method and treatment interaction were reported to be significant. Iron showed noticeable loss after soaking by either method as compared to the original iron content in unprocessed beans (Tables 7 and 8). Hot-soaked beans lost more iron than cold-soaked beans (Figures 19 and 20). Analysis of variance of navy beans (Table 9) indicated significant effects from soaking method and treatment interaction, but not from cook time. This implied that iron content in navy beans did not change significantly with the increase of cook time, but hot-soaked beans showed greater decrease during cooking than 16-hour-soaked beans. For kidney beans, neither treatment nor treatment interaction was statistically significant (Table 10).

Significant effects of treatments on magnesium were

Table 7. Changes of mineral content during preparation of navy beans.[1,2]

	Ca	Cu	Fe	Mg	Mn	Na	P	Zn	K
COLD SOAKING									
Raw beans	1642 a	8.8 a	84.9 e	1602 bc	18.4 bc	65.2 a	5439 c	36.9 c	16337 de
Soak time									
2 hours	1816 b	9.5 b	76.8 b	1661 de	17.7 a	45.1 a	5392 abc	34.1 b	16477 e
4 hours	2001 c	10.0 cde	80.0 d	1779 f	18.9 c	84.5 ab	5644 d	35.7 bc	17138 f
6 hours	2221 d	9.5 b	74.8 a	1696 e	17.7 a	45.9 a	5277 ab	34.0 b	16240 cde
8 hours	1832 b	10.1 de	78.8 cd	1677 de	18.3 bc	57.0 a	5494 cd	35.5 bc	16281 de
10 hours	1811 b	9.5 b	79.3 cd	1650 cde	18.4 bc	52.1 a	5445 c	35.5 bc	15848 bcd
12 hours	1874 bc	9.7 bcd	77.6 bc	1633 bcd	18.4 bc	61.6 a	5421 bc	35.4 bc	15634 bc
14 hours	1935 bc	9.6 bc	79.3 cd	1632 bcd	18.7 bc	46.6 a	5429 bc	35.3 bc	15751 bcd
16 hours	1884 bc	9.6 bcd	79.1 cd	1586 b	18.4 bc	63.6 a	5458 c	35.3 bc	15462 b
Cook time (after 16 hours soak)[3]									
30 minutes	2498 a	9.7 a	81.4 a	1425 b	19.1 a	41.5 a	5272 b	33.7 a	11677 c
60 minutes	2528 a	10.5 a	82.3 a	1360 a	19.2 a	35.9 a	5095 a	33.7 a	11146 b
90 minutes	2501 a	10.2 a	80.2 a	1341 a	19.1 a	79.5 a	5117 ab	34.5 b	10562 a
HOT SOAKING									
Raw beans	1642 a	8.8 a	84.9 e	1602 bc	18.4 bc	65.2 a	5439 c	36.9 c	16337 de
Hot-soaked beans	1917 bc	10.4 e	76.0 ab	1417 a	18.3 ab	118.5 b	5245 a	31.8 a	13395 a
Cook time (after hot soak)[3]									
30 minutes	2641 a	9.9 c	79.4 c	1279 a	19.9 a	77.5 b	5007 b	34.6 a	10011 b
60 minutes	2467 a	8.8 a	77.9 a	1211 a	19.2 a	46.1 a	4787 a	34.0 a	9049 a
90 minutes	2590 a	9.4 b	78.9 b	1206 a	19.7 a	47.4 a	4889 a	34.2 a	9044 a

1. Like letters within each column indicate no significant differences ($P \leq 0.05$).
2. All values are in parts per million (dry basis).
3. Tukey mean separation within this group was done separately.

Table 8. Changes of mineral content during preparation of kidney beans.[1,2]

	Ca	Cu	Fe	Mg	Mn	Na	P	Zn	K
COLD SOAKING									
Raw beans	1108 a	6.4 a	70.0 ab	1714 a	17.6 cd	54.7 ab	6011 abc	45.5 bc	16981 b
Soak time									
2 hours	1540 cd	7.0 ab	69.0 ab	1690 a	17.9 d	86.0 ab	6349 c	46.6 c	16344 b
4 hours	1564 cd	6.9 ab	71.0 ab	1673 a	16.7 abc	96.1 ab	6156 abc	45.1 bc	16339 b
6 hours	1556 cd	7.0 ab	72.6 b	1667 a	17.3 bcd	32.6 a	6157 abc	44.7 bc	16380 b
8 hours	1587 cd	7.2 ab	71.6 ab	1728 a	17.3 abcd	146.7 b	6404 c	45.7 c	16571 b
10 hours	1672 e	6.3 a	71.0 ab	1659 a	16.9 abcd	47.5 ab	6173 abc	45.0 bc	16129 b
12 hours	1608 de	7.0 ab	68.3 a	1643 a	16.7 abc	62.7 ab	5979 abc	43.3 ab	15787 ab
14 hours	1387 b	7.5 ab	71.0 ab	1657 a	16.2 a	99.7 ab	6329 bc	43.2 ab	15841 ab
16 hours	1581 cd	7.0 ab	70.2 ab	1595 a	17.1 abcd	40.3 ab	5913 ab	44.5 bc	15602 ab
Cook time (after 16 hours soak)[3]									
30 minutes	1845 a	7.8 a	70.7 a	1494 b	16.8 a	103.1 a	5787 a	40.5 a	13140 b
60 minutes	2022 a	7.6 a	73.3 a	1399 a	19.0 b	29.6 a	5530 a	42.7 a	12019 a
90 minutes	2018 a	8.1 b	72.2 a	1432 ab	17.0 a	81.7 a	5845 a	42.2 a	11709 a
HOT SOAKING									
Raw beans	1108 a	6.4 a	70.0 ab	1714 a	17.6 cd	54.7 ab	6011 abc	45.5 bc	16981 b
Hot-soaked beans	1514 c	9.0 b	68.4 a	1589 a	16.3 ab	84.5 ab	5837 a	41.0 a	14510 a
Cook time (after hot soak)[3]									
30 minutes	2152 a	7.2 a	70.2 a	1385 a	17.6 a	39.8 a	5518 a	42.5 a	11411 b
60 minutes	2463 b	6.9 a	71.6 b	1277 a	18.9 b	24.8 a	5775 a	46.2 b	10675 a
90 minutes	2478 b	7.4 a	71.6 b	1342 a	17.2 a	77.4 a	5644 a	43.6 ab	10465 a

1. Like letters within each column indicate no significant difference ($P \leq 0.05$).
2. All values are in parts per million (dry basis).
3. Tukey mean separation within this group was done separately.

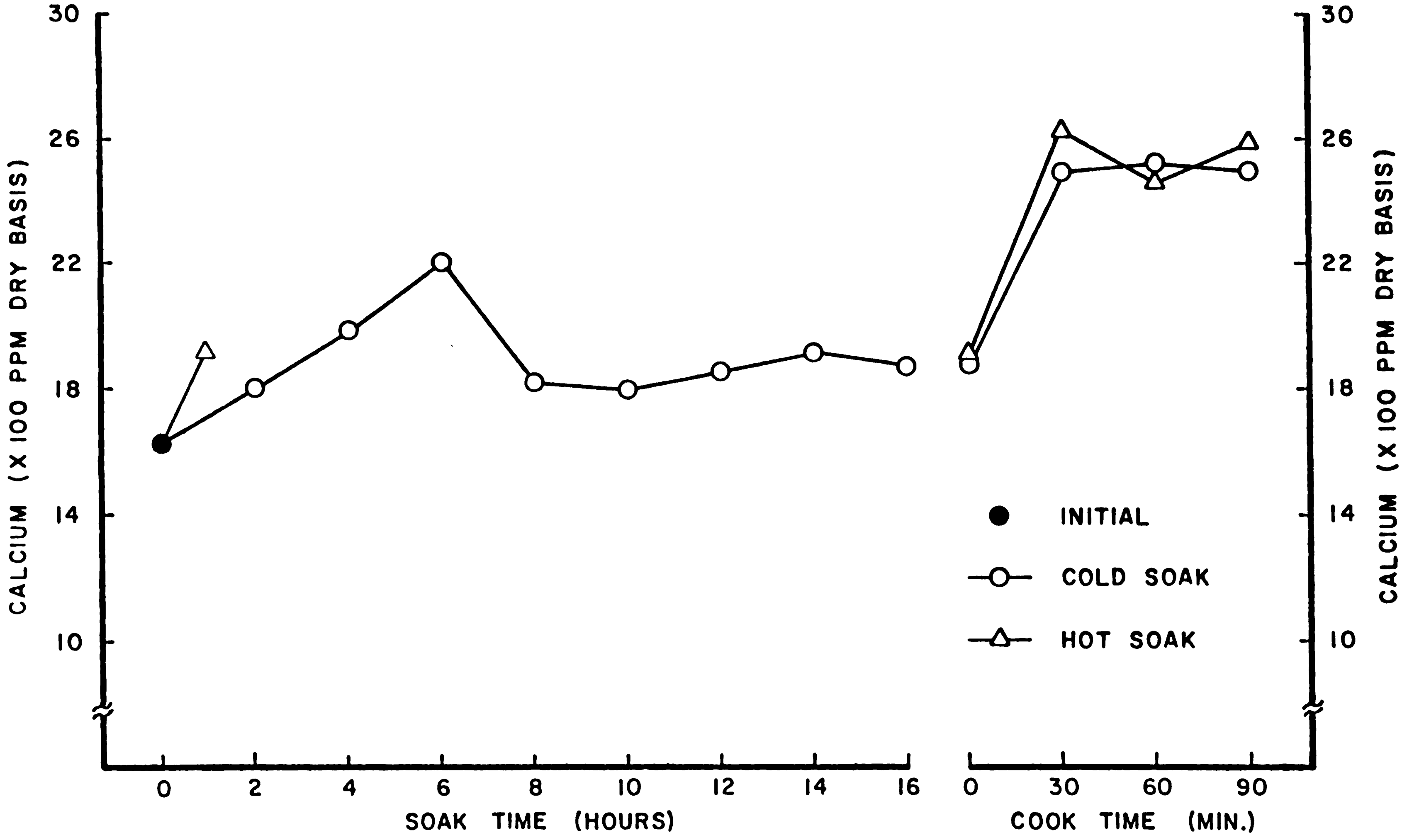

Figure 15. Changes of calcium content during preparation of navy beans.

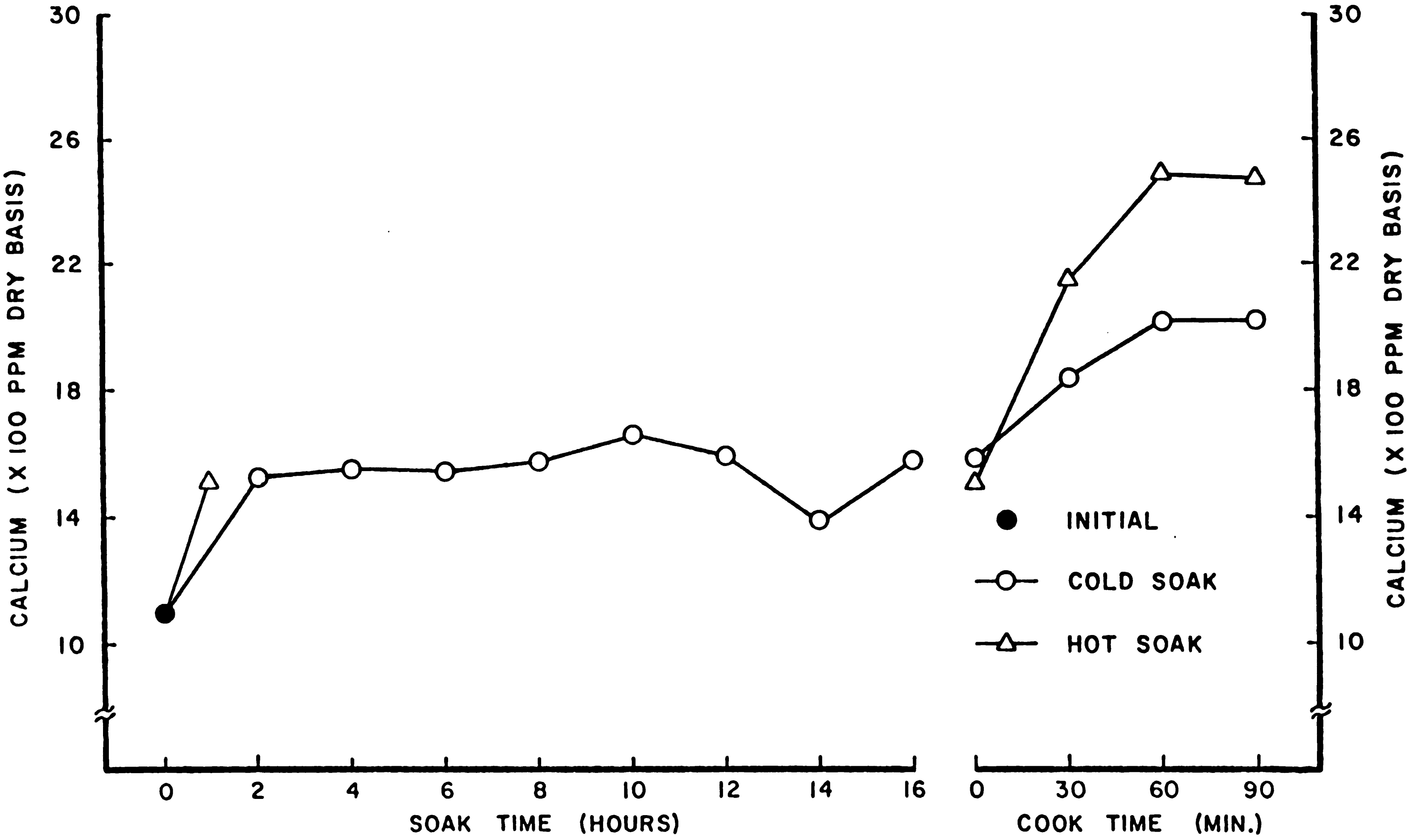

Figure 16. Changes of calcium content during preparation of kidney beans.

Table 9. Analysis of variance for changes of mineral content during preparation of navy beans.

Source of variation	df	Mean Squares								
		Ca	Cu	Fe	Mg	Mn	Na	P	Zn	K
Main effects	3	6846.8	0.588 **[1]	7.207 **	25312.7 ***	0.252 *	406.1	98790.6 ***	0.300 ***	0.387 E+07 ***
Soak method (SM)	1	9804.1	1.718 ***	20.150 ***	61633.3 ***	0.559 **	65.3	213867.0 ***	0.301 **	0.930 E+07 ***
Cook time (CT)	2	5368.1	0.024	0.736	7152.3 **	0.098	576.6	41252.3 ***	0.300 **	0.115 E+07 ***
Two-way										
SM x CT	2	11188.1 *	0.943 **	2.772 *	54.3	0.198 *	1183.1 *	1603.0	0.391 ***	90484.3 ***
Residual	6	2030.1	0.043	0.479	91.3	0.034	161.7	1242.7	0.015	428.3
%CV		1.8	2.133	0.865	0.7	0.952	23.3	0.7	0.359	0.2

1. Indicate probability level of significance:
   * $P \leq 0.05$
   ** $P \leq 0.01$
   *** $P \leq 0.001$

Table 10. Analysis of variance for changes of mineral content during preparation of kidney beans.

Source of variation	df	Mean Squares								
		Ca	Cu	Fe	Mg	Mn	Na	P	Zn	K
Main effects	3	216218.0 ***[1]	0.634 *	4.349	18285.1 **	2.976 ***	2701.3	13148.6	10.856 *	0.311 E+07 ***
Soak method (SM)	1	486421.3 ***	1.394 **	3.403	34240.1 **	0.258 *	1745.8	16875.0	15.436 *	0.621 E+07 ***
Cook time (CT)	2	81116.3 **	0.254	4.823	10307.6 *	4.335 ***	3179.0	11285.3	8.566 *	0.156 E+07 ***
Two-way										
SM x CT	2	6894.3	0.006	0.343	267.6	0.203 *	1152.3	77956.0 *	1.290	65575.0
Residual	6	4368.2	0.077	0.978	1237.1	0.031	1790.9	11152.3	1.593	35884.2
%CV		3.1	3.700	1.380	2.5	0.992	71.3	1.9	2.940	1.6

1. Indicate probability level of significance:
   - * $P \leq 0.05$
   - ** $P \leq 0.01$
   - *** $P \leq 0.001$

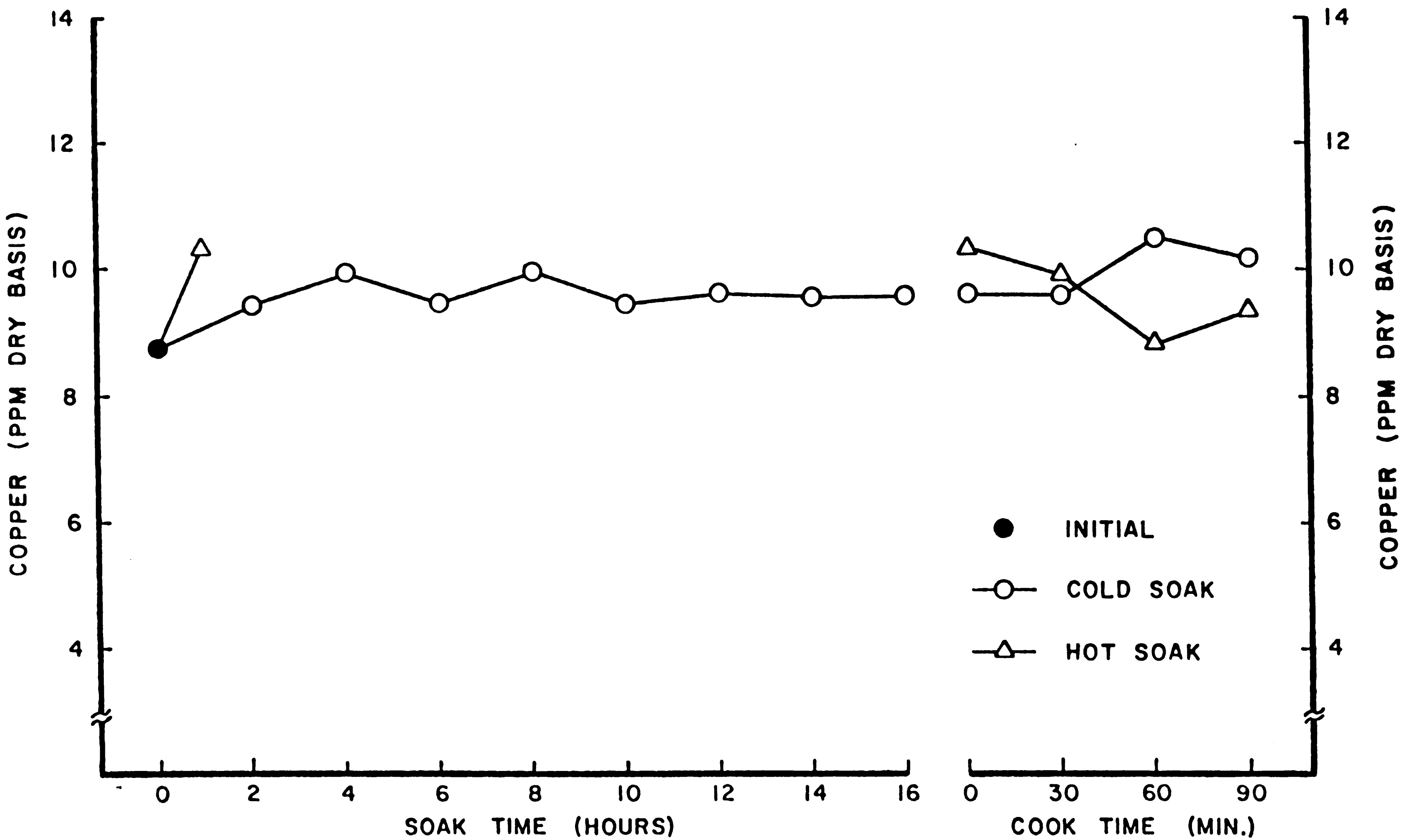

Figure 17. Changes of copper content during preparation of navy beans.

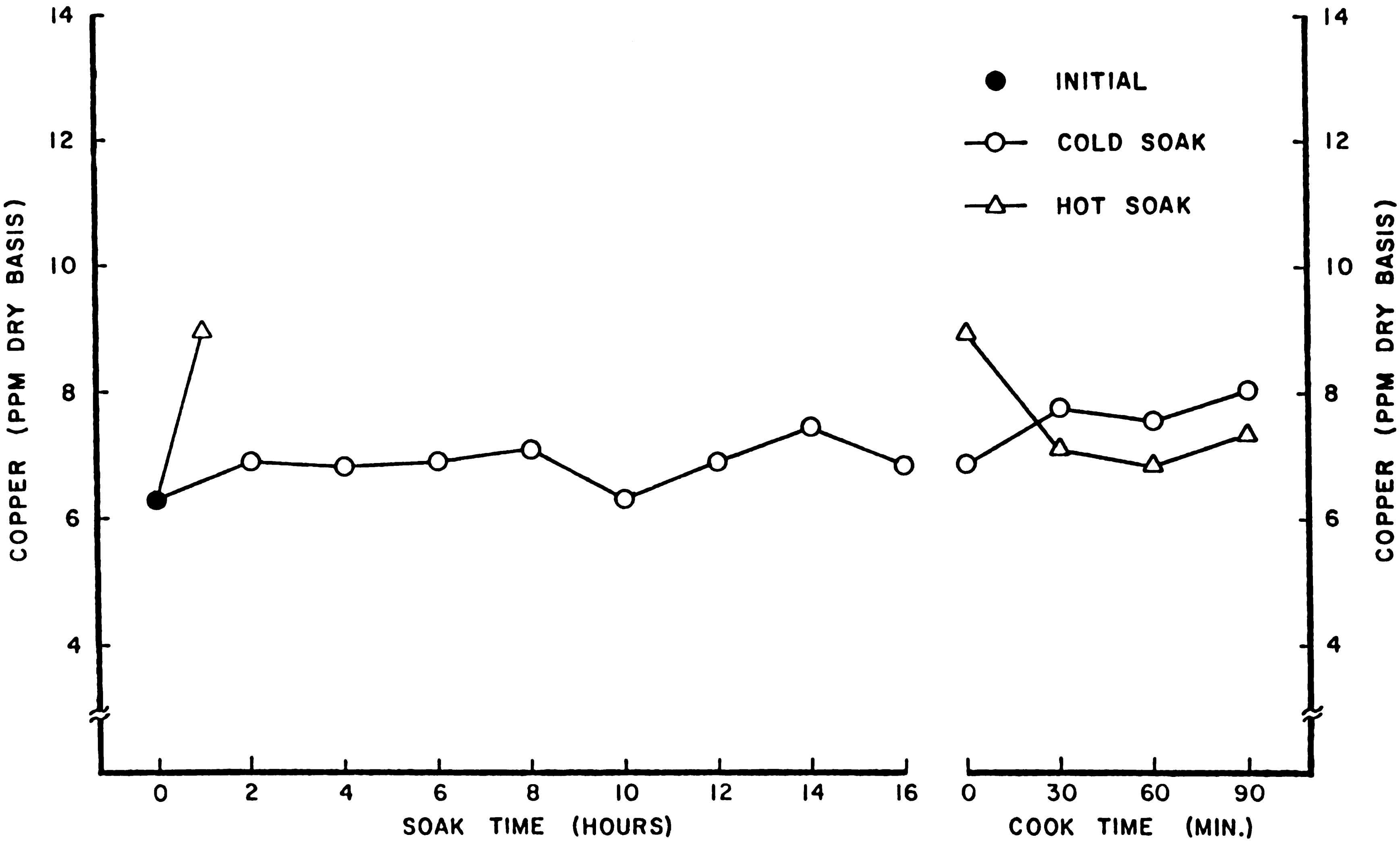

Figure 18. Changes of copper content during preparation of kidney beans.

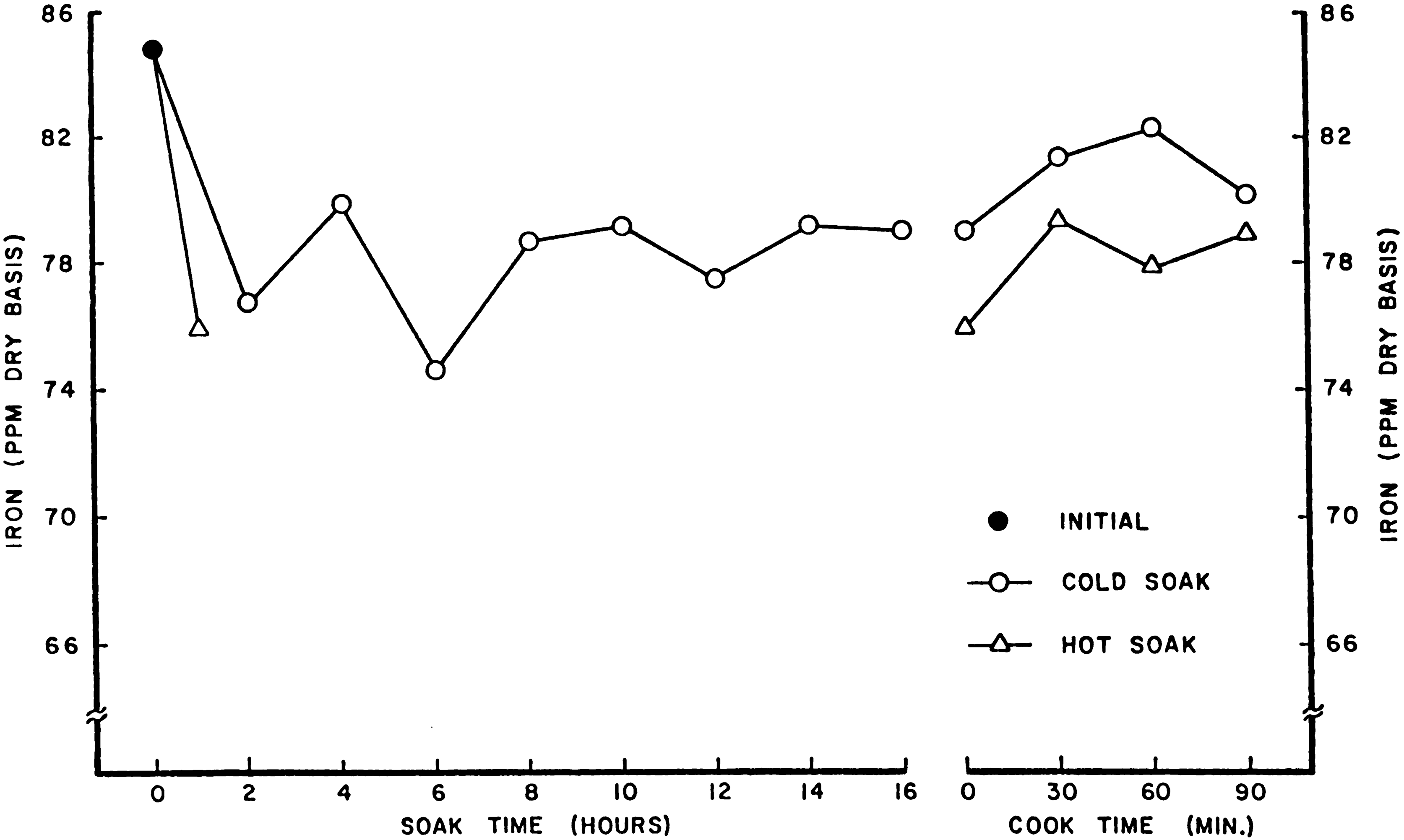

Figure 19. Changes of iron content during preparation of navy beans.

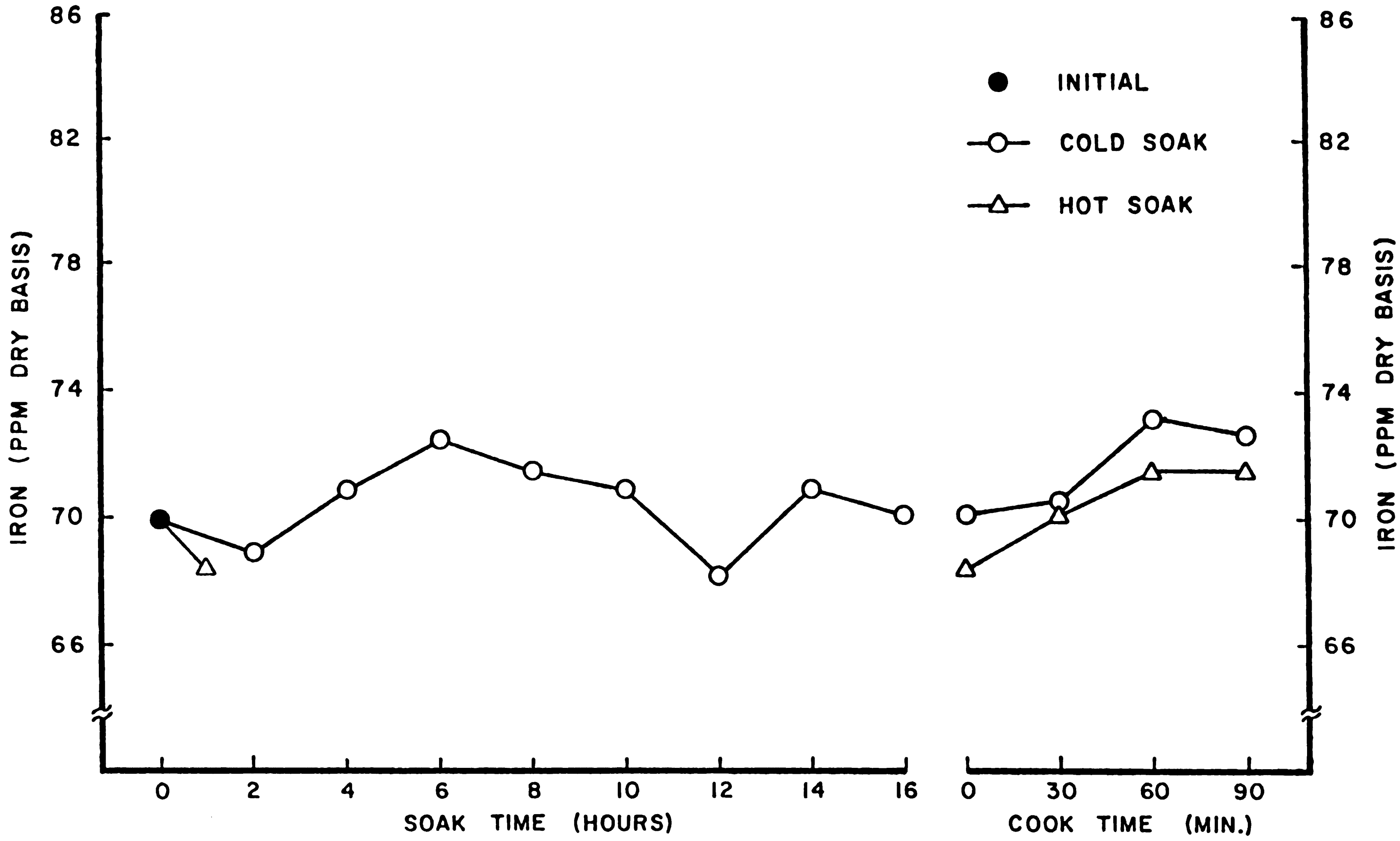

Figure 20. Changes of iron content during preparation of kidney beans.

detected for both navy and kidney beans, but the interactions were not significant (Tables 9 and 10). The amount of magnesium did not change markedly in cold-soaking (Figures 21 and 22). Hot-soaked navy beans showed greater decrease than did kidney beans. Significant losses occurred during cooking, with greater losses observed in hot-soaked beans. Navy and kidney beans showed little reduction of manganese from either hot- or cold-soaking as compared to the original manganese amount (Tables 7 and 8; Figures 23 and 24). For navy beans, the cook time had negligible effect on the amount of manganese, but soaking method was significant (Table 9). All treatments and treatment interactions were significant for kidney beans (Table 10). The range of sodium content reported in both bean types was very wide and the values showed high fluctuation during the whole preparation process (Tables 7 and 8; Figures 25 and 26). This might be associated with the procedures in both preparation of beans and analysis of minerals. Hot-soaking and cooking were performed in glass containers, from which the sodium could be dissolved into soaking and cooking media. The inherently low sodium concentration in beans might also cause high error in sodium analysis. These might be the contributary factors to the large variability of sodium content in processed beans. However, the overall outlook did not reveal significant changes of sodium during soaking and cooking. The analysis of variance (Tables 9 and 10) showed insignificance of treatment and treatment

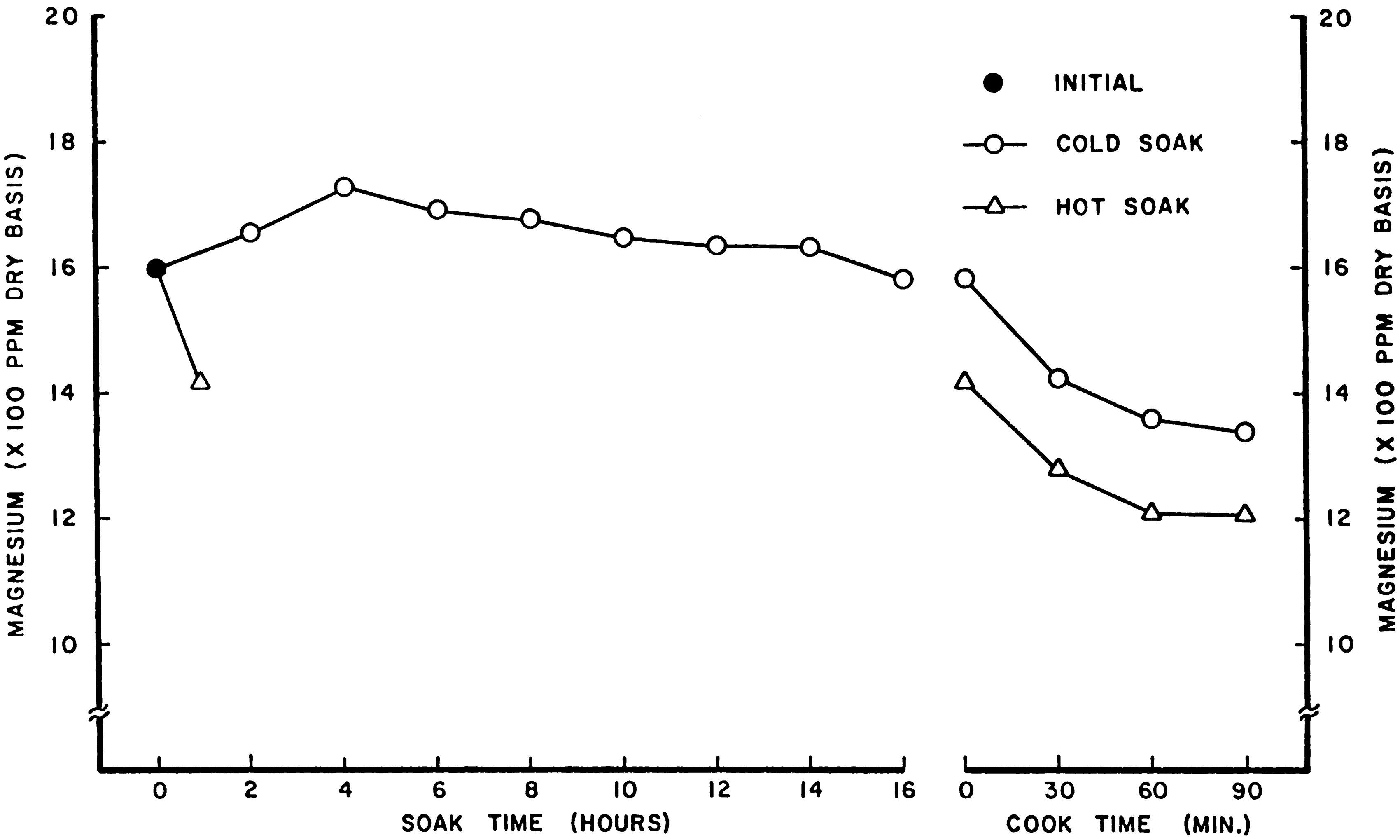

Figure 21. Changes of magnesium content during preparation of navy beans.

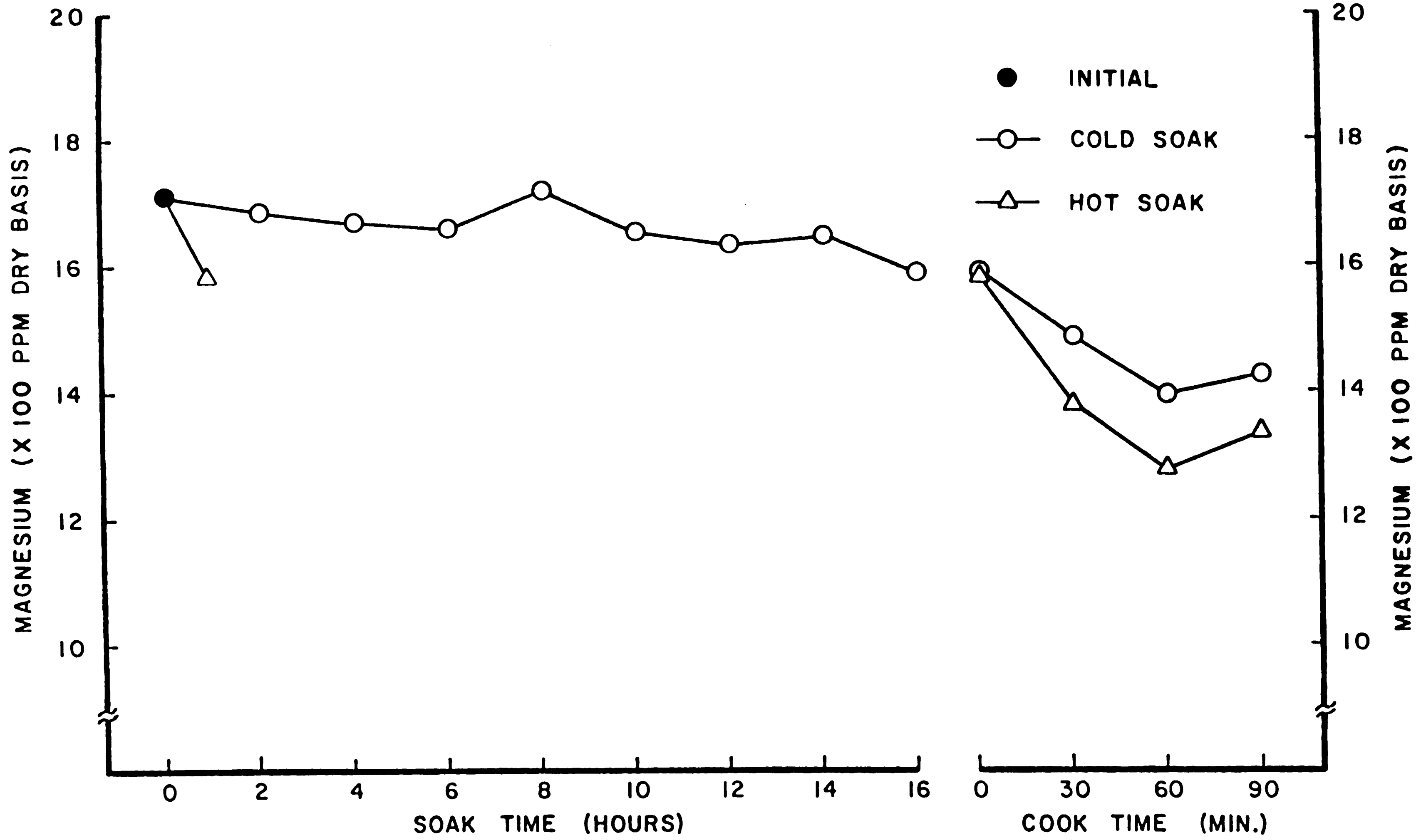

Figure 22. Changes of magnesium content during preparation of kidney beans.

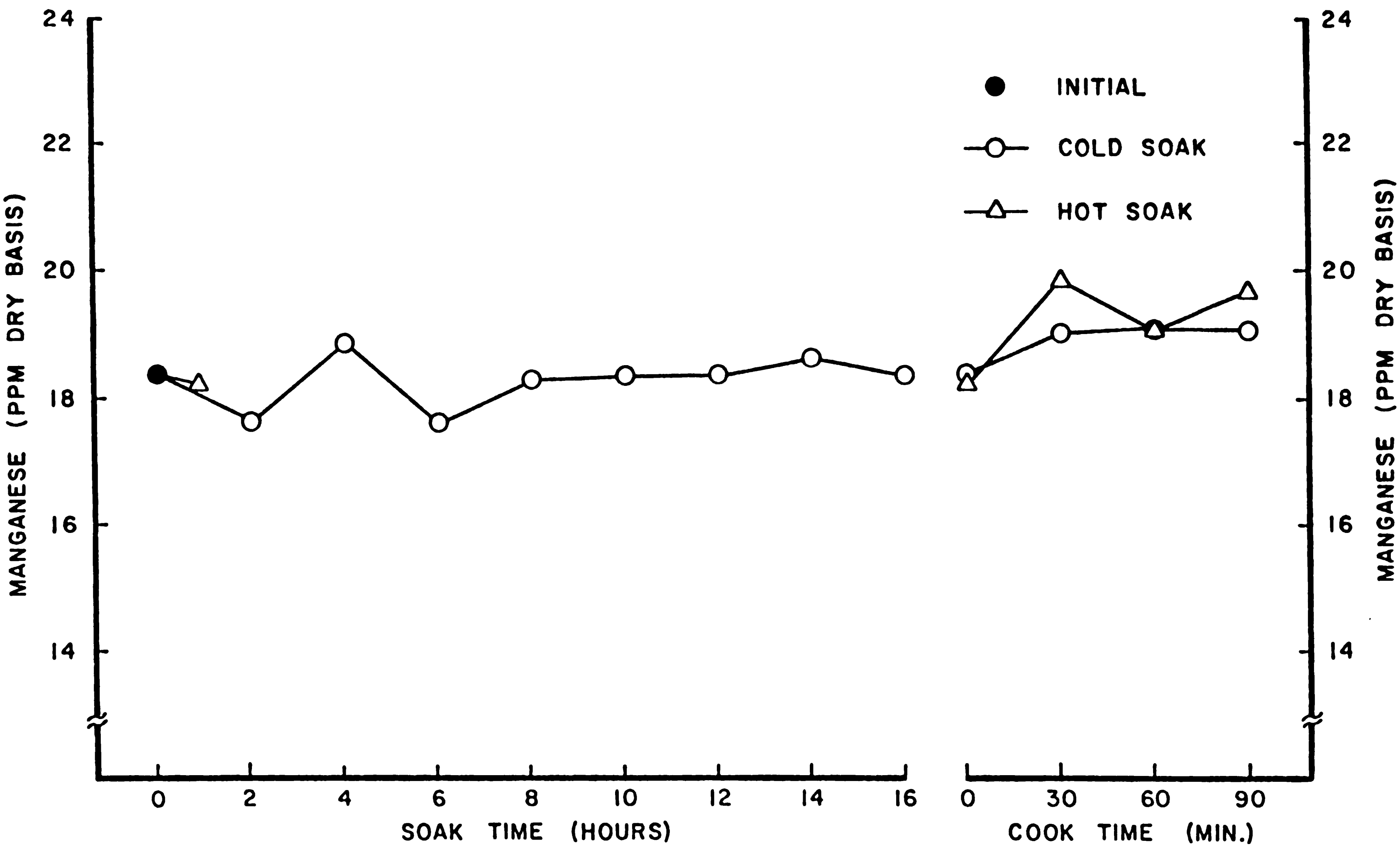

Figure 23. Changes of manganese content during preparation of navy beans.

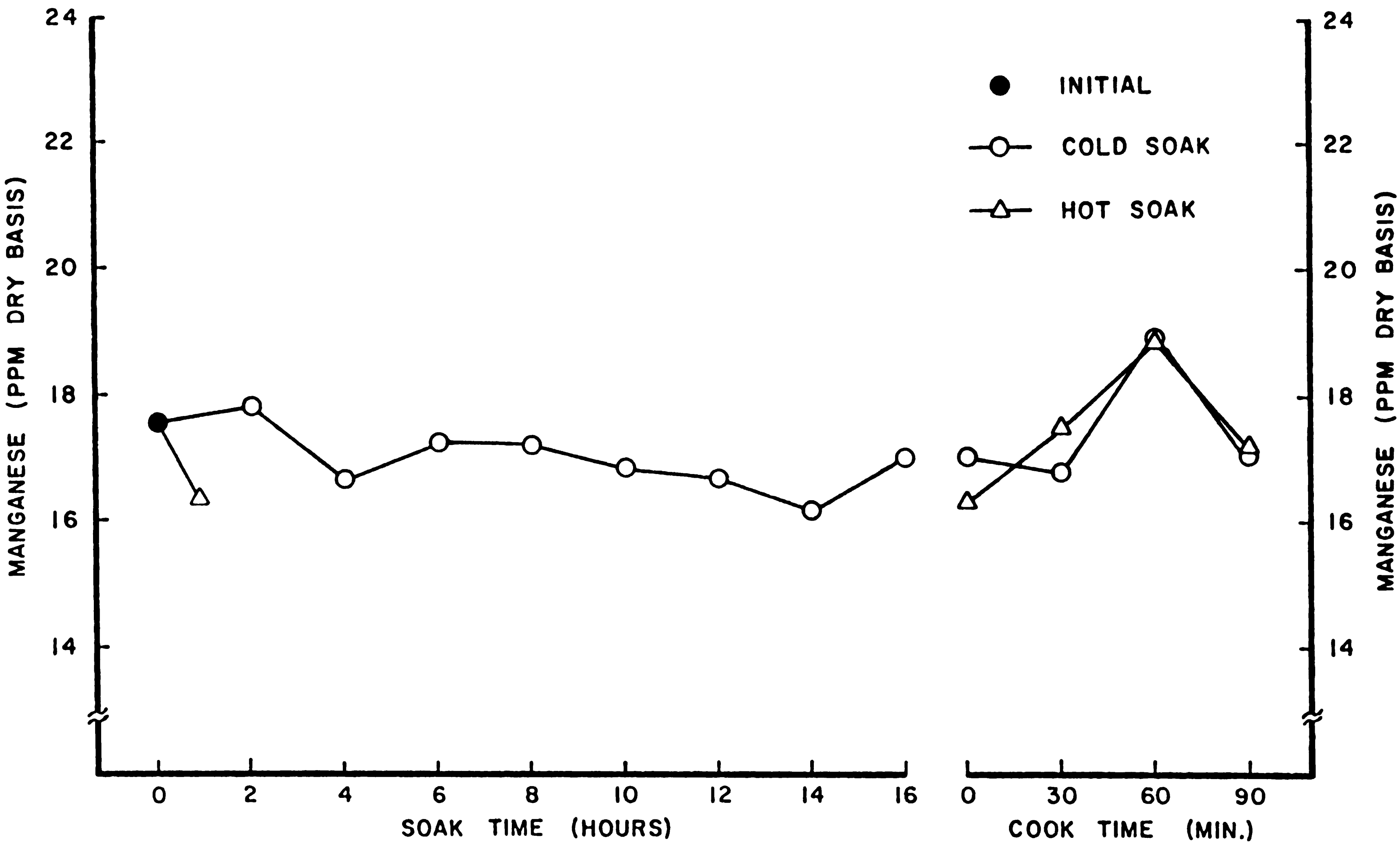

Figure 24. Changes of manganese content during preparation of kidney beans.

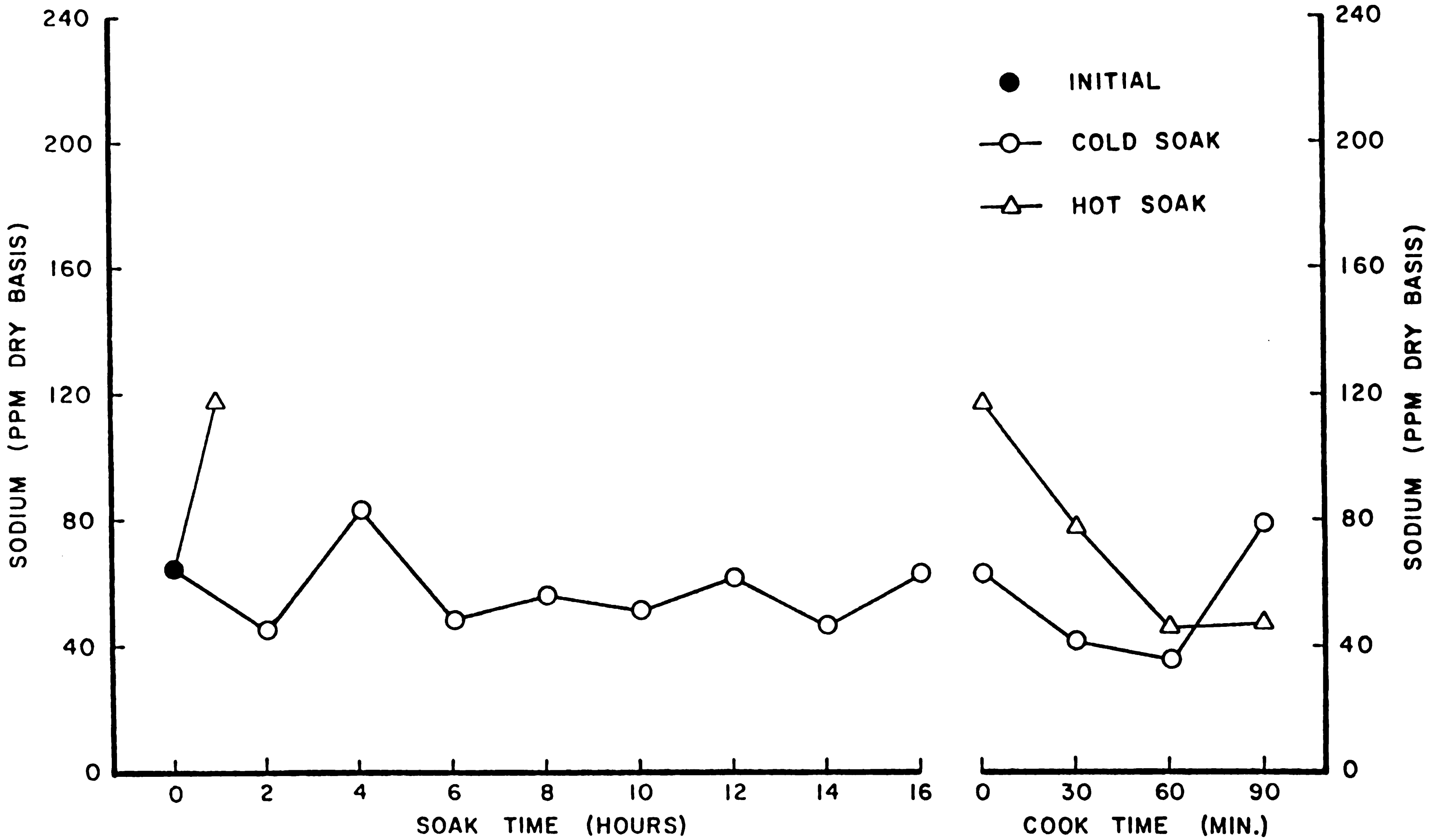

Figure 25. Changes of sodium content during preparation of navy beans.

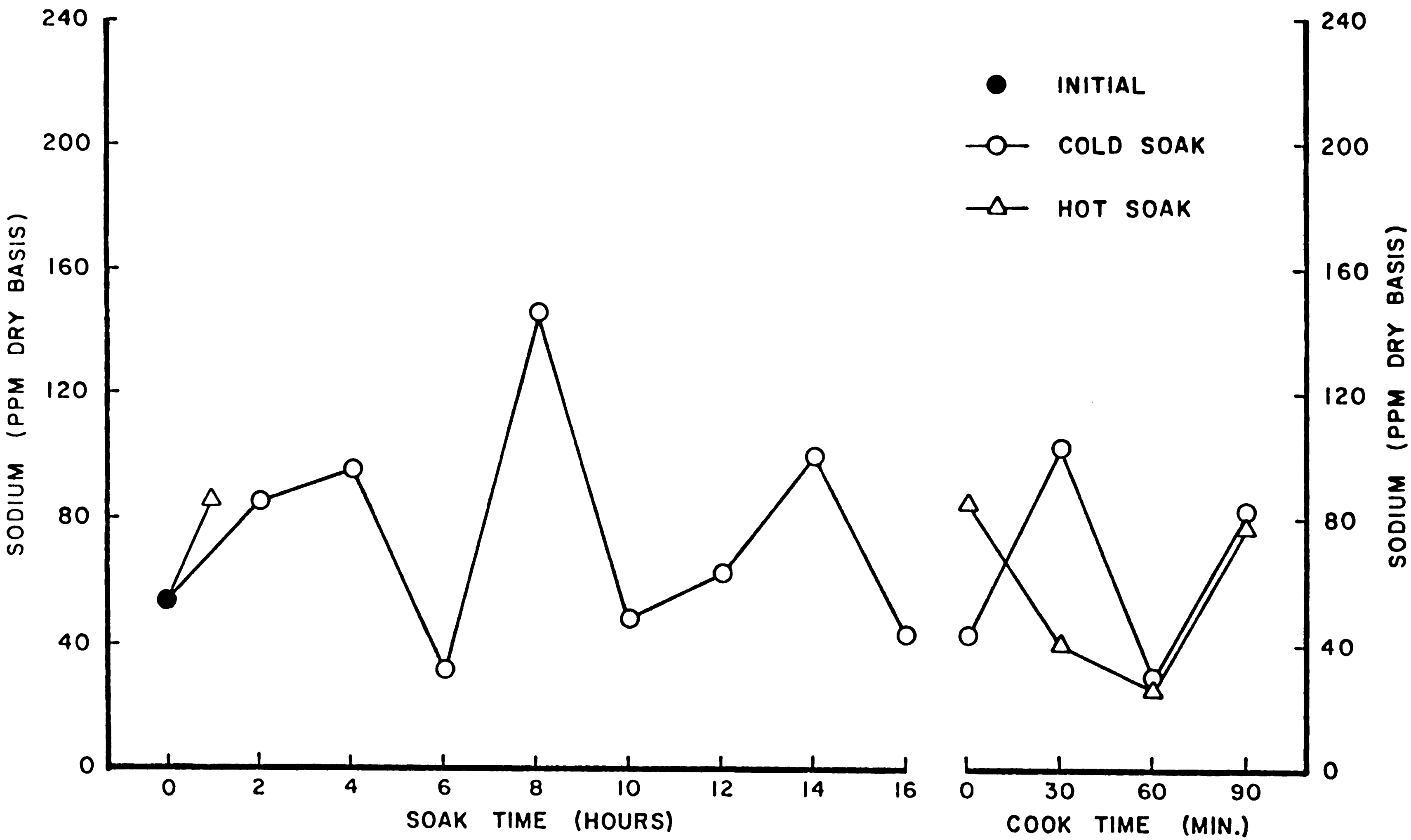

Figure 26. Changes of sodium content during preparation of kidney beans.

interaction effects on kidney beans, but the treatment interaction had slight effect on navy beans.

All treatments had pronounced effects on phosphorus content in navy beans but treatment interaction was not important (Tables 9 and 10). The reverse was true with kidney beans, on which the treatment interaction produced little effect. Oneway analysis (Tables 7 and 8) indicated greater reduction of phosphorus during cooking than during soaking. Hot-soaked beans showed higher losses than did cold-soaked beans (Figures 27 and 28). The zinc content in kidney beans was less affected by treatments and treatment interaction than in navy beans (Tables 9 and 10). Reduction of zinc from hot-soaking was greater than that from cold-soaking and cooking of beans resulted in higher losses of zinc than soaking (Figures 29 and 30; Tables 7 and 8).

Of all the minerals studied, potassium showed the highest decrease after cooking although insignificant reduction was observed during cold-soaking (Figures 31 and 32). Hot-soaking resulted in greater loss than did cold-soaking. Hot-soaked beans lost more potassium than did 16-hour-soaked beans after cooking (Tables 7 and 8). The analysis of variance (Tables 9 and 10) indicated significance of all treatment and treatment interaction effects on both navy and kidney beans.

Research has been conducted to evaluate mineral losses from beans after cooking. Meiners et al. (1976b) soaked beans in a similar manner as hot-soaking of the current

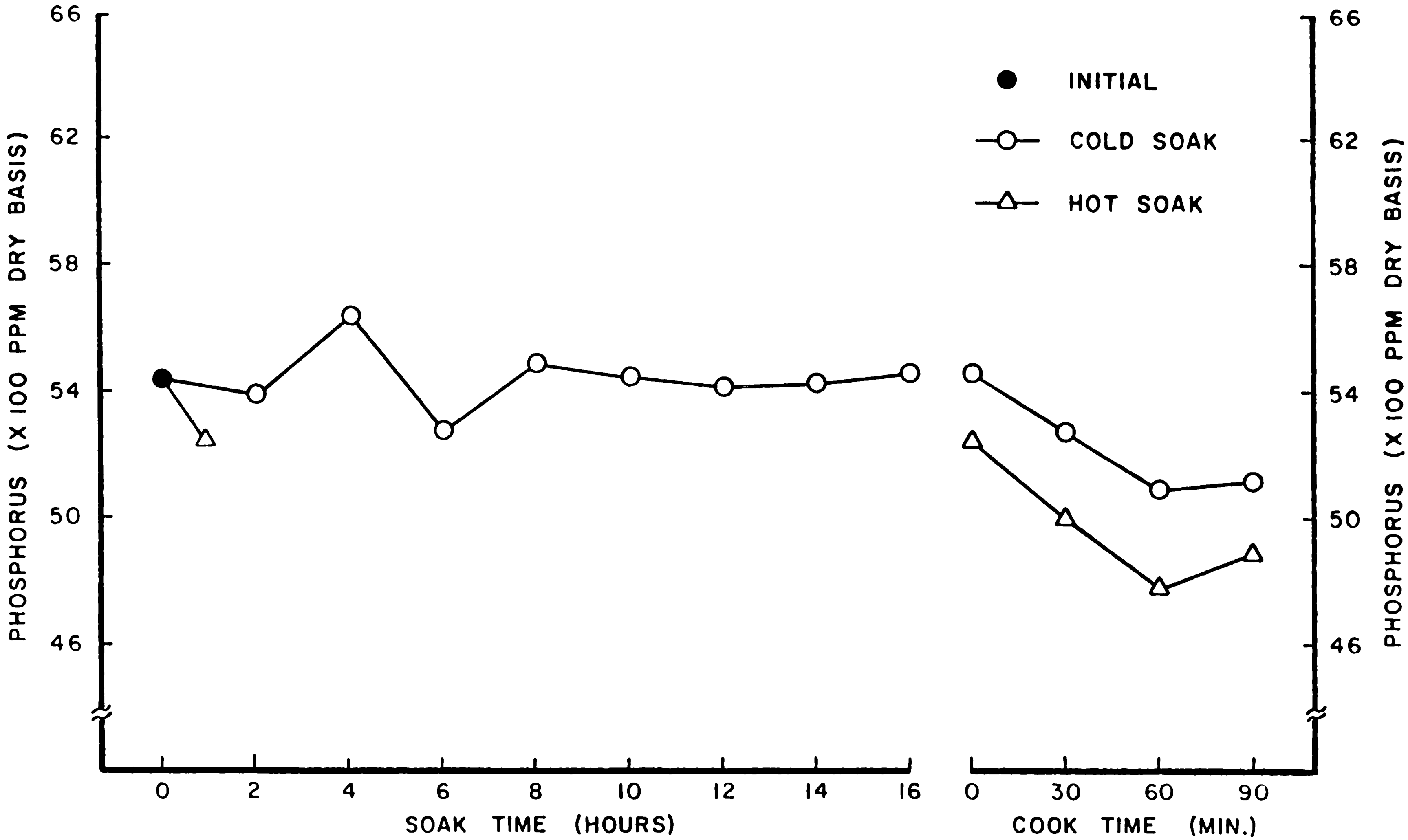

Figure 27. Changes of phosphorus content during preparation of navy beans.

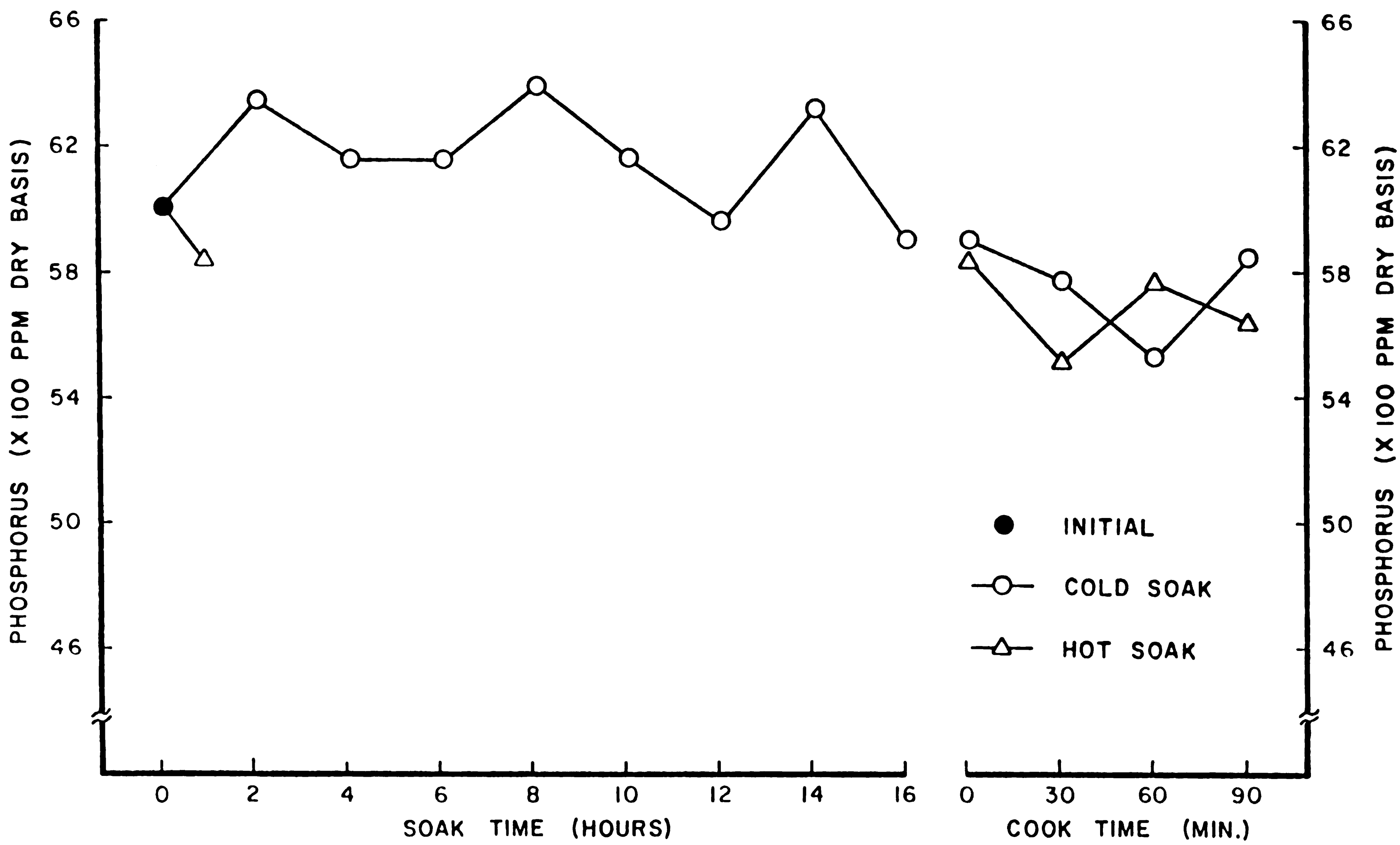

Figure 28. Changes of phosphorus content during preparation of kidney beans.

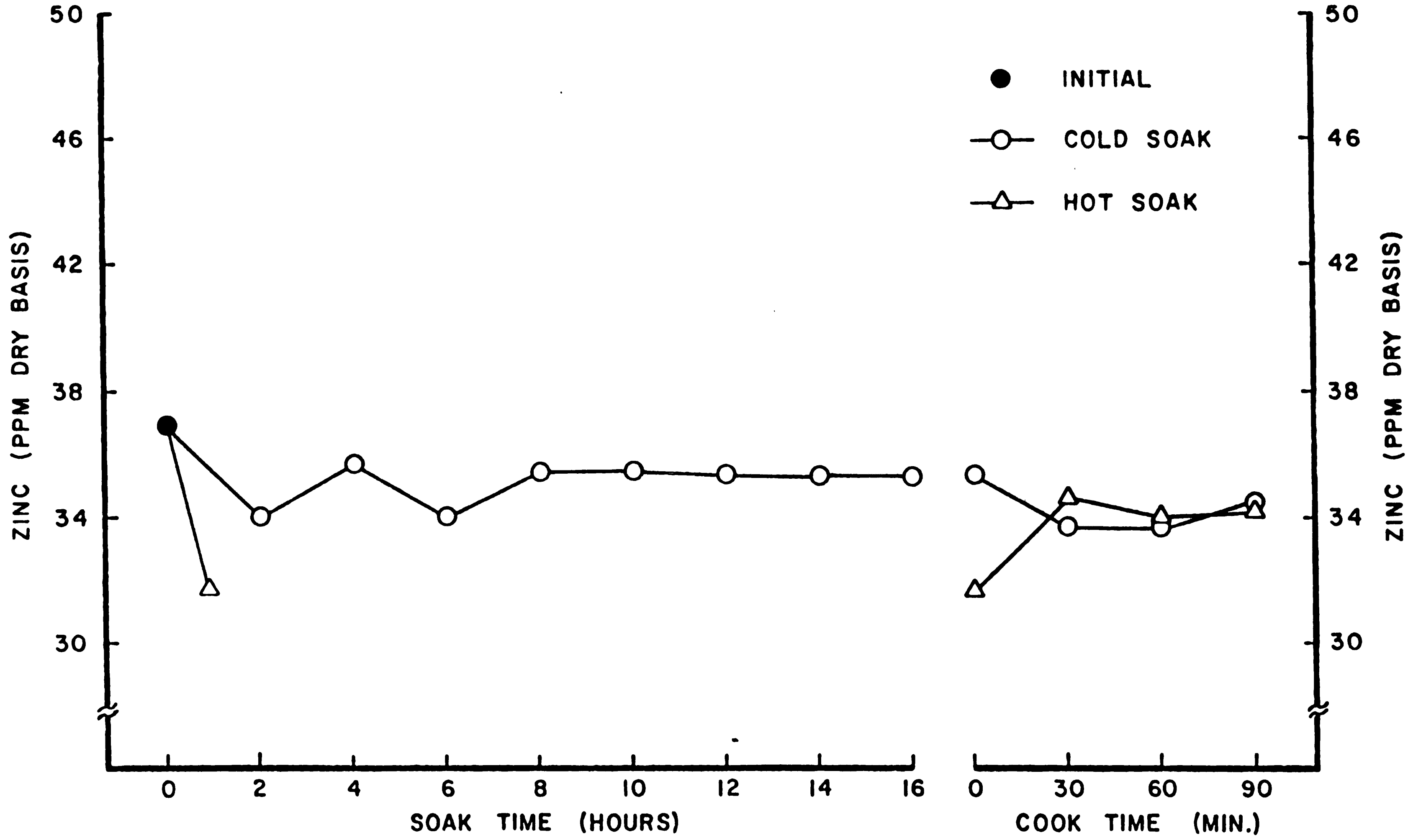

Figure 29. Changes of zinc content during preparation of navy beans.

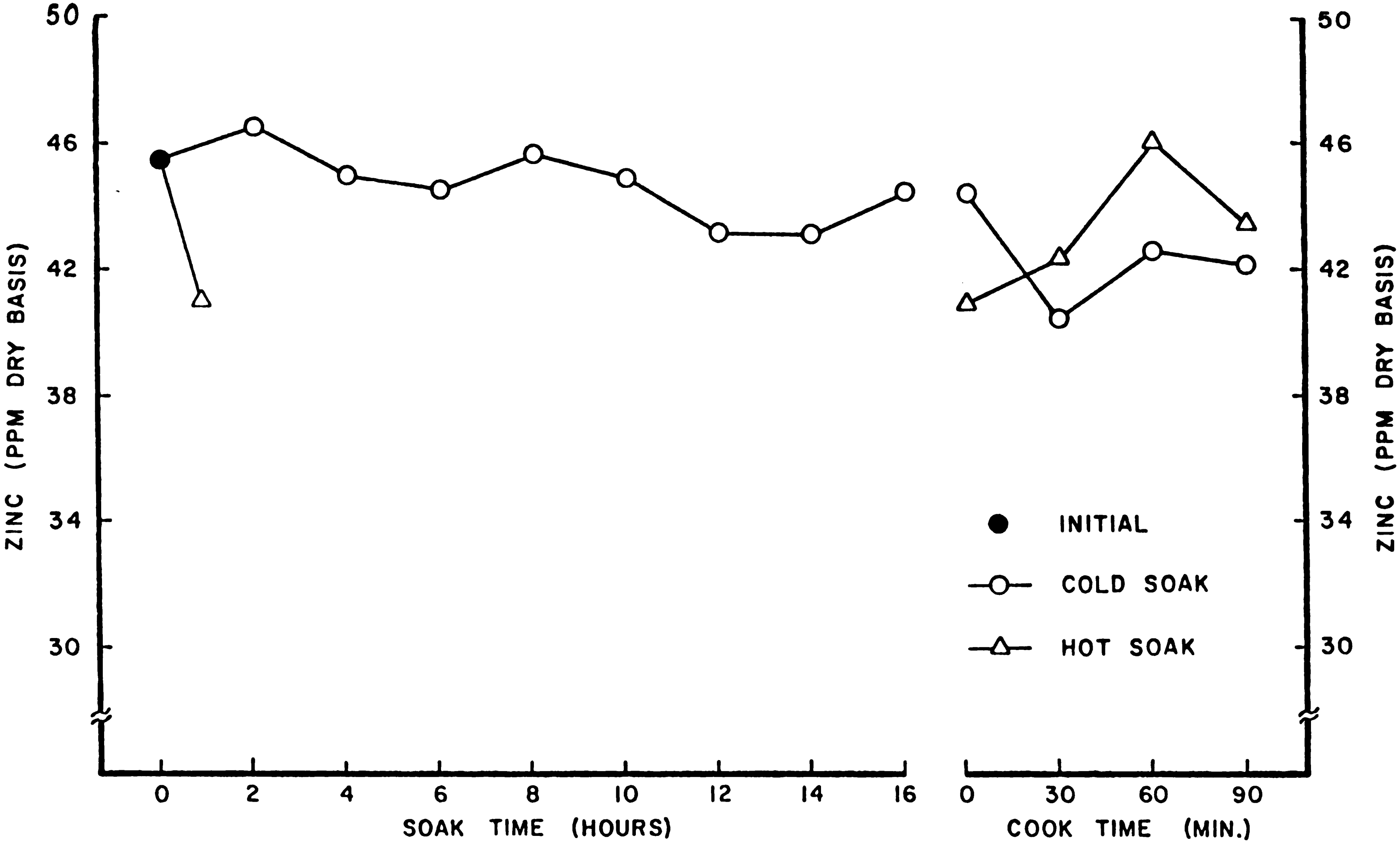

Figure 30. Changes of zinc content during preparation of kidney beans.

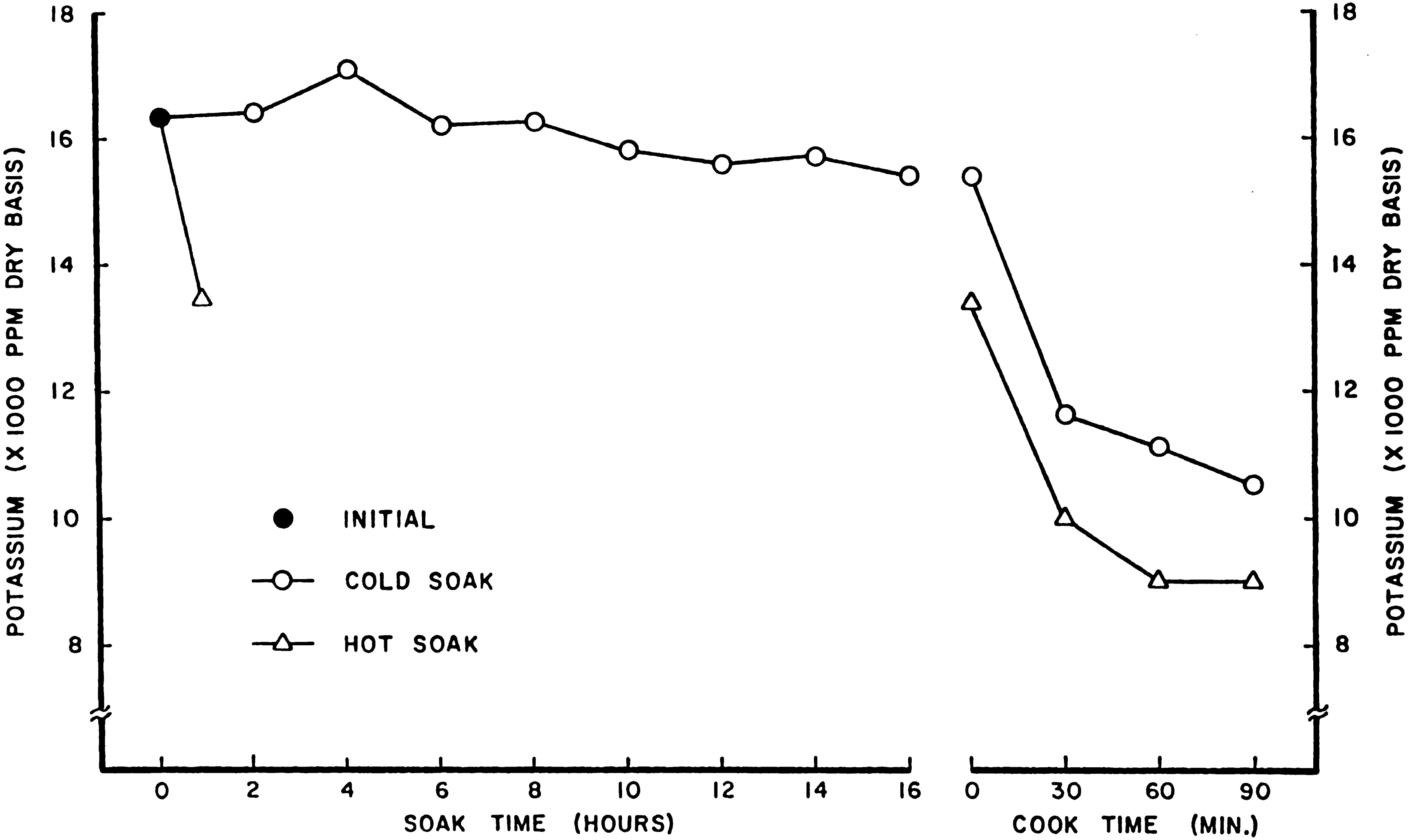

Figure 31. Changes of potassium content during preparation of navy beans.

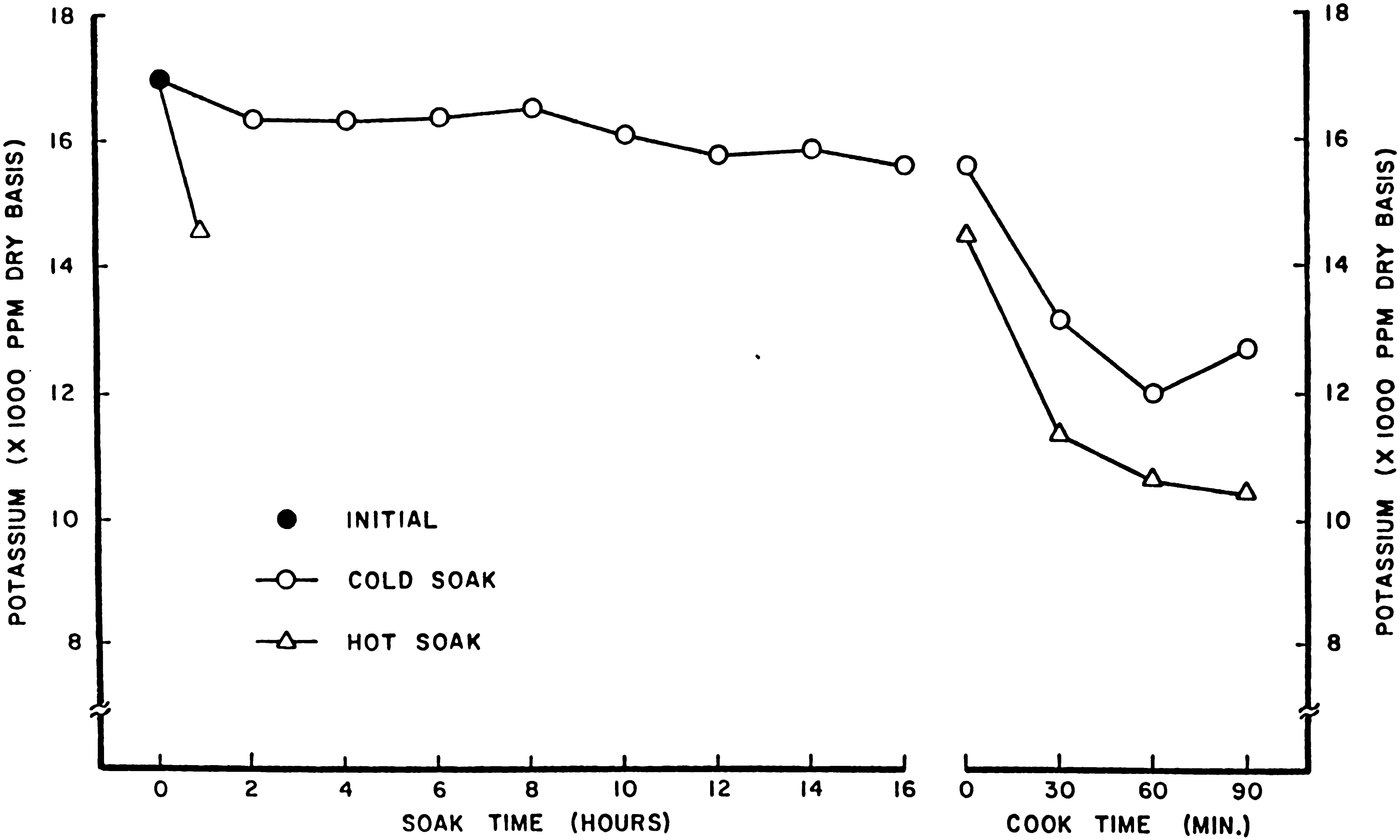

Figure 32. Changes of potassium content during preparation of kidney beans.

study. Navy and kidney beans were then cooked in excess water for 75 and 90 minutes, respectively. The same hot-soaking treatment was undertaken by Augustin et al. (1981), but both navy and kidney beans were cooked in limited amount of water for 45 minutes. Koehler and Burke (1981) also examined the minerals in raw and cooked (then freeze-dried) beans but the method of bean preparation was not mentioned. The mineral losses from hot-soaking and 90-minute-cooking in the current study were compared to the values from these researchers. All values in the current study were totally different from those of Meiners et al. (1976b), who reported 50% to 70% losses of most minerals after cooking. Increase in calcium content was in good agreement with Koehler and Burke (1981) and Augustin et al. (1981). Copper retention was higher than that of Augustin et al. (1981). Data of iron was consistent with Augustin et al. (1981) but was higher than the iron retention of Koehler and Burke (1981). The losses of magnesium were greater than those of Augustin et al. (1981) while manganese losses were in good agreement. Sodium retentions in all studies were completely different and a good conclusion could not be made. This might be due to differences in preparation procedures and analytical methods as described previously. Reduction of phosphorus was similar to the result from Augustin et al. (1981). Koehler and Burke (1981) reported greater loss of zinc than that of Augustin et al. (1981) and the current study. Potassium reduction was in the range of 38% to 45% while

Augustin et al. (1981) reported 12% to 17%. However, the values from the current study were slightly higher than 32% to 35% range found by Koehler and Burke (1981).

Sugars. Sucrose was found to be the most abundant of all sugars in both navy and kidney beans in this study (Tables 11 and 12), followed by stachyose, raffinose and glucose, respectively. The data reported in raw beans were in good agreement with the values compiled by Reddy et al. (1984).

Substantial reduction of all sugars was found during bean preparation (Figures 33-36). Loss of glucose was reported in navy beans, with a decrease to a nondetectable level after 16 hours of cold-soaking and hot-soaking. Glucose in cooked navy beans could not be detected at all. Significant reduction of glucose in kidney beans was also illustrated, with remarkably higher decrease from hot-soaking method. In navy beans, the reduction of sucrose after soaking by either method was about 60% and differences between soaking methods were not significant. In kidney beans, cold-soaking resulted in higher decrease of sucrose. Greater losses of sucrose occurred during cooking than during soaking and hot-soaked beans lost more sucrose into the cook water than did cold-soaked beans. Appreciable decrease of raffinose was also observed. In navy beans, raffinose in cold-soaked beans could not be detected after 90 minutes of cooking, while hot-soaked beans lost all raffinose after cooking for 30 minutes. Raffinose in kidney

Table 11. Changes of sugar content during preparation of navy beans.[1,2]

	Glucose	Sucrose	Raffinose	Stachyose
COLD SOAKING				
Raw beans	0.12 a	2.50 c	0.27 a	2.32 b
Soak time				
8 hours	0.10 a	2.05 b	0.44 a	1.35 a
16 hours	ND	1.44 a	0.42 a	1.15 a
Cook time (after 16 hours soak)[3]				
30 minutes	ND	1.03 b	0.27 a	0.88 b
60 minutes	ND	0.76 a	0.23 a	0.87 b
90 minutes	ND	0.62 a	ND	0.73 a
HOT SOAKING				
Raw beans	0.12 a	2.50 c	0.27 a	2.32 b
Hot-soaked beans	ND	1.42 a	0.22 a	1.38 a
Cook time (after 16 hours soak)[3]				
30 minutes	ND	0.63 c	ND	0.76 b
60 minutes	ND	0.52 b	ND	0.60 a
90 minutes	ND	0.40 a	ND	0.53 a

1. Like letters within each column indicate no significant differences ($P \leq 0.05$).
2. All values are in per cent (dry basis).
3. Tukey mean separation within this group was done separately.

Table 12. Changes of sugar content during preparation of kidney beans.[1,2]

	Glucose	Sucrose	Raffinose	Stachyose
COLD SOAKING				
Raw beans	1.20 b	2.47 ab	0.37 a	1.73 b
Soak time				
8 hours	0.96 b	2.26 ab	0.42 a	1.46 a
16 hours	0.91 b	2.03 a	0.42 a	1.36 a
Cook time (after 16 hours soak)[3]				
30 minutes	0.83 a	1.91 b	0.41 b	0.94 b
60 minutes	0.49 a	1.90 b	0.26 ab	0.83 a
90 minutes	0.30 a	1.67 a	0.17 a	0.78 a
HOT SOAKING				
Raw beans	1.20 b	2.47 ab	0.37 a	1.73 b
Hot-soaked beans	0.26 a	2.66 b	0.39 a	1.47 ab
Cook time (after 16 hours soak)[3]				
30 minutes	0.08 a	1.85 b	0.19 a	0.84 a
60 minutes	0.06 a	1.38 a	0.16 a	0.71 a
90 minutes	0.03 a	1.28 a	0.16 a	0.65 a

1. Like letters with in each column indicate no significant differences ($P \leq 0.05$).
2. All values are in per cent (dry basis).
3. Tukey mean separation within this group was done separately.

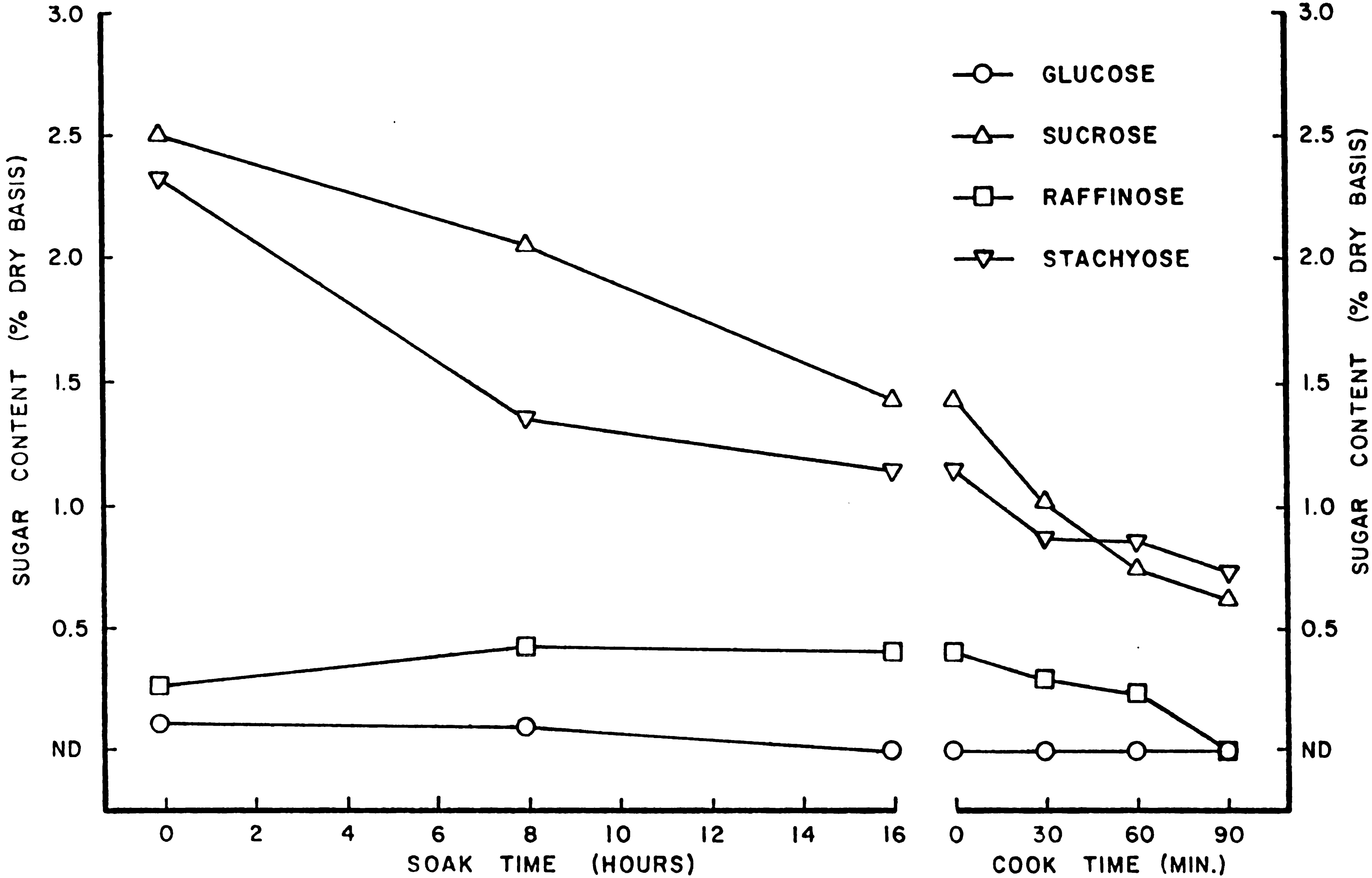

Figure 33. Changes of sugar content during cold soak preparation of navy beans.

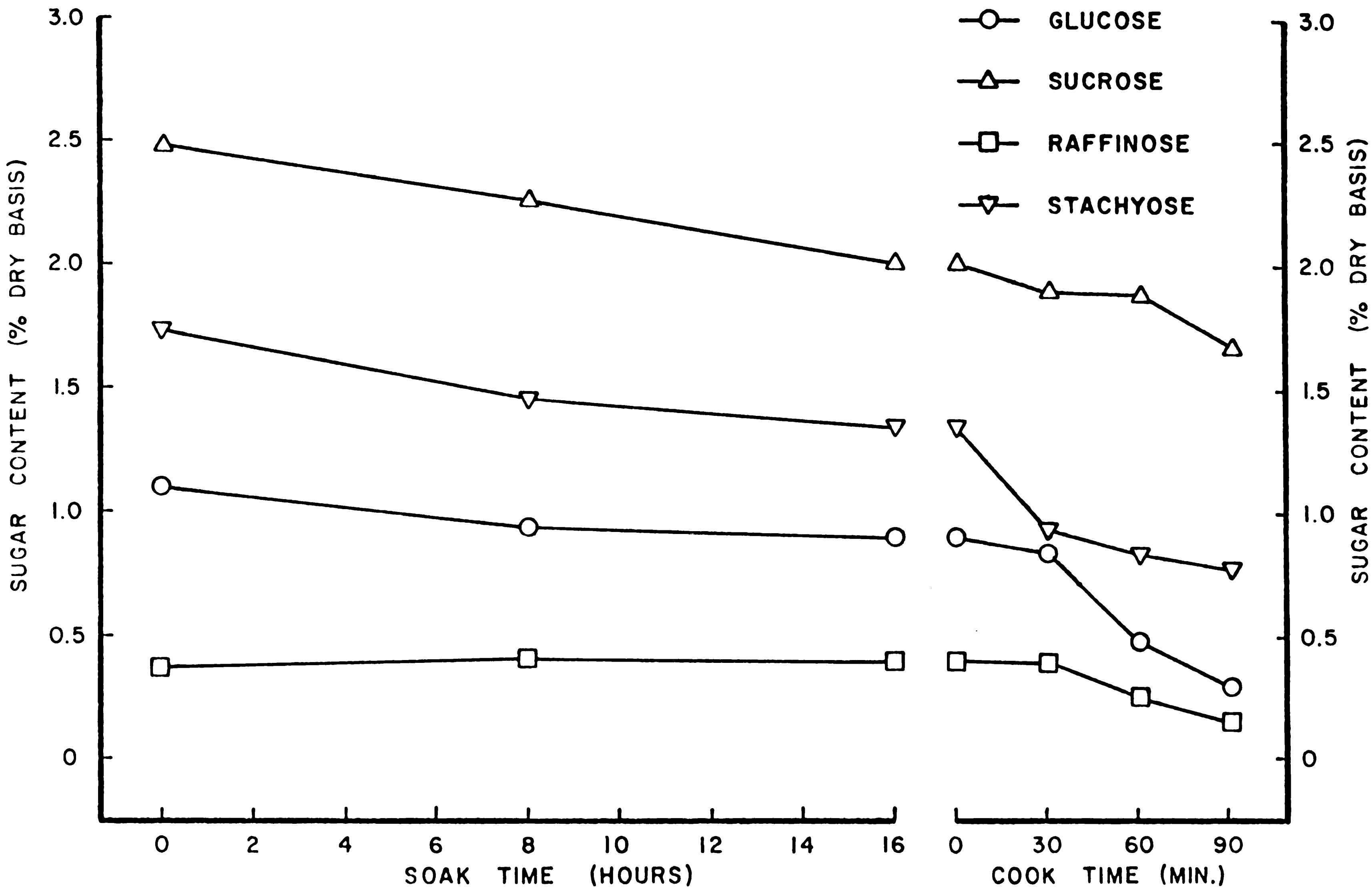

Figure 34. Changes of sugar content during cold soak preparation of kidney beans.

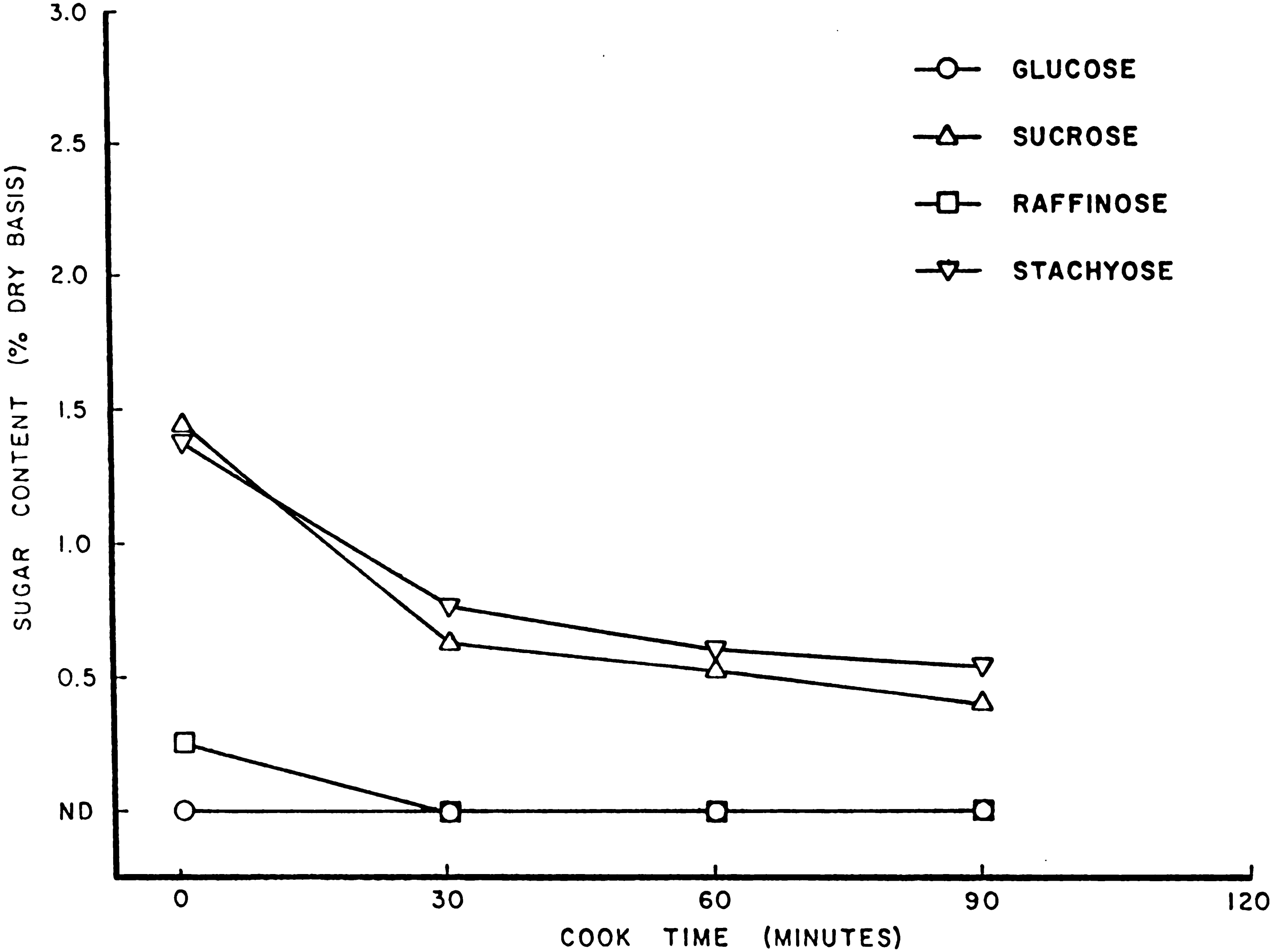

Figure 35. Changes of sugar content during hot soak preparation of navy beans.

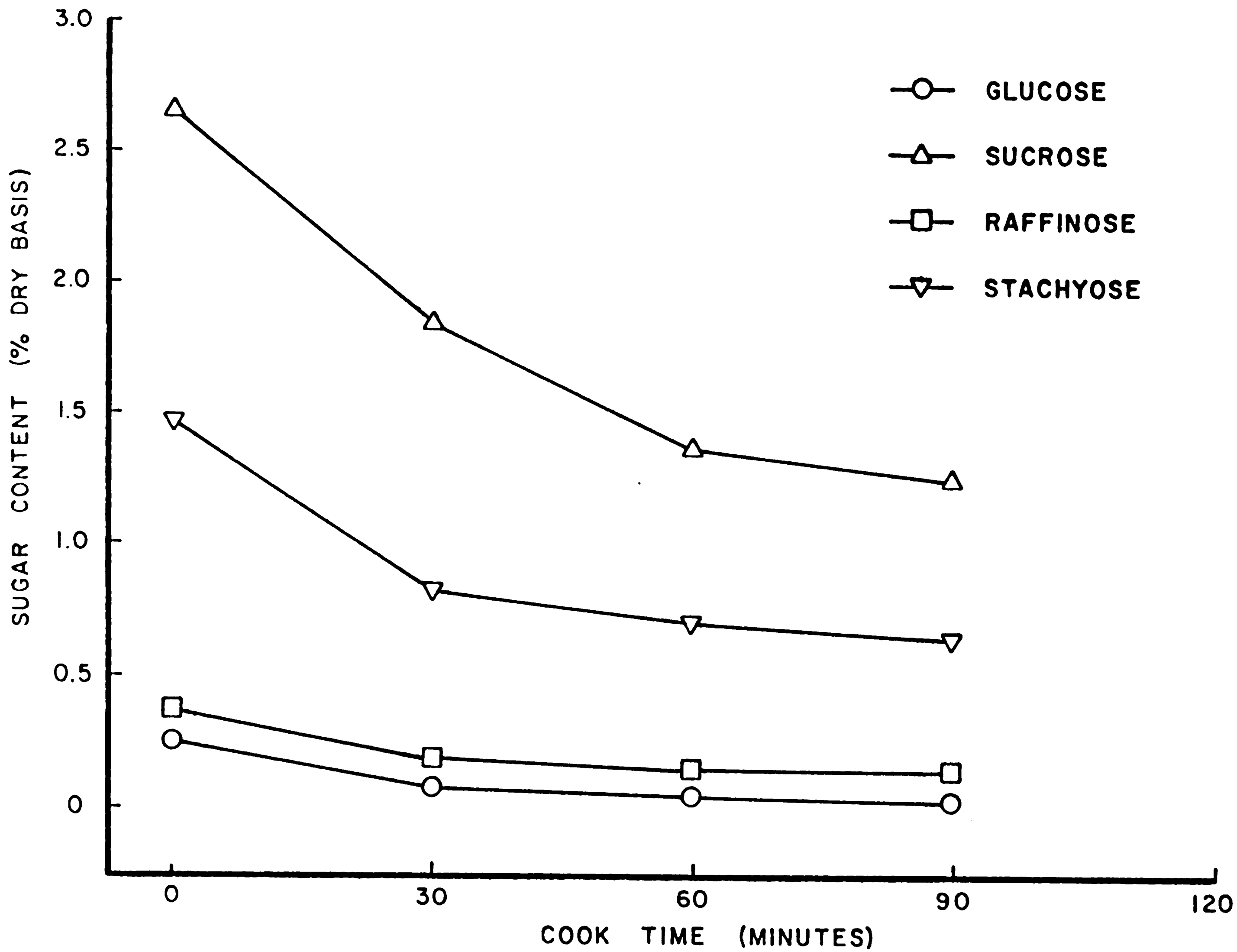

Figure 36. Changes of sugar content during hot soak preparation of kidney beans.

beans showed a smaller decrease and was still detectable after cooking. Again, hot-soaked beans were reported to lose more raffinose than did cold-soaked beans. For stachyose, soaking method did not produce significant effects and similar trends were found in cooked beans of different soaking preparation.

From the stand point of oligosaccharide removal, navy beans showed 20.93% loss of raffinose when they were hot-soaked and the raffinose was nondetectable after the beans were hot-soaked and cooked. Sixteen hours of cold-soaking and hot-soaking resulted in 50.71% and 40.83% decrease of stachyose, respectively. When these soaked beans were cooked for 90 minutes, 68% to 77% reduction of stachyose occurred. Therefore, about 39% of oligosaccharides were removed from hot-soaking, and 90 minutes cooking of hot-soaked and 16-hour-soaked beans caused 79.57% and 71.94% decrease of oligosaccharides, respectively. The results were in good agreement with the values reported in the literature (Ku et al., 1976; and Iyer et al., 1980). In kidney beans, 35.45% and 30.05% of oligosaccharides were removed from 16-hour-soaking and hot-soaking respectively. After these beans were cooked for 90 minutes and cook water was discarded, 54% to 62% decrease in oligosaccharides resulted. The values for kidney beans were lower than those from the literature, possibly due to differences in sugar analysis techniques.

Kettle Cooking

The effects of soak time and cook time were investigated in navy and kidney beans cooked in a steam kettle at 190 ^{o}F (87.8 ^{o}C). Mean values and Tukey mean separations for the results are presented in Tables 13, 14, 17, and 18. Analysis of variance are summarized in Tables 15, 16, 19, and 20 and graphical presentation of all data are in Figures 37 to 40.

Shear Force. High significance was noted for the effects of both soak and cook time as well as their interaction (Tables 15 and 16). As the cook time increased, the beans of all soaking treatments became softer (Tables 13 and 14). It was graphically shown (Figures 37 and 38) that regardless of cook time applied, the shear force decreased dramatically as the soak time increased to 8 hours, but there was no significant change after that. However, oneway analysis (Tables 13 and 14) indicated no significant difference in the firmness of beans soaked differently while cooked for the same length of time.

Protein Content. For kidney beans, the effects of soak time and cook time as well as their interaction were significant (Tables 15 and 16), but soak time did not affect the protein content in navy beans. However, oneway analysis (Tables 13 and 14) showed no significant changes in protein of either bean type during cooking. Noticeable fluctuation could be detected from the values reported and a possible

Table 13. Physical and chemical changes during preparation of navy beans.[1]

Cook time	Shear force[2]	Protein[3]	Ash[3]
0 hour soak (raw beans)[4]			
30 minutes	945 c	24.6 a	3.60 b
60 minutes	705 b	24.9 ab	3.17 a
90 minutes	440 a	25.4 b	3.01 a
8 hours soak			
30 minutes	560 c	24.7 a	3.23 b
60 minutes	475 b	25.1 a	2.98 a
90 minutes	390 a	25.7 a	2.93 a
12 hours soak			
30 minutes	610 c	24.3 a	3.16 b
60 minutes	495 b	24.9 a	2.97 a
90 minutes	410 a	25.1 a	2.94 a
16 hours soak			
30 minutes	675 c	25.4 a	3.13 b
60 minutes	510 b	24.9 a	2.92 a
90 minutes	440 a	25.1 a	2.97 a

1. Like letters within each column indicate no significant differences ($P \leq 0.05$).
2. Shear force is expressed in pounds per 100 grams of bean.
3. Protein and ash are expressed in per cent (dry basis).
4. Tukey mean separation for each soak time was done separately.

Table 14. Physical and chemical changes during preparation of kidney beans.[1]

Cook time	Shear force[2]	Protein[3]	Ash[3]
0 hour soak (raw beans)[4]			
30 minutes	1185 c	31.6 a	3.59 b
60 minutes	940 b	33.4 b	3.21 ab
90 minutes	770 a	34.2 b	3.02 a
8 hours soak			
30 minutes	518 a	33.7 a	3.36 b
60 minutes	480 a	34.2 a	3.00 a
90 minutes	460 a	33.7 a	2.87 a
12 hours soak			
30 minutes	525 b	33.0 a	3.29 c
60 minutes	480 a	32.4 a	2.99 b
90 minutes	450 a	33.5 a	2.88 a
16 hours soak			
30 minutes	513 b	33.4 a	3.29 b
60 minutes	490 b	32.9 a	2.98 a
90 minutes	450 a	33.9 a	2.90 a

1. Like letters within each column indicate no significant differences ($P \leq 0.05$).
2. Shear force is expressed in pounds per 100 grams of bean.
3. Protein and ash are expressed in per cent (dry basis).
4. Tukey mean separation for each soak time was done separately.

Table 15. Analysis of variance for physical and chemical changes during preparation of navy beans.

Source of variation	df	Mean Squares		
		Shear force	Protein	Ash
Main effects	5	96747.5 ***[1]	0.316 *	0.142 ***
Soak time	3	58293.1 ***	0.222	0.084 ***
Cook time	2	154429.2 ***	0.458 *	0.230 ***
Two-way				
Soak time x Cook time	6	12301.4 ***	0.298 *	0.019 ***
Residual	12	137.5	0.079	0.002
%CV		2.1	1.125	1.452

1. Indicate probability level of significance:
   * $P \leq 0.05$
   ** $P \leq 0.01$
   *** $P \leq 0.001$

Table 16. Analysis of variance for physical and chemical changes during preparation of kidney beans.

Source of variation	df	Mean Squares		
		Shear force	Protein	Ash
Main effects	5	225528.3 ***[1]	1.218 ***	0.224 ***
Soak time	3	342469.4 ***	0.905 *	0.067 ***
Cook time	2	50116.7 ***	1.689 ***	0.460 ***
Two-way				
Soak time x Cook time	6	15119.4 ***	1.050 **	0.004
Residual	12	235.4	0.152	0.003
%CV		2.5	1.170	1.756

1. Indicate probability level of significance:
   * $P \leq 0.05$
   ** $P \leq 0.01$
   *** $P \leq 0.001$

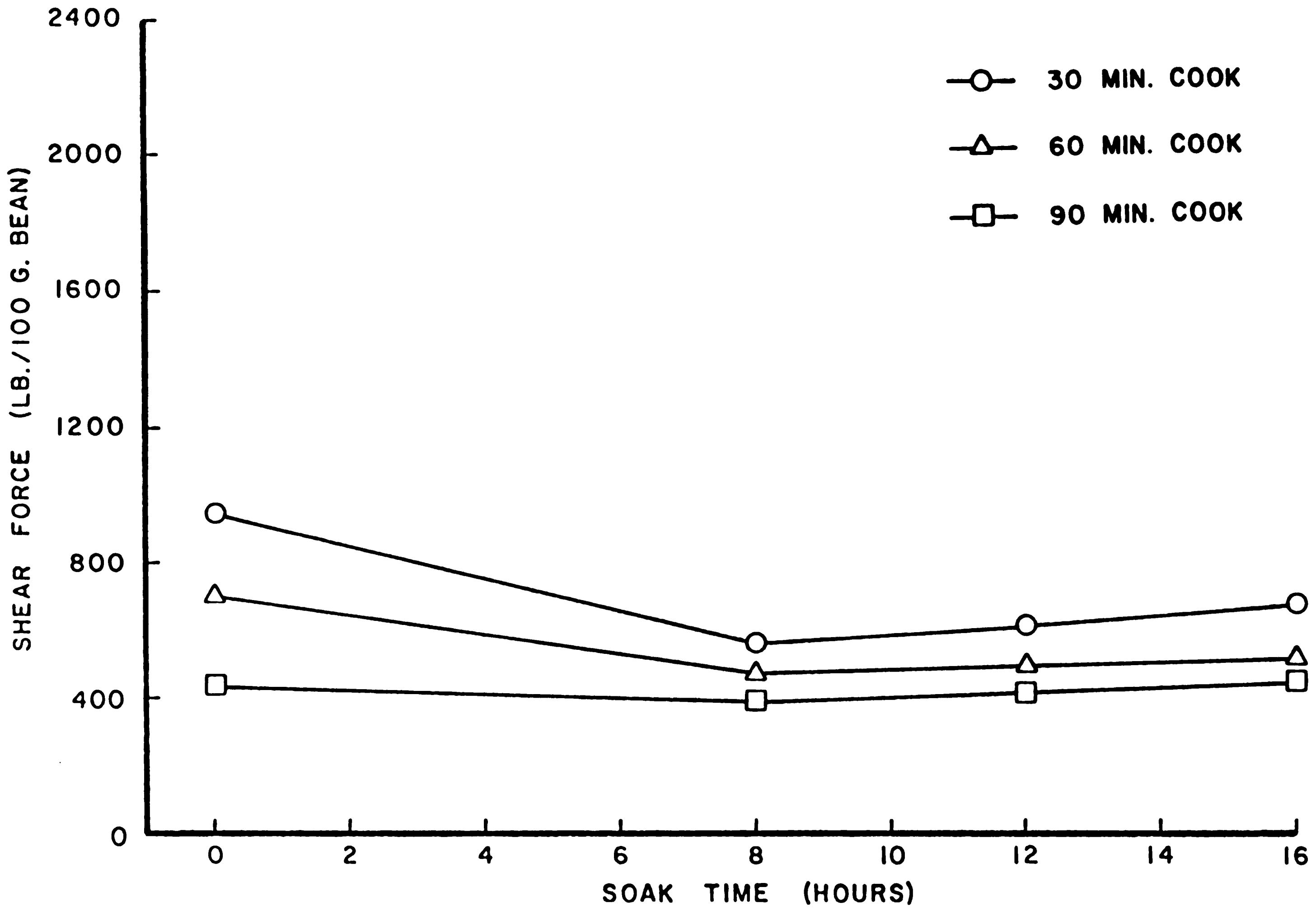

Figure 37. Changes of shear force during preparation of navy beans.

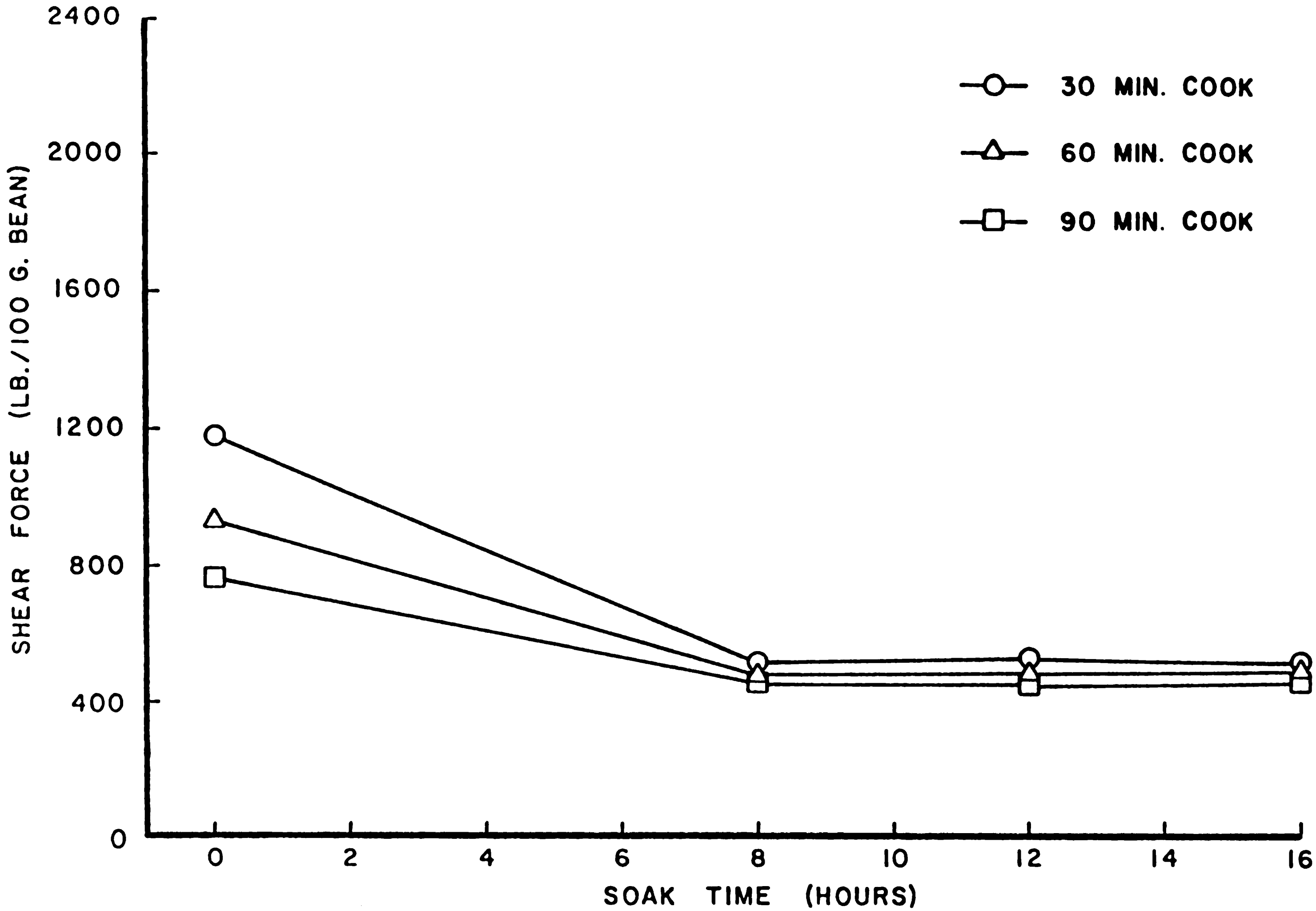

Figure 38. Changes of shear force during preparation of kidney beans.

explanation might be that there was a mass transfer between the bean and the cook water during cooking since all samples were cooked in the same cook water and container.

Ash and Minerals. The ash content in both navy and kidney beans was significantly affected by soak time, cook time, and their interaction (Tables 15 and 16). The ash content in all navy beans cooked for 30 minutes was higher than that in beans cooked for longer time. The ash levels in beans cooked for 60 and 90 minutes were not statistically different (Tables 13 and 14). In addition, for the same length of cooking time, beans which were soaked longer showed greater loss of ash (Figures 39 and 40). The results of kidney beans followed a similar trend.

Mean values and Tukey mean separation of all minerals are presented in Tables 17 and 18. The analysis of variance of all values are summarized in Tables 19 and 20.

Cook time and treatment interaction effects were less significant than the effect of soak time on calcium content of navy beans. Whereas for kidney beans, all treatment effects were significant except the effect of treatment interaction. Calcium was found to increase rapidly in all cooked beans which were unsoaked or soaked for 8 hours; but for cooked beans which were soaked for 12 and 16 hours, the increase was not statistically significant. However, oneway analysis indicated that all reported values were not statistically different. The change in copper content in

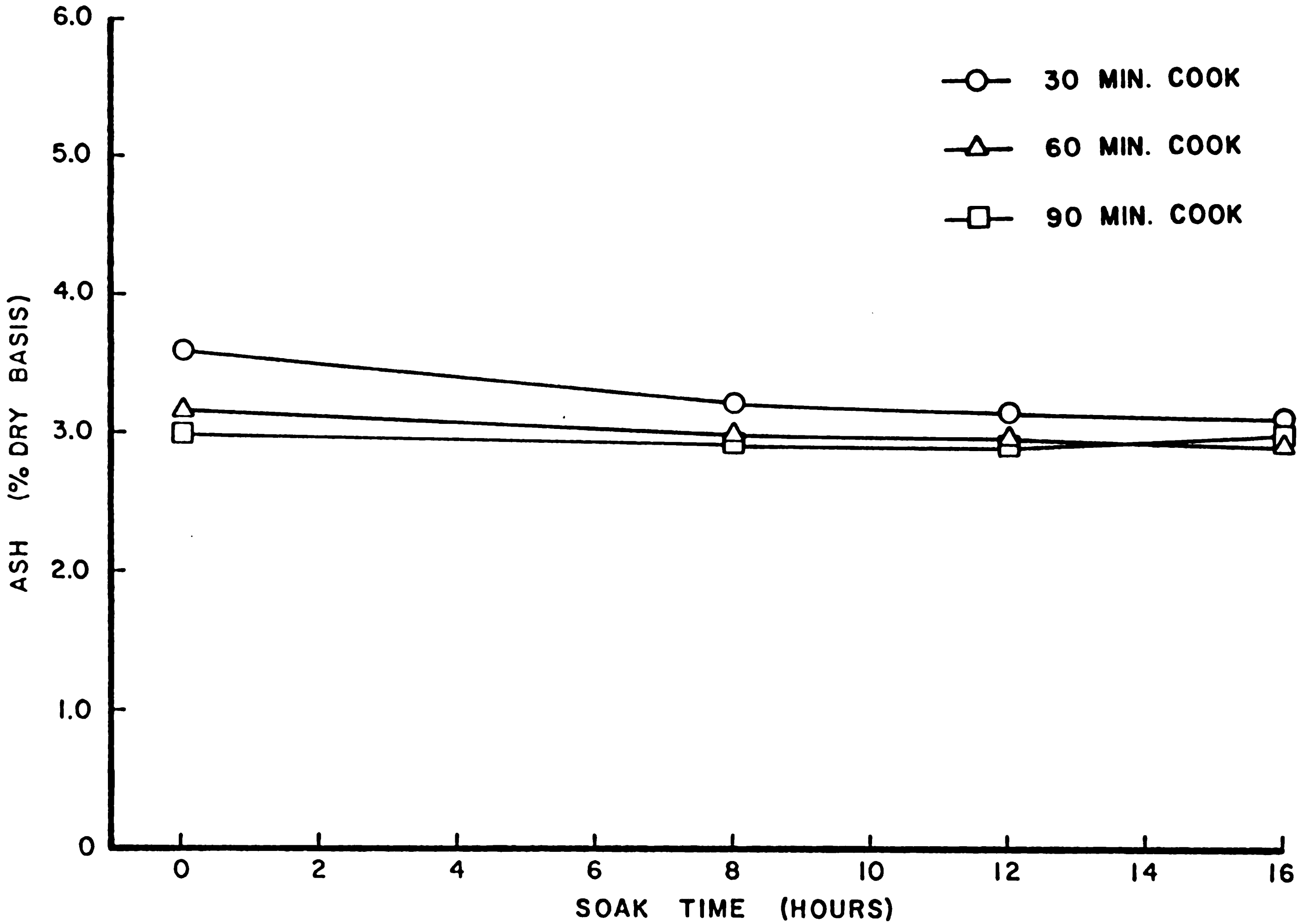

Figure 39. Changes of ash content during preparation of navy beans.

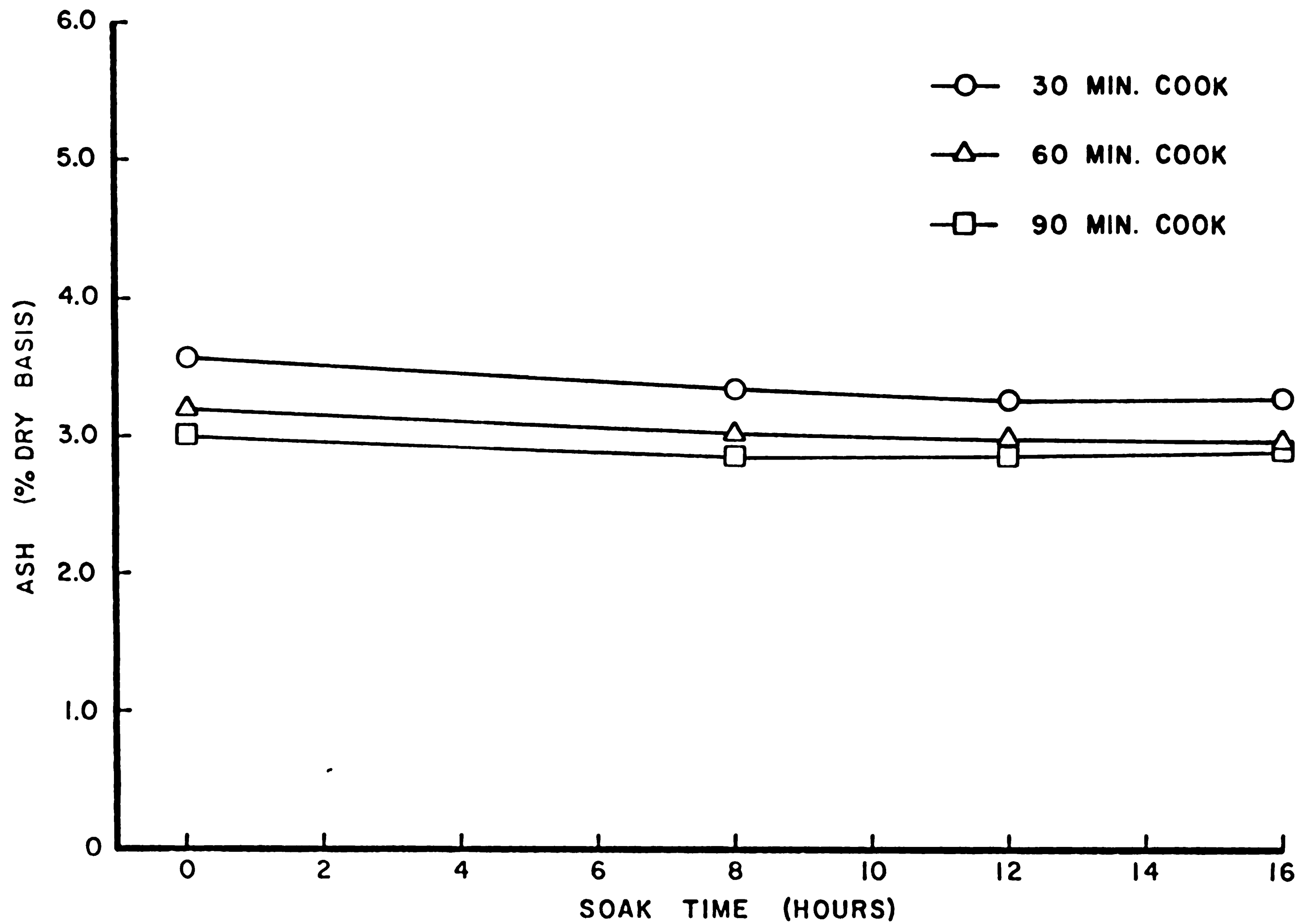

Figure 40. Changes of ash content during preparation of kidney beans.

Table 17. Changes of mineral content during preparation of navy beans.[1,2]

Cook time	Ca	Cu	Fe	Mg	Mn	Na	P	Zn	K
0 hour soak (raw beans)[3]									
30 minutes	1861 a	10.4 a	72.9 a	1210 a	16.7 a	20.3 a	4495 a	22.8 a	13755 a
60 minutes	2125 b	10.1 a	73.2 a	1242 a	17.8 a	28.0 a	4547 a	24.0 ab	14678 a
90 minutes	2234 b	10.6 a	77.3 a	1260 a	18.6 a	30.8 a	4540 a	25.1 b	11174 a
8 hours soak									
30 minutes	2294 a	10.2 ab	77.1 a	1341 a	18.2 a	25.2 a	4614 a	24.3 a	12138 a
60 minutes	2680 a	10.5 b	82.2 a	1399 a	20.0 a	27.1 a	4849 a	27.0 a	11500 a
90 minutes	2759 a	9.9 a	79.7 a	1333 a	19.3 a	22.6 a	4658 a	26.3 a	10549 a
12 hours soak									
30 minutes	2647 a	10.7 a	79.1 a	1383 a	18.5 a	23.4 a	4858 a	25.2 a	12280 a
50 minutes	2402 a	8.9 a	73.8 a	1231 a	17.6 a	24.6 a	4331 a	24.2 a	9806 a
90 minutes	2574 a	9.7 a	79.0 a	1294 a	19.0 a	27.3 a	4588 a	26.4 a	9905 a
16 hours soak									
30 minutes	2668 a	10.8 b	80.6 a	1387 a	19.0 a	31.4 a	4858 b	25.6 a	12322 c
60 minutes	2809 a	10.0 a	81.0 a	1362 a	19.1 a	22.5 a	4731 ab	26.6 a	10975 b
90 minutes	2639 a	9.6 a	83.0 a	1312 a	19.8 a	20.1 a	4584 a	27.2 a	10052 a

1. Like letters within each column indicate no significant differences ($P \leq 0.05$).
2. All values are in parts per million (dry basis).
3. Tukey mean separation for each soak time was done separately.

Table 18. Changes of mineral content during preparation of kidney beans.[1,2]

Cook time	Ca	Cu	Fe	Mg	Mn	Na	P	Zn	K
0 hour soak (raw beans)[3]									
30 minutes	1358 a	6.4 a	58.5 a	1288 a	13.6 a	34.4 a	4646 a	29.6 a	14920 a
60 minutes	1501 a	6.6 a	58.0 a	1246 a	14.5 b	33.5 a	4712 a	31.5 a	13280 a
90 minutes	1635 a	6.2 a	57.4 a	1217 a	13.7 a	40.9 a	4740 a	33.2 a	12114 a
8 hours soak									
30 minutes	1828 a	6.1 a	56.1 a	1293 b	14.0 a	30.6 a	4864 b	30.8 a	13829 b
60 minutes	1864 a	5.7 a	54.0 a	1197 a	13.1 a	35.1 a	4580 a	30.7 a	11413 a
90 minutes	1890 a	5.8 a	56.5 a	1178 a	14.8 a	34.2 a	4593 a	32.7 b	10892 a
12 hours soak									
30 minutes	1793 a	6.4 a	56.7 a	1265 a	13.5 a	39.1 a	4709 a	30.4 a	12582 b
60 minutes	1819 a	7.0 a	55.7 a	1199 a	14.7 b	40.9 a	4560 a	31.2 a	11006 a
90 minutes	1868 a	6.0 a	56.8 a	1176 a	14.2 b	43.4 a	4468 a	32.3 a	10100 a
16 hours soak									
30 minutes	1822 a	6.5 a	60.2 a	1271 a	13.4 a	35.4 a	4764 a	30.8 a	12669 c
60 minutes	1844 ab	6.3 a	57.8 a	1187 a	14.1 a	37.7 a	4499 a	31.2 a	11271 b
90 minutes	1916 b	6.0 a	60.2 a	1191 a	13.8 a	34.0 a	4577 a	32.6 a	10214 a

1. Like letters within each column indicate no significant differences ($P \leq 0.05$).
2. All values are in parts per million (dry basis).
3. Tukey mean separation for each soak time was done separately.

Table 19. Analysis of variance for changes of mineral content during preparation of navy beans.

Source of variation	df	Mean Squares								
		Ca	Cu	Fe	Mg	Mn	Na	P	Zn	K
Main effects	5	304457.5 ***[1]	0.638 **	38.998 *	12200.9 **	2.870 *	2.216	43532.4	6.539 **	0.840 E+07 **
Soak time (ST)	3	458593.0 ***	0.378	56.078 *	18996.1 **	3.252 *	3.331	53139.7	6.743 **	0.744 E+07 **
Cook time (CT)	2	73254.1 *	1.027 **	13.378	2008.2	2.297	0.544	29121.5	6.232 *	0.984 E+07 **
Two-way ST x CT	6	57566.8 *	0.587 *	10.978	5489.1	0.792	49.122	60205.7	1.376	0.152 E+07
Residual	12	14194.7	0.123	9.653	2121.5	0.754	28.275	26091.0	1.009	0.121 E+07
%CV		4.8	3.472	3.971	3.5	4.661	21.042	3.5	3.956	9.487

1. Indicate probability level of significance:
   - * $P \leq 0.05$
   - ** $P \leq 0.01$
   - *** $P \leq 0.001$

Table 20. Analysis of variance for changes of mineral content during preparation of kidney beans.

Source of variance	df	Mean Squares								
		Ca	Cu	Fe	Mg	Mn	Na	P	Zn	K
Main effects	5	124981.7 ***[1]	0.375	12.727 *	8154.6 **	0.351 *	47.370 **	36909.5	4.141 *	0.954 E+07 ***
Soak time (ST)	3	186760.4 ***	0.398	17.609 *	1732.3	0.126	64.752 ***	18849.4	0.065	0.608 E+07 ***
Cook time (CT)	2	32313.8 **	0.340	5.404	17788.2 ***	0.690 **	21.296	63999.5	10.256 ***	0.147 E+07 ***
Two-way ST x CT	6	5236.0	0.155	1.173	378.3	0.751 **	12.863	19596.3	0.504	113246.6
Residual	12	3288.1	0.161	3.016	1223.1	0.099	6.356	22727.4	0.864	176073.8
%CV		3.3	6.410	3.030	2.9	2.256	6.890	3.2	2.959	3.5

1. Indicate probability level of significance:
   * $P \leq 0.05$
   ** $P \leq 0.01$
   *** $P \leq 0.001$

both bean types was not significant. In navy beans, analysis of variance showed moderate significance for all treatment effects and treatment interactions except for effect of soak time. But the effects of treatment and treatment interaction were not significant for kidney bean copper content. Iron values in both bean types did not differ statistically. This is supported by the analysis of variance which showed only small significant effect of soak time on the iron content of both navy and kidney beans. The results revealed that there was no marked change of iron during cooking. As for iron, magnesium in both beans showed no significant change during cooking. However, magnesium content was moderately affected by soak time in the case of navy beans, and was significantly affected by treatment interaction according to the analysis of variance. The change of manganese in navy beans during cooking was also found to be negligible and similar results were reported for kidney beans. The analysis of variance revealed moderately significant effects of cook time and treatment interaction on the amount of manganese in kidney beans. A slight effect of soak time was also detected in navy beans.

Oneway analysis for sodium, phosphorus, and zinc indicated no significant changes of these elements in both bean types during cooking. This was also shown for potassium except in cooked beans soaked for 16 hours. Potassium decreased significantly with the increase in cook time.

Analysis of variance of navy beans indicated insignificant effects of treatments and their interactions on sodium and phosphorus contents, but treatment effects on zinc and potassium were moderately significant. In kidney beans, soak time had meaningful effect on sodium, while zinc was affected by cook time. Phosphorus was not affected by any of the treatments, but for potassium, both treatments and treatment interaction were significant.

When comparing the mineral contents of beans soaked for 16 hours and cooked for 90 minutes from blancher cooking and kettle cooking, it was found that for kidney beans, all values from blancher cooking were higher than those from kettle cooking. However, for navy beans, most values were close except for sodium, potassium, and zinc, which were lower for kettle cooked beans than for those from blancher cooking.

Cooking Temperature Effect on Physical Characteristics of Beans

Each sample of beans was cooked in a separate flask in the blancher. The effects of cooking temperature, soak time, cook time, and their interactions were investigated. Mean values and Tukey mean separations are presented in Tables 21 and 22. Analysis of variance are summarized in Tables 23 and 24 and Figures 41 to 46 are graphical presentation of all data obtained from the study.

Table 21. Effect of cooking temperature on physical characteristics of navy beans.[1]

Cook time	Hydration ratio	Shear force[2]	Total solids in water[3]
	COOKING TEMPERATURE 181.3 °F (82.9 °C)		
0 hour soak (raw beans)			
30 minutes	1.64 a	1650 c	0.54 a
60 minutes	1.76 b	1245 ab	1.42 cd
90 minutes	1.85 bc	1095 ab	1.69 ef
6 hours soak			
30 minutes	1.78 bc	1320 b	1.23 b
60 minutes	1.83 bc	1110 ab	1.51 de
90 minutes	1.83 bc	990 a	1.70 f
12 hours soak			
30 minutes	1.84 bc	1320 b	1.24 bc
60 minutes	1.87 c	1065 ab	1.51 de
90 minutes	1.87 c	998 a	1.71 f
	COOKING TEMPERATURE 190.7 °F (88.1 °C)		
0 hour soak (raw beans)			
30 minutes	1.59 a	1680 d	0.71 a
60 minutes	1.76 b	1118 c	1.49 bc
90 minutes	1.82 bcd	773 ab	1.72 de
6 hours soak			
30 minutes	1.81 bc	1095 c	1.32 b
60 minutes	1.87 cd	750 ab	1.62 cd
90 minutes	1.91 cd	500 a	1.89 ef
12 hours soak			
30 minutes	1.89 cd	915 bc	1.36 b
60 minutes	1.91 cd	735 ab	1.72 de
90 minutes	1.93 d	595 a	1.96 f
	COOKING TEMPERATURE 200.0 °F (93.3 °C)		
0 hour soak (raw beans)			
30 minutes	1.56 a	1680 d	0.92 a
60 minutes	1.76 b	795 bc	1.56 b
90 minutes	1.88 bcd	538 abc	1.83 bc
6 hours soak			
30 minutes	1.85 bc	840 c	1.34 ab
60 minutes	1.93 cd	485 abc	1.65 b
90 minutes	2.02 de	370 a	2.18 c
12 hours soak			
30 minutes	1.92 cd	698 abc	1.50 b
60 minutes	1.97 cde	498 abc	1.76 bc
90 minutes	2.10 e	415 ab	2.20 c
	COOKING TEMPERATURE 207.5 °F (97.5 °C)		
0 hour soak (raw beans)			
30 minutes	1.67 a	1185 d	0.93 a
60 minutes	1.86 ab	590 c	1.63 bc
90 minutes	2.09 cd	313 ab	2.30 d
6 hours soak			
30 minutes	1.87 ab	555 bc	1.51 b
60 minutes	2.15 d	310 a	1.75 c
90 minutes	2.15 d	293 a	2.41 d
12 hours soak			
30 minutes	1.89 bc	600 c	1.51 b
60 minutes	2.03 bcd	390 abc	1.77 c
90 minutes	2.16 d	305 a	2.50 d

1. Like letters within each column indicate no significant differences ($P \leq 0.05$) and Tukey mean separation within each group of cooking temperature was done separately.
2. Shear force is expressed in pounds per 100 grams of bean.
3. Total solids in water is expressed in per cent.

Table 22. Effect of cooking temperature on physical characteristics of kidney beans.[1]

Cook time	Hydration ratio	Shear force[2]	Total solids in water[3]
	COOKING TEMPERATURE 181.3 °F (82.9 °C)		
0 hour soak (raw beans)			
30 minutes	1.46 a	2055 f	0.45 a
60 minutes	1.65 b	1440 e	0.94 b
90 minutes	1.79 c	1230 cd	1.49 cd
6 hours soak			
30 minutes	1.93 d	1260 d	1.05 b
60 minutes	1.96 d	1170 bcd	1.50 d
90 minutes	1.96 d	1110 ab	1.83 ef
12 hour soak			
30 minutes	1.95 d	1238 d	1.28 c
60 minutes	1.96 d	1133 bc	1.63 de
90 minutes	2.00 d	1020 a	1.94 f
	COOKING TEMPERATURE 190.7 °F (88.1 °C)		
0 hour soak (raw beans)			
30 minutes	1.44 a	2010 f	0.62 a
60 minutes	1.64 b	1380 e	1.01 b
90 minutes	1.78 c	1095 cde	1.53 d
6 hours soak			
30 minutes	1.91 cd	1140 de	1.12 b
60 minutes	1.94 d	825 abc	1.53 d
90 minutes	1.94 d	610 a	1.85 e
12 hours soak			
30 minutes	1.98 d	953 bcd	1.35 c
60 minutes	1.98 d	733 ab	1.63 d
90 minutes	2.00 d	663 a	2.00 f
	COOKING TEMPERATURE 200.0 °F (93.3 °C)		
0 hour soak (raw beans)			
30 minutes	1.32 a	2220 d	0.57 a
60 minutes	1.53 b	1680 cd	0.83 b
90 minutes	1.58 b	1320 bc	1.01 b
6 hours soak			
30 minutes	1.91 c	945 ab	1.22 c
60 minutes	1.94 c	625 a	1.61 de
90 minutes	1.99 c	490 a	1.88 fg
12 hours soak			
30 minutes	1.99 c	735 ab	1.43 cd
60 minutes	2.03 c	533 a	1.70 ef
90 minutes	2.08 c	450 a	2.06 g
	COOKING TEMPERATURE 207.5 °F (97.5 °C)		
0 hour soak (raw beans)			
30 minutes	1.71 a	1358 d	0.64 a
60 minutes	1.73 a	1083 c	1.37 bc
90 minutes	1.87 b	678 b	1.48 bc
6 hours soak			
30 minutes	1.97 c	585 b	1.27 b
60 minutes	2.09 d	355 a	1.71 bc
90 minutes	2.13 d	340 a	2.34 d
12 hours soak			
30 minutes	1.98 c	615 b	1.45 bc
60 minutes	2.08 d	403 a	1.88 cd
90 minutes	2.13 d	395 a	2.34 d

1. Like letters within each column indicate no significant difference ($P \leq 0.05$) and Tukey mean separation within each group of cooking temperature was done separately.
2. Shear force is expressed in pounds per 100 grams of bean.
3. Total solids in water is expressed in per cent.

Table 23. Analysis of variance for physical changes during preparation of navy beans.

Source of variation	df	Mean Squares		
		Hydration ratio	Shear force	Total solids in water
Main effects	7	0.175 ***[1]	0.145 E+07 ***	1.657 ***
Temperature (T)	3	0.114 ***	0.159 E+07 ***	0.574 ***
Soak time (ST)	2	0.216 ***	927259.2 ***	0.767 ***
Cook time (CT)	2	0.226 ***	0.177 E+07 ***	4.169 ***
Two-way				
Temperature x Soak time	6	0.010 ***	31004.2 ***	0.004
Temperature x Cook time	6	0.017 ***	21694.3 **	0.078 ***
Soak time x Cook time	4	0.018 ***	189723.6 ***	0.175 ***
Three-way				
T x ST x CT	12	0.002	13094.4 *	0.010
Residual	36	0.001	6235.2	0.006
%CV		1.682	9.5	4.841

1. Indicate probability level of significance:
   * $P \leq 0.05$
   ** $P \leq 0.01$
   *** $P \leq 0.001$

Table 24. Analysis of variance for physical changes during preparation of kidney beans.

Source of variation	df	Mean Squares		
		Hydration ratio	Shear force	Total solids in water
Main effects	7	0.382 ***[1]	0.207 E+07 ***	2.164 ***
Temperature (T)	3	0.078 ***	0.129 E+07 ***	0.259 ***
Soak time (ST)	2	1.102 ***	0.392 E+07 ***	3.570 ***
Cook time (CT)	2	0.119 ***	0.140 E+07 ***	3.614 ***
Two-way				
Temperature x Soak time	6	0.022 ***	179817.9 ***	0.039 ***
Temperature x Cook time	6	0.000	16158.9	0.037 ***
Soak time x Cook time	4	0.026 ***	193451.4 ***	0.012
Three-way				
T x ST x CT	12	0.005 ***	9116.2	0.022 ***
Residual	36	0.001	8756.3	0.006
%CV		1.691	9.4	5.417

1. Indicate probability level of significance:
 * $P \leq 0.05$
 ** $P \leq 0.01$
 *** $P \leq 0.001$

(a)

(b)

(c)

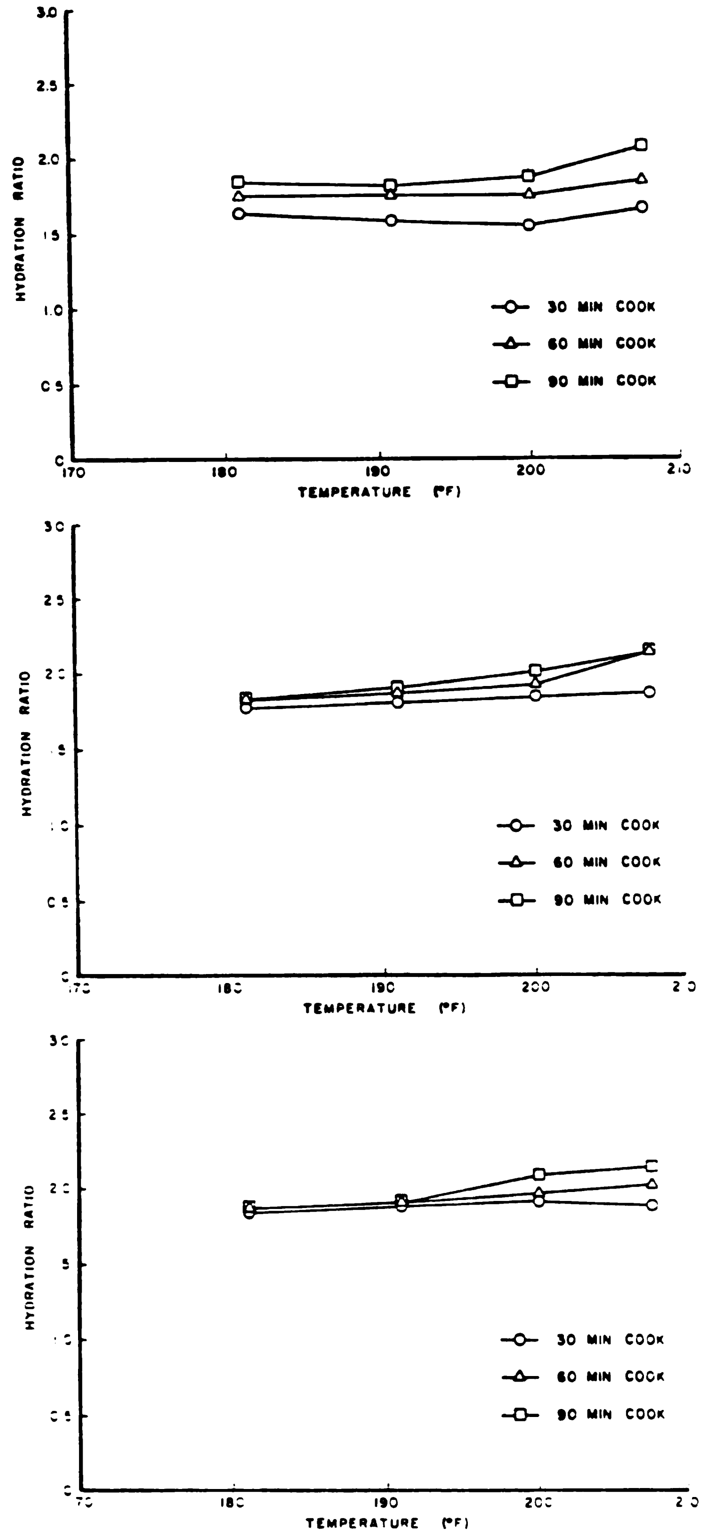

Figure 41. Cooking temperature effect on hydration ratio of navy beans with various processing conditions: (a) no soak; (b) 6 hours soak; (c) 12 hours soak.

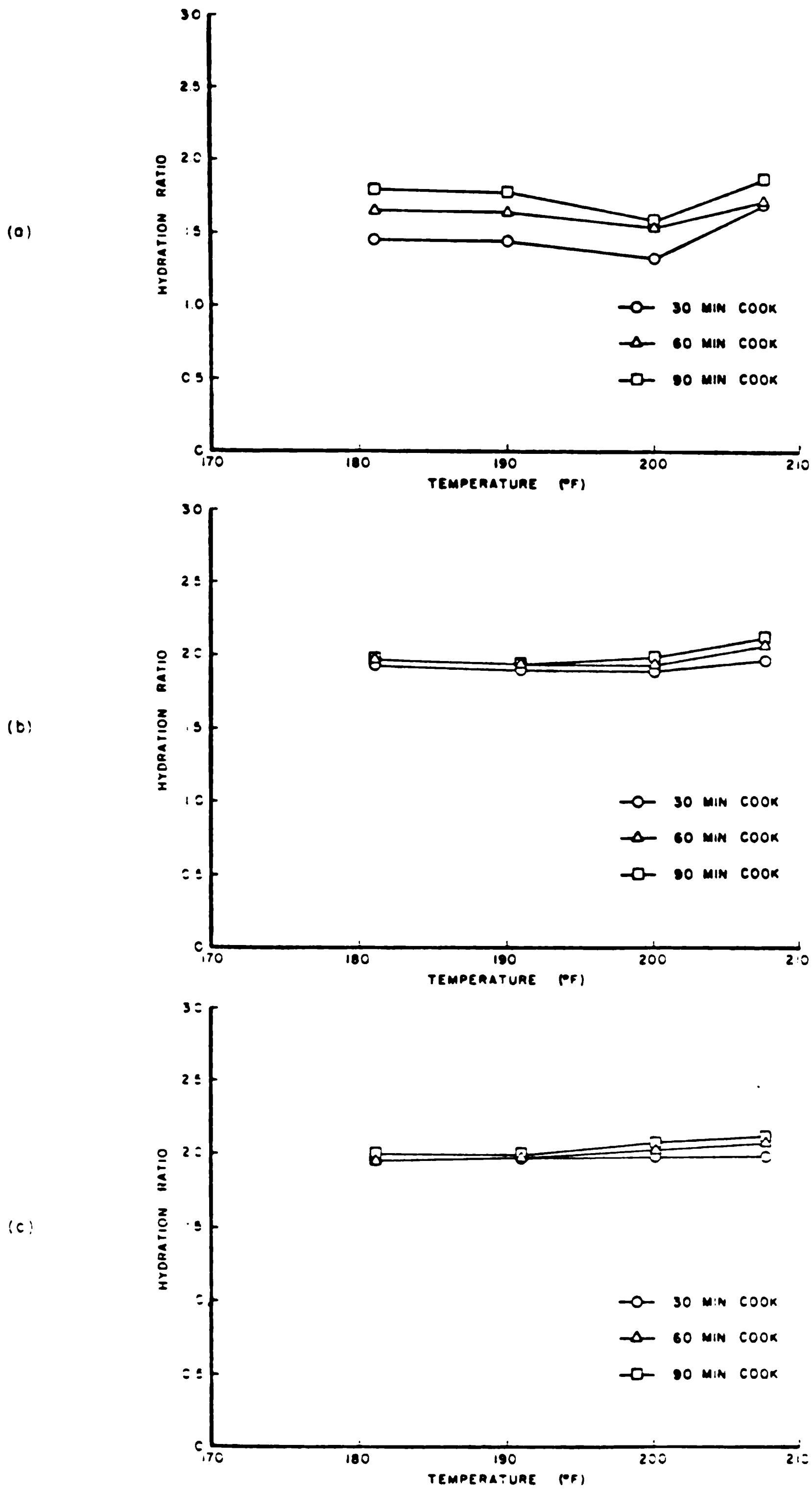

Figure 42. Cooking temperature effect on hydration ratio of kidney beans with various processing conditions: (a) no soak; (b) 6 hours soak; (c) 12 hours soak.

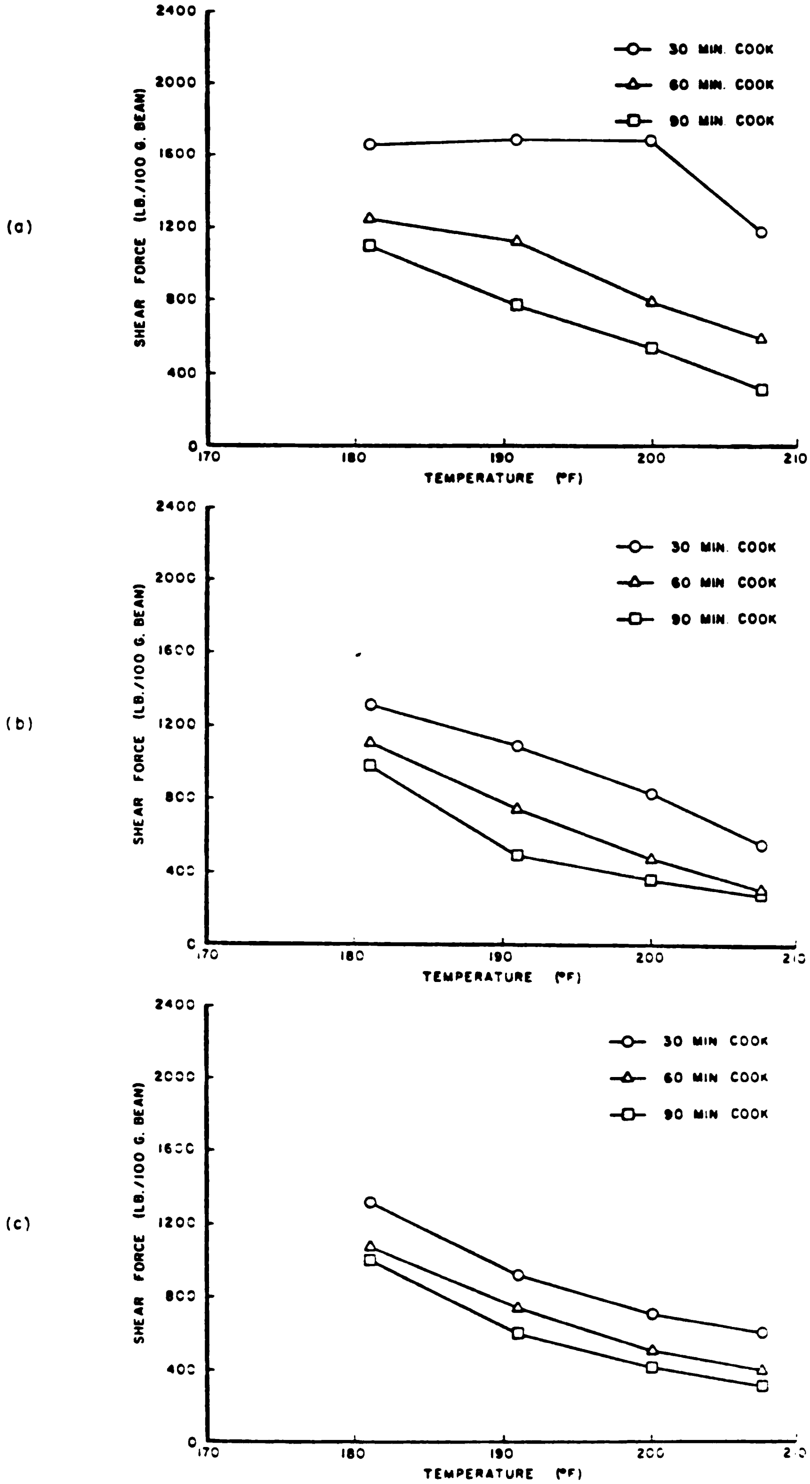

Figure 43. Cooking temperature effect on shear force of navy beans with various processing conditions: (a) no soak; (b) 6 hours soak; (c) 12 hours soak.

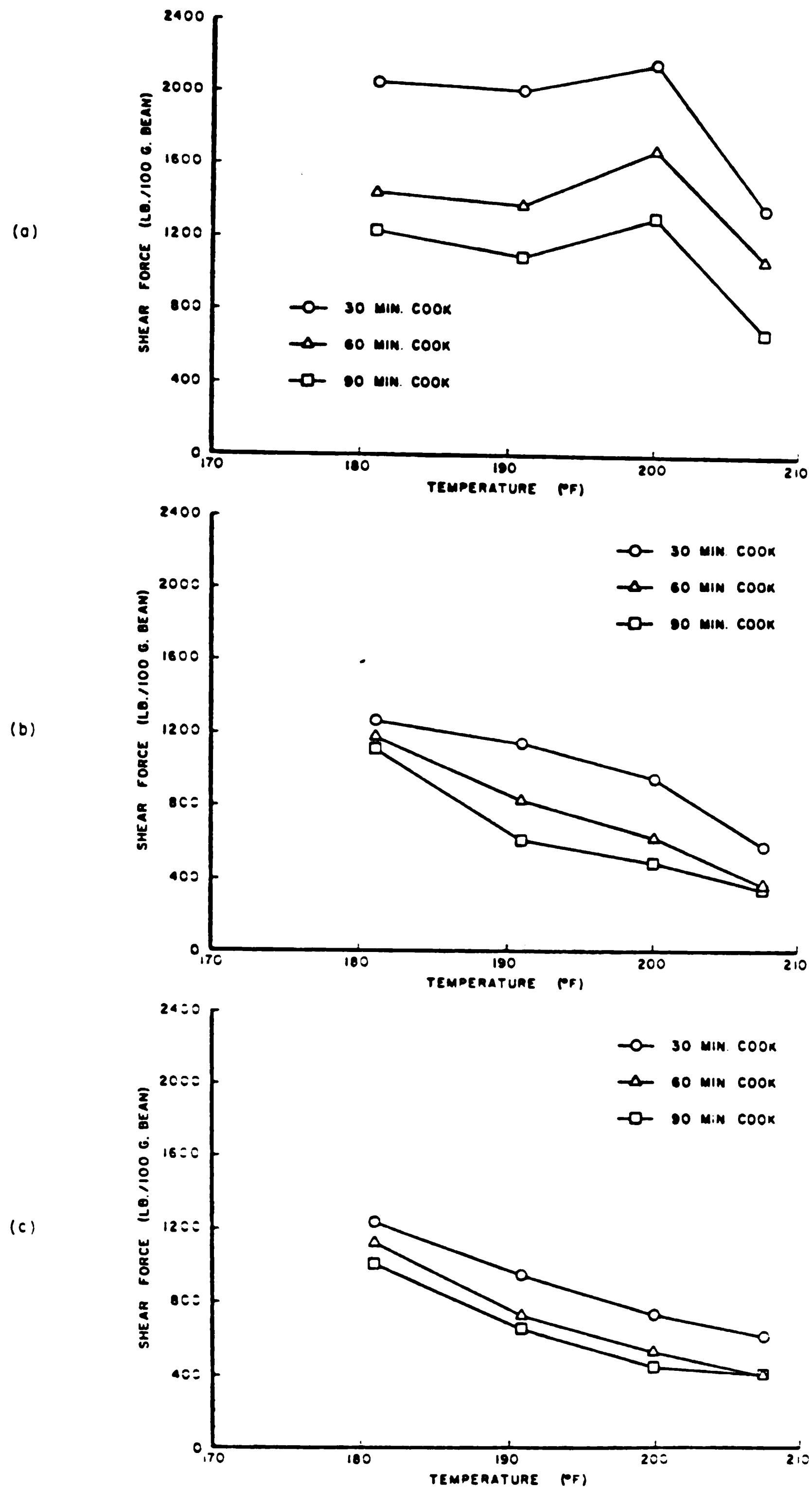

Figure 44. Cooking temperature effect on shear force of kidney beans with various processing conditions: (a) no soak; (b) 6 hours soak; (c) 12 hours soak.

Analysis of variance illustrated significant effects of all treatments as well as most of the treatment interactions on the hydration ratio, shear force, and total solids in cook water of both navy and kidney beans. In Figure 41, the difference of hydration ratio between unsoaked and soaked navy beans was obvious. Hydration ratio did not increased markedly with increased cooking temperature. The effect of cook time on hydration ratio decreased as beans were soaked longer, which implied that after a long soaking, beans did not absorb more water as the cook time increased. Effect of soak time on hydration ratio was less after six hours of soaking. Unsoaked kidney beans absorbed remarkably less water than did 6-hour- and 12-hour-soaked beans (Figure 42). Kidney bean results were similar to those of navy beans except at the cooking temperature of 200 ^{o}F (93.3 ^{o}C), where all unsoaked kidney beans showed a hydration ratio reduction. Shear force generally decreased with higher cooking temperature (Figures 43 and 44). In beans cooked for the same period of time, unsoaked beans were significantly firmer than the other two groups. All unsoaked kidney beans cooked at 200 ^{o}F (93.3 ^{o}C) were found to be the toughest. For soaked navy and kidney beans, the effects of soak and cook times on bean texture were less as the soak and cook times increased. Beans tended to lose higher amounts of solids into the cook water as the cooking temperature increased (Figures 45 and 46). Again, the difference between unsoaked and soaked beans was very obvious.

For navy beans cooked for the same length of time (Figure 45), the loss of total solids did not increase significantly after six hours of soaking. All unsoaked kidney beans cooked at 200 °F (93.3 °C) lost markedly lower amount of solids than did those cooked at other temperatures (Figure 46). Soak and cook times had more effect on solid losses of kidney beans than on those of navy beans.

It should be noted that the results of unsoaked and cooked kidney beans at 200 °F (93.3 °C) were very consistent. The hydration ratio dropped, the beans were firmer and leached out fewer solids than beans cooked at lower or higher temperatures (Figures 42a, 44a, and 46a). It was clearly seen from visual observation as well that these beans were wrinkled and had not absorbed much water. In addition, longer cook time did not appreciably improve the texture or water absorption capacity of these beans.

In conclusion, cooking temperature produced significant effects on bean texture and solid losses, but had little effect on hydration ratio. Elevated temperatures as well as prolonged soaking and cooking resulted in softer products but also greater loss of solids from beans.

The decrease of bean firmness by increasing the cooking temperature was also interested. Shear force values of cooked beans were plotted against cooking temperatures on semi-logarithmic scales as shown in Figures 47 and 48. Regression equation for each line was calculated (Tables 25

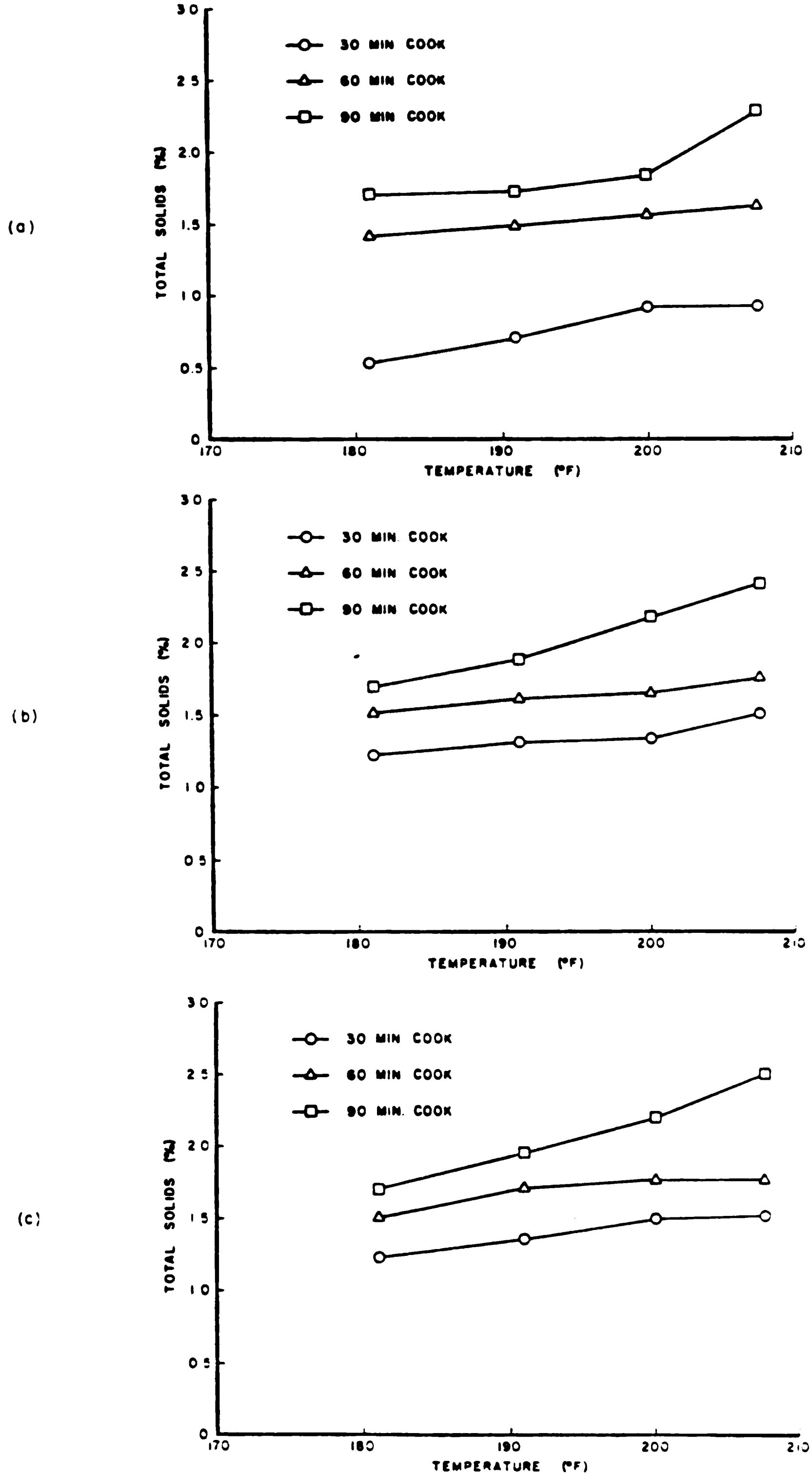

Figure 45. Cooking temperature effect on total solids of navy bean cook water with various processing conditions: (a) no soak; (b) 6 hours soak; (c) 12 hours soak.

(a)

(b)

(c)

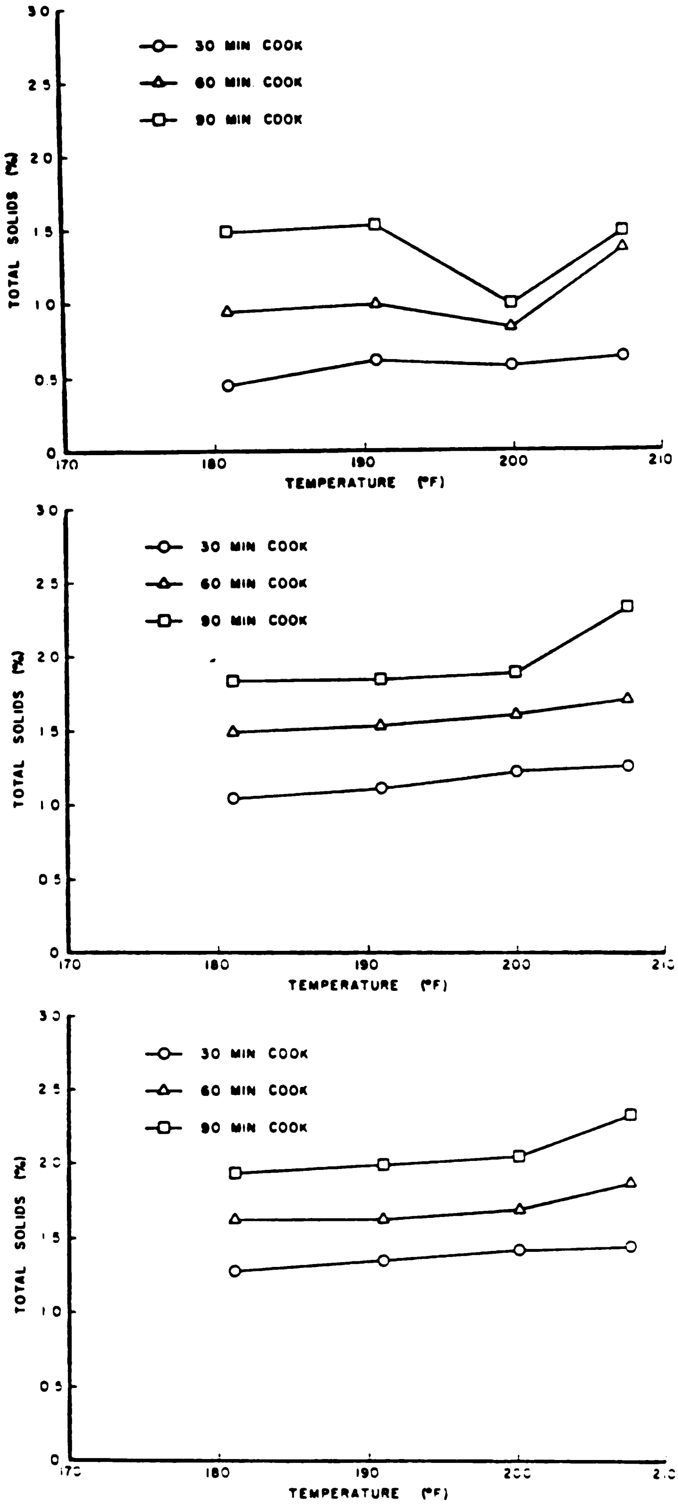

Figure 46. Cooking temperature effect on total solids of kidney bean cook water with various processing conditions: (a) no soak; (b) 6 hours soak; (c) 12 hours soak.

(a)
(b)
(c)

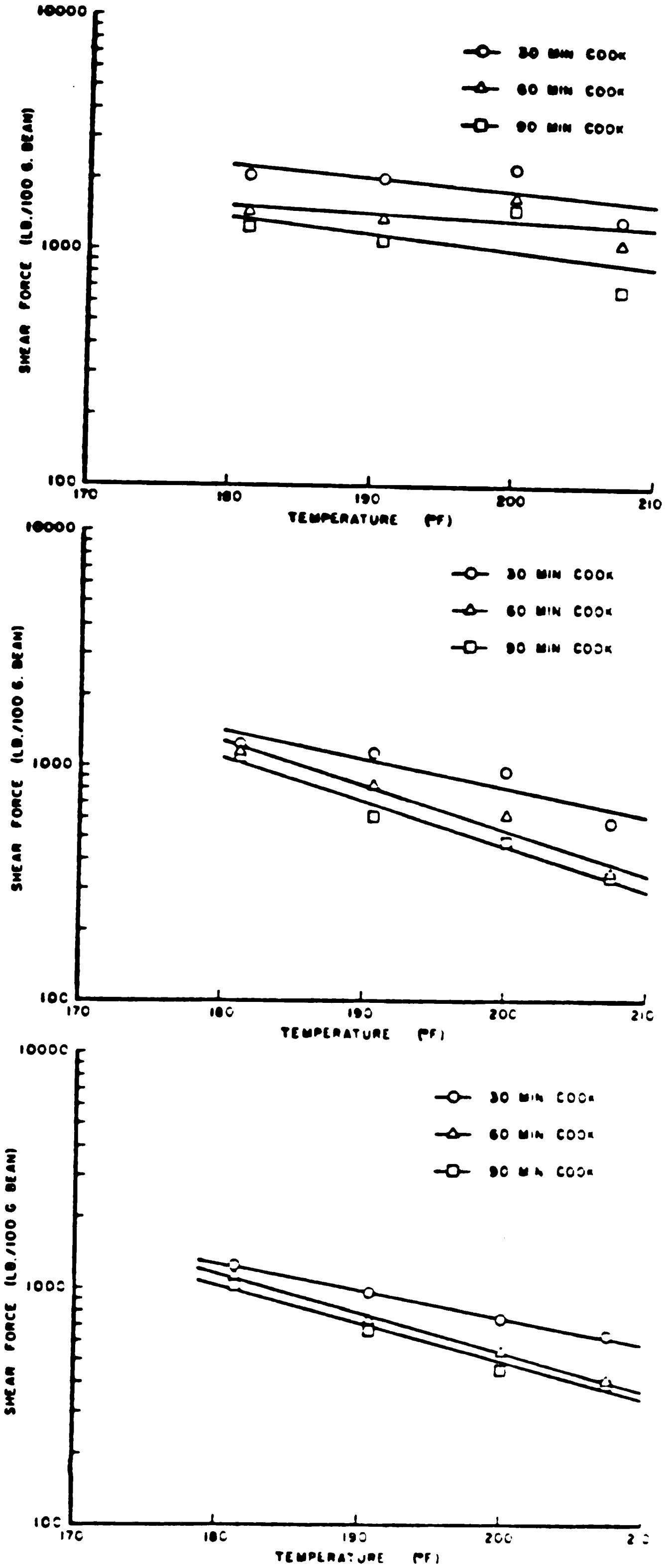

Figure 47. Z-value evaluation of navy beans with various processing conditions: (a) no soak; (b) 6 hours soak; (c) 12 hours soak.

(a)

(b)

(c)

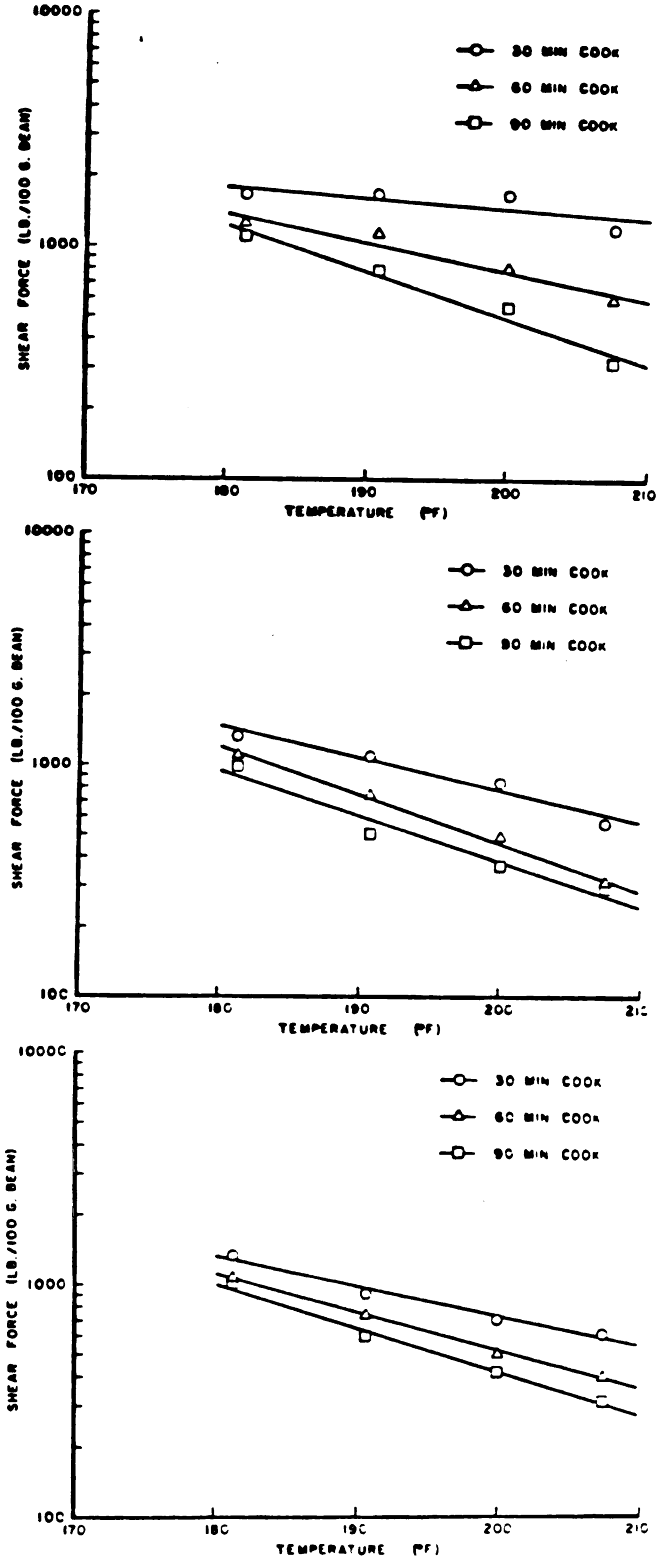

Figure 48. Z-value evaluation of kidney beans with various processing conditions: (a) no soak; (b) 6 hours soak; (c) 12 hours soak.

Table 25. Z-values of navy beans.

Cook time	S = a - bT[1]	Z = 1/b[2]
0 hour soak (raw beans)		
30 minutes	S = 4.0923557 - 0.0046543 T	214.855
60 minutes	S = 5.4115456 - 0.0126142 T	79.275
90 minutes	S = 6.7156805 - 0.0201567 T	49.611
6 hours soak		
30 minutes	S = 5.6760120 - 0.0139536 T	71.666
60 minutes	S = 6.8341154 - 0.0208459 T	47.971
90 minutes	S = 6.5099691 - 0.0196435 T	50.907
12 hours soak		
30 minutes	S = 5.4745064 - 0.0130797 T	76.454
60 minutes	S = 6.0724960 - 0.0168187 T	59.458
90 minutes	S = 6.4887368 - 0.0193471 T	51.687

1. S represents the log of shear force value.
   T represents the cooking temperature in degree Fahrenheit.
2. Z-value is expressed in degree Fahrenheit.

Table 26. Z-values of kidney beans.

Cook time	$S = a - bT$[1]	$Z = 1/b$[2]
0 hour soak (raw beans)		
30 minutes	S = 4.3076411 - 0.0053059 T	188.468
60 minutes	S = 3.7129946 - 0.0029433 T	339.755
90 minutes	S = 4.3461369 - 0.0067337 T	148.507
6 hours soak		
30 minutes	S = 5.3163224 - 0.0120161 T	83.221
60 minutes	S = 6.4965368 - 0.0188034 T	53.182
90 minutes	S = 6.3867728 - 0.0185973 T	53.771
12 hours soak		
30 minutes	S = 5.1994718 - 0.0116388 T	85.919
60 minutes	S = 6.1053109 - 0.0168993 T	59.174
90 minutes	S = 5.9018318 - 0.0160735 T	62.214

1. S represents the log of shear force value.
   T represents the cooking temperature in degree Fahrenheit.
2. Z-value is expressed in degree Fahrenheit.

and 26). The Z-values, which are the increase of temperature required to reduce the firmness or shear force values of cooked beans by 90%, are the slopes of the regression lines. The results showed very high Z-values for unsoaked and cooked navy and kidney beans. In beans of the same soak treatment, Z-values decreased as the cook time increased. Davis (1976) suggested that one should increase cooking temperature instead of cook time in order to obtain a desired texture of navy beans. From the current study, if a specific cook time is to be maintained, an increase of cooking temperature of at least 50 ^{o}F (27.8 ^{o}C) is required to soften the beans by 90%.

SUMMARY AND CONCLUSIONS

The objective of Study I was to investigate physical and chemical changes in navy and kidney beans during cooking preparation. Results from both blancher cooking and kettle cooking revealed that beans should be either hot-soaked or cold-soaked for at least eight hours prior to cooking. Beans became softer as the cook time increased. No changes in shear peak configuration (Type A or Type B, Hosfield and Uebersax, 1980) were observed under different soak and cook conditions. All conditions showed predominant compresssion peaks (Type B). It was found that chemical changes in beans during soaking were not significant when compared to the changes occurred in cooking, and that hot-soaking generally resulted in greater changes than cold-soaking. Protein content did not change significantly during preparation. Most minerals showed remarkable decreases except for calcium, copper, and sodium. Potassium showed the greatest losses of 31% to 45% followed by magnesium, phosphorus, zinc, and manganese. Again, the decrease occurred more during cooking and the changes were greater as the cook time increased. Sugars also showed substantial losses during cooking. It was shown that hot-soaking of navy and kidney beans resulted in 30% and 39% reduction of sugars of the raffinose family, respectively, while 16-hour-soaking removed 35% to 50% of these sugars from both bean types. When cook time of 90 minutes was applied and the cook water was discarded, 62% to 80% decrease of these sugars occurred. It was concluded that discarding the soak and cook waters provided both positive and negative results, i.e., the undesirable sugars were removed but valuable soluble minerals were also discarded.

The effect of cooking temperatures, as well as soak and cook times, were evaluated in Study II. It was shown that cooking temperature and time did produce significant effects on both bean texture and the amount of solids leached out into cook water, but their effects on hydration ratio were less significant. Soak time, on the other hand, played a less meaningful role on all physical changes in beans than did the cook time and cooking temperature. In this study, the Z-values for bean texture were also calculated and it was found that in order to decrease 90% of the bean firmness, an increase of cooking temperature of at least 50 ^{o}F (27.8 ^{o}C) was required for both bean types.

APPENDIX

APPENDIX

CALCULATION OF SOAK AND COOK WATER PREPARATION

The soak and cook water used was distilled water containing 100 ppm of calcium. Calcium chloride ($CaCl_2$) was added to yield the desired hardness.

Molecular weight of $CaCl_2$

$$40.08 \text{ g } Ca^{++} + 2(35.5) \text{ g } Cl_2 = 111.08 \text{ g}$$

$$\text{Percent of } Ca^{++} \text{ in } CaCl_2 = \frac{40.08 \times 100}{111.08}$$

$$= 36.08\%$$

The desired hardness of water was 100 ppm, that is, one kg of water contains 0.1 g of Ca^{++}.

$$CaCl_2 \text{ needed to get } 0.1 \text{ g } Ca^{++} = \frac{0.1 \times 100}{36.08}$$

$$= 0.28 \text{ g}$$

Therefore, one kg of water required 0.28 g of $CaCl_2$ to obtain 100 ppm of calcium.

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