

**PRODUCTION OF BULGUR-LIKE FOODS
FROM SOYBEAN AND RYE**

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Ph. D. Thesis

TC. FİNERANCIŞTAN BAKANLIĞI
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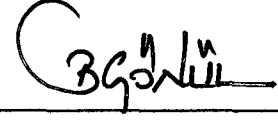
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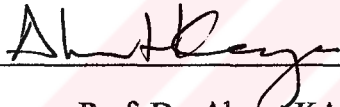
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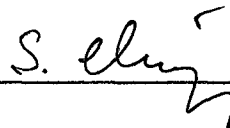
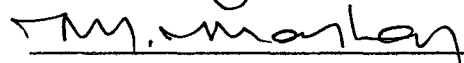
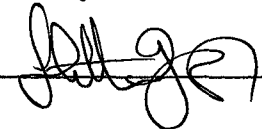
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ABSTRACT

PRODUCTION OF BULGUR-LIKE FOODS FROM SOYBEAN AND RYE

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In this study, bulgur-like food products were produced from soybean and rye. Study was focused on the critical bulgur processing steps like soaking, cooking and drying. Soaking of soybean and rye were made at 30, 50 and 70°C in water with a pH of 5, 7 and 9. Atmospheric, pressure and microwave cooking were applied at 87, 92 and 97°C for 120 minutes; 10, 15 and 18 psig for 3, 6 and 9 minutes; and 350, 490 and 700 W power supply for 3, 6 and 9 minutes, respectively. Before the pressure and microwave cooking, soybean and rye were soaked to reach 40% moisture, using pre-determined optimum soaking conditions. Column type dryer was used to drying of cooked soybean and rye with drying air at 70, 80 and 90°C and 1.55 m/s velocity.

Change in the dimensions, weight, volume, density, moisture content, texture, color and cooking degree of soybean and rye were measured during soaking and cooking. pH, soluble solids content, absorbance, conductivity and color of the soaking water and atmospheric cooking water were measured. Dry and wet bulb temperature, moisture loss and color changes were measured during the drying operation. Power and energy requirements of the systems used were determined. Hectoliter-weight of soybean and rye, which were processed at optimum conditions, were also determined.

The best result for soaking operations of soybean and rye, based on moisture content (40%) and low soaking temperature applied, was obtained at 30°C and pH 7 for 20 and 160 minutes, respectively. These optimum soaking conditions were used for the soaking of soybean and rye before pressure and microwave cooking operations.

Pressure cooking was chosen as optimum cooking operation due to shorter processing time, better energy economy, lowest moisture level (40%) before drying, better system control and finally higher product quality compared to atmospheric and microwave cooking operations. Optimum pressure cooking times at 15 psig for soybean and rye were determined as 6 and 9 minutes, respectively.

During drying, constant and falling rate periods were obtained for rye, in contrast to soybean, which had only falling rate period. Drying times of rye were 2.67, 2.42 and 2.00 hours to reach the equilibrium moisture content that were shorter than that of soybean which were 5.33, 3.83 and 3.50 hours at 70, 80 and 90°C, respectively. Hectoliter-weight values of soybean and rye increased during soaking and cooking, but hectoliter-weight of soybean decreased after drying operation.

Results revealed that bulgur-like food products can be successfully produced from soybean and rye.

Keywords: bulgur, bulgur-like, soybean, rye, semi-ready-to-eat food product soaking, cooking, drying

ÖZ

SOYAFASULYESİ VE ÇAVDARDAN BULGUR BENZERİ GIDALARIN ÜRETİLMESİ

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Bu çalışmada, soya fasulyesi ve çavdar kullanılarak bulgur benzeri gıda ürünleri üretilmiştir. Çalışma kritik bulgur işleme basamakları olan ıslatma, pişirme ve kurutma üzerine yoğunlaştırılmıştır. Soya fasulyesi ve çavdar pH 5, 7 ve 9'daki ıslatma suları içinde 30, 50 ve 70°C'de ıslatılmıştır. Atmosferik, basınçlı ve mikrodalga pişirme işlemleri, sırası ile; 120 dakika süresince 87, 92 ve 97°C'de; 3, 6 ve 9 dakika süresince 10, 15 ve 18 psig'de ve 3, 6 ve 9 dakika süresince 350, 490 ve 700 W güç seviyelerin de yapılmıştır. Basınçlı ve mikrodalga pişirme işlemlerinden önce soya fasulyesi ve çavdar %40 neme ulaşmaları için optimum ıslatma şartları uygulanarak ıslatılmıştır. Kolon tipi kurutucu, 70, 80 ve 90°C'deki ve 1.55 m/s hızındaki hava ile, pişirilmiş soya fasulyesi ve çavdarı kurutmak için kullanılmıştır.

Islatma ve pişirme işlemleri esnasında, soya fasulyesinin ve çavdarın boyutlarında, ağırlıklarında, hacimlerinde, yoğunluklarında, nem miktarlarında, yapılarında, renklerinde ve pişme derecelerinde meydana gelen değişimler ölçülmüştür. Islatma ve atmosferik pişirme suyunun, pH, suya çözünebilir madde miktarı, absorban, iletkenlik ve renk değerleri ölçülmüştür. Kurutma işlemi esnasında, kuru ve ıslak termometre sıcaklıkları, nem kaybı ve renk değişimleri ölçülmüştür. Kullanılan sistemlerin güç ve enerji gereksinimleri belirlenmiştir. Optimum şartlarda işlenen soya fasulyesi ve çavdarın hektolitreye-ağırlık değerleri de belirlenmiştir.

Nem miktarı (%40) ve uygulanan düşük ıslatma sıcaklığı esas alınarak, soya fasulyesi ve çavdarın ıslatma işlemleri için en iyi sonuç 30°C’de ve pH 7’de sırası ile 20 ve 160 dakika olarak elde edilmiştir. Bu optimum ıslatma şartları, basınçlı ve mikrodalga pişirme işlemlerinden önce soya fasulyesi ve çavdarın ıslatılması için kullanılmıştır.

Basınçlı pişirme, atmosferik ve mikrodalga pişirme işlemleri ile karşılaştırıldığında, kısa proses süresi, daha iyi enerji ekonomisi, kurutma öncesi düşük nem seviyesi (%40), daha iyi sistem kontrolü ve son olarak yüksek ürün kalitesinden dolayı optimum pişirme işlemi olarak seçilmiştir. Soya fasulyesi ve çavdar için 15 psig’de optimum basınçlı pişirme süreleri sırası ile 6 ve 9 dakika olarak belirlenmiştir.

Kurutma esnasında, çavdarın, bir tane azalan hız periyoduna sahip soya fasulyesi ile karşılaştırıldığında, sabit ve azalan hız periyotlarına sahip olduğu belirlenmiştir. Çavdarın 70, 80 ve 90°C’lik kurutma sıcaklıklarında, denge nem seviyesine ulaşması için gereken kurutma zamanı, 2.67, 2.42 ve 2.00 saat olup, bu sıcaklıklarda kurutma zamanı 5.33, 3.83 ve 3.50 saat olan soya fasulyesinden daha kısadır. Soya fasulyesi ve çavdarın hektolitre-ağırlık değerleri ıslatma ve pişirme işlemleri esnasında artmasına rağmen, soya fasulyesinin hektolitre-ağırlık değeri kurutma işleminden sonra düşmüştür.

Araştırma sonuçları, soya fasulyesi ve çavdar kullanılarak bulgur benzeri gıdaların üretilebileceğini göstermiştir.

Anahtar kelimeler: bulgur, bulgur benzeri gıda maddeleri, soya fasulyesi, çavdar, yenilmeye yarı hazır gıda maddesi, ıslatma, pişirme, kurutma

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To my son
KARAN ARORA

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LIST OF ABBREVIATIONS

t	Time (min)
T	Temperature (°C)
x	Length of kernel (mm)
y	Joint or crease side width of kernel (mm)
z	Second width of kernel (mm)
W	Weight of kernel (g)
V	Volume of kernel (mm ³)
ρ	Density of kernel (g mm ⁻³)
mc	Moisture content (% wet basis)
L	Hunter Lab colour degree, lightness
a	Hunter Lab colour degree, redness (+), grayness (0) or greenness (-)
b	Hunter Lab colour degree, yellowness (+), grayness (0) or blueness (-)
YI	Yellowness index
F _{max}	Maximum force in texture analysis (N)
A _p	Partial area under the curve till maximum force in texture analysis (N.s)
L _s	Dry solid (kg)
A	Drying area (m ²)
x	Moisture content in drying rate equation
R	Drying rate (kg/m ² hr)
<i>R</i>	Drying rate (kg/hr)
V _{TS}	Total volume of sample
a _p	Polarization value
L _p	Length of polarization tube (dm)
α^{20}_D	Conversion factor (specific rotation) of Ewers method for starch
W _s	Weight of sample (g)

CHAPTER I

INTRODUCTION

The role of cereals and legumes in the diet is increasing while the role of others appears to be decreasing. Nourishment from these sources is not always readily identified because cereals and legumes contribute the diet in multiple forms and at multiple stages of processing. Sometimes they enter under their own identity such as for rice and sometimes they are disguised, as in bologna, and oftentimes they are one of many ingredients in a complex product like bread. Cereals and legumes are treated as in milling, bleaching, extruding, toasting, puffing, isolating, soaking, drying and refrying, among other things, before consumers encounter them as edible food. Consciously or not, however, they continue to provide a stable, relatively inexpensive source of calories and protein for consumers around the world with some promising new developments in process.

Food processors are continuously trying to design new and better foodstuffs that will not only bring them profits but will also fill the needs of consumers. Consumers' food needs consist from not only of nutritional fuel but also of satisfactory taste, variety, and convenience for their life style all at a price they are willing and able to pay. Since food habits are always culture bound and difficult to change, a critical extension of technological changes in food production and processing is an examination of what foods consumers want, how they can best be informed about new choices, and how they can best be protected from current and yet unknown hazards to their health and safety (Kirsey, 1987).

Consumers' welfare is ultimately changed by how well their preferences are met by the products they consume. Potential changes in consumers' welfare resulting from activities in the cereal and legume industries will be the focus (Kirsey, 1987).

Legumes and cereals are economical sources of protein, energy, vitamins and minerals. In spite of their good nutritional qualities, especially legumes consumption is declining worldwide. This could be due to extensive preparation and cooking, production of gastro-intestinal distress after ingestion and the presence of some nutritional problems (Iyer *et.al.*, 1980).

It is well-known that unprocessed dry legumes stored under inappropriate conditions (elevated temperature and humidity) progressively lose their ability to soften during cooking. This is a nutritional problem for those populations living in humid tropical and subtropical areas that depend on legumes for supplying a large part of their dietary protein. Economic problems due to the loss of an important functional property of the legumes and an energy problem for those areas (where fuel is costly and long cooking times are needed to soften the stored legumes) affect their utilization (Morris, 1963; Garruti and Bourne, 1985).

In order to solve these problems, alternative methods should be used to process the legumes and cereals into new forms such as semi-ready-to-eat-food products (i.e. bulgur). Production of legume and cereal based food materials should be developed throughout the world to increase nutritional intake, production and consumption of legumes and cereals, because of their nutritional properties.

1.1. Consumers' Preferences for Cereals and Legumes

Looking at trends in consumption of cereals and legumes in the United States (USDA, 1982) shows that per capita consumption has decreased for beans, peanuts and soy products, leading the decline (Table 1.1).

Studies of consumer food preferences in the United States (Chou, 1982) and in Europe (Anon, 1982) show that consumers prefer foods that are healthy, natural, and safe and they are willing to pay more for such foods.

How consumers define healthy, natural and safe foods is not always obvious. In Europe, "healthy" means foods that were associated with high protein, high fiber and low calories. It also implied an absence of excessive amounts of refined white sugar and preservatives or artificial coloring. Europeans consider healthy foods to include

yogurt, protein fortified snacks and pasta, low calorie salad dressings, bran and brown bread (Bodwell, 1987).

Table 1.1 Percent change in per capita consumption of cereals and legumes for United States (USDA, 1982)

Food type	Percent change in pounds per capita
Beans, Peanuts, Soy Products	-9
Edible Dry Beans	-44
Dry Peas	-30
Cereal and Flour	+3
Fats and Oils-Vegetable	+67
Sugars and Sweeteners	+24
Corn Syrup	+439
Dry Corn Sweeteners	+284
Rice	+80
Corn	+754

Studies of consumer food preferences in developing countries are less readily available but experience has shown that they prefer to eat their traditional foods. Educating individual households to use new foods is tedious but it may be the only way to influence the adoption of new food technology. The American Soybean Association is trying this approach in Mexico in an attempt to introduce high protein soy flour into home baked tortillas (Anon, 1983). Traditional foods are important to people's sense of security and identity. One of the major concerns with high technology food research is that it will not be applied to improving crop yields and nutritional content of foods that people actually want to eat but will be applied only to crops with high dollar value for commercial agriculture and international trade (Hardin, 1979; Ward, 1979).

1.2. Nutritional Advantages

The dietary goals or guidelines recommend increased consumption of complex carbohydrates and fiber and decreased consumption of saturated fats (Table 1.2). In practice this means an increased consumption of cereals and legumes (Bodwell, 1987).

Table 1.2 Estimated protein available for human consumption (g per day per capita)
(Bodwell, 1987)

	Plant Protein	Animal Protein	Total
Developed countries	41.3	48.8	90.1
Developing countries	43.5	11.9	55.4
All countries	44.8	24.6	69.4
United States	33.5	72.7	106.2

1.2.1. Nutrient content vs calories

The levels of nutrients some cereals and legumes products provide high amounts of protein and energy in the national diet. Cereals and legumes provide much higher levels of carbohydrate (for the most part, complex), in relation to both protein and fat, than do foods of animal origin. In addition, cereals and legumes can be generally excellent sources of copper, magnesium, manganese, phosphorous and potassium. Levels of iron and zinc are often high although, nutritionally, these may not be completely available. Cereals and legumes are also reasonably good sources of many vitamins.

Compared to foods of animal origin, the lipids of cereals and legumes have high ratios of polyunsaturated to saturated fatty acids. Most foods that are primarily of cereal or legume origin have no cholesterol or quite low levels per 1,000 kilocalories compared to foods of animal origin (Bodwell, 1987).

EC YÜKSEKÖĞRETİM KURULU
DOKÜMAN TAYİN MERKEZİ

1.2.2. Protein quality

In comparison with an ideal protein, most cereals or legumes have low levels of one or more essential amino acids. The pattern for an ideal protein, however, is based on the requirements of young children. The requirements of adults for essential amino acids are much lower. Recent reports have emphasized that protein from plant sources meets the protein and amino acid requirements of adults and, that protein from some plant sources meets those of young children (Bodwell, 1979; Torun *et al.*, 1981).

Even the poorer plant proteins (with respect to their amino acid composition), such as rye and peanut flour, provide an excess of essential amino acids if they are consumed at levels that provide the RDA (Recommended Dietary Allowances) for protein (e.g., for males, 0.8 g proteins/kg body weight/day). The RDA values for

protein are based on the assumption that protein from our usual diets, which contain various sources of protein, is utilized at an efficiency of only 75% compared to 100% for protein from animal sources such as eggs, milk or meat. With very few exceptions, most cereals and legumes are utilized with efficiency, which is greater than 75% (Bodwell, 1987).

1.2.3. Source of complex carbohydrates, dietary fiber and polyunsaturated fats

As noted in the section entitled "Nutritional advantages, nutrient content vs. calories", cereals and legumes are excellent potential sources of polyunsaturated fats and, together with fruits and vegetables, of complex carbohydrates (i.e., starch and other non-fiber polysaccharides). Legumes and whole grain cereals are also excellent sources of dietary fiber. Although there are numerous claims for the potential health benefits of the consumption of moderate to high levels of dietary fiber, few claims have been substantiated (Kimura, 1977; NRC, 1982).

1.2.4. Possible effects of plant protein on blood lipid status

The influence of dietary soy protein on blood lipids (primarily cholesterol) has been examined in several studies. Sirtori *et al.* (1979) found an average decrease of 20% in total cholesterol levels after two weeks in subjects fed diets high in soy protein. Likewise, Carroll *et al.* (1978) reported a slight, but statistically significant, reduction in cholesterol levels in college-age girls. No effects on cholesterol levels in over 60 subjects were observed by Van Raaij *et al.* (1979). In a study with men of various ages dietary intakes of cholesterol were quite low (200-250 mg/day) and cholesterol levels thus decreased when subjects were fed either an animal protein diet or a soy protein diet (Shorey and Davis, 1979). In studies in which 16 or 17 men were fed diets based on either of two different soy preparations or on animal protein and also were given "normal" levels of saturated animal fats, total dietary lipids, and cholesterol (Bodwell *et al.*, 1980), no significant decreases in blood lipids were observed.

1.3. Potential Disadvantages

Almost every food has some nutritional or potential disadvantages. Cereals and legumes and products made from them are not exceptions.

1.3.1. Digestibility

Foods must be digested before their nutrients can be utilized. Few data, however, document the effects of digestibility on the utilization by humans of such nutrients as vitamins and minerals. Some data are available on energy utilization, but the most extensive body of data is on protein (nitrogen) utilization.

The true digestibility of protein of animal origin ranges from 40 to 100% (Table 1.3) generally, digestibility is between 80 and 90% for cereals or cereal products and above 90% for most legumes. Digestibility can be lower (<70-80%) for highly processed cereals, such as some ready-to-eat breakfast foods, and for severely or improperly processed legumes (Bodwell, 1987).

1.3.2. Effects on mineral utilization

Cereals and legumes contain phytic acid and fiber that have been implicated as agents that depress the biological availability of minerals. The numerous studies of phytic acid and fiber have been reviewed (Bodwell, 1983; Young and Janghorbani, 1981).

In two studies, the effects of phytate from wheat bran were separated from the effects of the bran fiber. Bran or dephytinized bran was provided in muffins in both mineral balance studies and iron absorption tests. In the iron absorption tests, muffins containing no bran were also used. The results of the balance studies are summarized in Table 1.4. The apparent absorptions of zinc, iron, manganese and copper were not improved by the removal of the phytate. In the studies of iron, absorption was markedly inhibited (74%) when about 12 g of whole bran was included in the test meal (Bodwell, 1987).

Removal of the phytate from the bran does not improve absorption. Those studies indicate that the fiber and not the phytic acid in wheat bran inhibit iron absorption.

1.3.3. Effects of dietary fructose

Fructose is one of the most lipogenic sources of carbohydrate. Compared to glucose, two rate-limiting steps mediated by enzymes (hexose kinase, phosphofructose kinase) are bypassed in its conversion to triglyceride. In rats, fructose has been

implicated in the development of diabetes. Elevated triglyceride levels increased insulin response, and decreased insulin sensitivity (Cohen *et. al.*, 1977; Blakely *et. al.*, 1981). In copper-deficient rats death rate from spontaneous heart failure was high in rats fed fructose (Smith *et. al.*, 1983; Fields *et. al.*, 1983; Reiser *et. al.*, 1983), but not in rats fed either starch or glucose. Although those results cannot be extrapolated directly to humans, fructose consumption by human subjects impaired their insulin binding and insulin sensitivity-effects that are similar to those observed in rats (Nielsen *et. al.*, 1980). Thus, some caution may be prudent in relation to making claims about the nutritional benefits of fructose in corn syrup and other foods.

Table 1.3 True digestibility of protein by adults in some common protein sources (Bodwell, 1987)

Protein Source	Digestibility (%)	
	Mean	Range
Animal Protein	96	90-106
Corn, whole	87	84-92
Corn, ready-to-eat cereal	70	62-78
Whole wheat	87	80-93
Wheat flour (white)	96	96-97
Wheat bread (white)	97	95-107
Wheat bread (coarse, brown or whole wheat)	92	91-92
Wheat gluten	99	96-104
Wheat, ready-to-eat cereal	77	53-88
Rice, polished	89	82-91
Rice, ready-to-eat cereal	75	77-85
Oatmeal	86	76-92
Oats, ready-to-eat cereal	72	63-89
Peas, Alaskan field	88	--
Peanut flour, butter	94	91-98
Soy flour	86	75-92
Soy isolate	95	93-97
Soy Protein, spun	104	101-107

Table 1.4 Effects of removal of phytate from bran on apparent absorption (mg/day) of trace minerals (Bodwell, 1987)

Trace Mineral	Whole bran muffins fed	Dephytinized bran muffins fed
Zinc	3.1 ± 0.4	2.4 ± 0.9
Iron	2.9 ± 0.7	2.0 ± 1.1
Manganese	1.4 ± 0.2	0.8 ± 0.7
Copper	0.59 ± 0.09	0.56 ± 0.06

1.3.4. Anti-nutrients and other factors

In addition to phytic acid, most plant sources of food contain various other anti-nutrients or other undesirable factors. Results from studies of those factors and their possible significance have been reviewed (Wilcke *et. al.*, 1979).

Some of the more common anti-nutrients and toxic or undesirable substances present in legumes and cereals are listed in Table 1.5. The hemagglutinins are heat-labile. The heterosides (goitrogens) are usually heat-labile. Flatulence factors are not a nutritional problem but are of concern in relation to the extensive utilization of legume products.

Table 1.5 Anti-nutrients and toxic or undesirable substances in cereals and legumes (Bodwell, 1987)

Substance	Occurrence	Heat-Labile
Hemagglutinins	Most legumes, wheat	Yes
Heterosides	Most legumes, wheat	Usually
Phytic Acid	Most legumes and cereals	No
Flatulence Factors	Most legumes	No
Protease Inhibitors	Most legumes and cereals	Variable

Various protease inhibitors are present in most cereals and legumes of particular current interest is the induction of hyperplastic nodules in the pancreases of rats fed soy protein (containing trypsin inhibitor) for 15 to 24 months (Morgan *et. al.* 1977). Becker (1981) reported that trypsin inhibitors, especially those from soybeans, inhibit cancerous tumor formation in tumor-prone mice, and Yavelow *et. al.* (1982, 1983) suggested that protease inhibitors from tofu, chickpeas and kidney beans might suppress tumor formation in humans. Only further study can determine the role of inhibitors in human health and disease.

Allergens saponins, and low levels of estrogenic substances may also be present in plant proteins. If products are improperly processed or heat-treated, toxic compounds such as tyrosinoalanine may be produced or the protein nutritive value may be lowered. Other reactions, such as the conversion of methionine to methionine sulfoxide or sulfone may also occur (Marable *et. al.*, 1980).

1.4. Some Implications for the Future

As noted above, it is highly that half of consumption of cereals and legumes and their products can increase during the next few years. This increase can be primarily due to the perception that reducing intakes of fat and increasing intakes of complex carbohydrates and fiber would result in significant long-term health benefits (Kirsey, 1987; Bodwell, 1987).

It is also likely that for both economic and health reasons, use of protein products, derived from soy or other legumes and from cereals for extending meat or meat products could increase. Use of high quality plant protein products and limiting the level of replacement would probably also greatly facilitate the acceptance and use by the general population of beef extended with plant protein (Kirsey, 1987; Bodwell, 1987).

Future research should investigate the significance and possible modulation of the effects of plant protein on mineral utilization and the effects of anti-nutrients and toxic or other undesirable substances on human nutrition. Research should be extended to legumes other than soybeans and to the cereal grains. The effects of high dietary levels of fructose on human nutrition also should be clearly defined (Kirsey, 1987; Bodwell, 1987).

1.5. Legumes-Soybean

Pulses are legumes, which produce seeds that are harvested when dry, then cooked for human food. They are high in protein and can substitute for meat in the diet. Their oil content ranges from almost none to high. They also provide good quantities of B vitamins. Also, their carbohydrate contents vary, but often include long chain carbohydrates that are difficult to digest and lead to flatulence (gas). Most grain legumes contain antinutrients or poisonous substances and need to thoroughly cook before eating. Under proper conditions they can be stored for many years.

Some grain legumes are commonly used for other purposes, as edible leaves or leguminous vegetables. Most tropical grain legumes are annuals, but some are weakly perennial. Their climatic adaptation varies, and some have severe insect and

disease problems, which limit their use. Variety trials are desirable, as there may be considerable variation within a species.

Legumes have been eaten around the world for more than 10,000 years - and even today they remain a popular, healthy and versatile food. The most common legume is the soybean. Other legumes include black-eyed peas, chickpeas, lentils, and black, red, white, navy and kidney beans. Not only are they tasty, legumes provide many of the nutrients the human body needs, such as protein and carbohydrates (Table 1.6). In addition, the iron, folic acid, calcium, magnesium, potassium and B vitamins found in legumes help meet daily vitamin and mineral requirements. Legumes are also high in dietary fibers, low in saturated fat, and cholesterol free.

Table 1.6 Comparing legumes with respect to their nutritional compositions
(ADA, 2000)

Legumes (for 100g)	Calories (g)	Protein (g)	Fat (g)	Iron (mg)	Calcium (mg)
Soybeans	86	14	8	4	88
Lentils	100	9	<1	3	19
Kidney beans	88	8	<1	3	25
Black beans	41	8	<1	2	25
Chickpeas	82	7	1	3	40

Consumer and processor expectations and uses of legumes vary widely throughout the world. In the case of value-added products containing legumes, regardless of the nutritional benefits that may be associated with legumes, if the texture, flavor, aroma, color and general appearance do not match consumer expectations, the success of the product will be severely curtailed.

Nutritional properties of legumes (soybeans, chickpea, beans, peanuts, peas etc.) can be classified in Table 1.7.

Cooking the legumes thoroughly will help with gaseous production. A longer cooking time enables more of the bean protein to be broken down into more digestible pieces. This helps to prevent gas buildup (which occurs as a result of body breaking down the bean protein).

Table 1.7 Nutritional considerations of legumes (ADA, 2000)

Amino acid ratio much better
Combination with cereals good
Indigestible oligosaccharides
Higher in protein than cereals
Low in sulfur containing amino acids
Contain antinutritional factors
Peanut and soybean high in fat

Soybean is a major member of the legume family and it plays an important role in healthy nutrition because of its valuable composition. Its protein content (38-44%) is higher than that of other legumes (20-30%) and much greater than that of cereals, (8-15%) (Synder and Kwon, 1987). This, coupled with its good amino acid profile, enhances its value as a foodstuff, and is one of the reasons for the economic importance of soybean. To produce semi-ready-to-eat-food products from legumes, soybean can be selected to represent this food group.

The soybean is rightly called "the cow of China" a glowing reference to the impressive range of delicious foods fashioned from this 3,000 year old legume. With the bustle and excitement of entrepreneurial activity in the U.S. today with soy foods -new companies, new products, growing consumer awareness the soybean might also be dubbed "the golden cow".

The generic term "soyfoods" denotes the expanding family of high protein, tightly processed, Asian-styled, naturally positioned, edible consumer products made from the soybean. These include tofu, tempeh, miso, soymilk, soy sauce, soy sprouts, soy flour, soy nuts, and an unlimited range of prepared secondary products, e.g. tofu burgers, tofu dips, tofu ravioli, tofu pizza, tempeh pate, soylami, tempehroni, miso dressings, soymilk ice cream. The term generally excludes soy protein ingredients intended for industrial reformulation, e.g. grits, isolates, concentrates, and extruded soy flour.

Soybean is a good protein source and large amount of soybean will be produced in Turkey after South Anatolia Project (GAP project) is completed.

Basic important factors and processing methods of soybean are given in Table 1.8.

Table 1.8 Important factors for soybean (Synder and Kwon, 1987)

Grown throughout the world
Eaten by humans mainly in the Orient
40-44% protein in soybean meal
2 nd crop in many countries
Used extensively for animal feeds

Approximate chemical composition of soybean can vary depending on the variety and the growing condition, but reasonable average figures are 40% protein, 20% lipid, 35% carbohydrate, and 5% ash on dry weight basis. The water content of stored mature soybean is usually about 12-14% to insure storage stability (Synder and Kwon, 1987).

The carbohydrate portion of soybean seeds is substantial, about 30% on a dry weight basis, but economically the carbohydrate are much less important than the lipid and the protein. Consequently, less research has been done and there is relatively less known about soybean carbohydrates compared to the lipids and proteins. Still there are important quality aspects of soybean and soybean products that hinge on the carbohydrate portion (Synder and Kwon, 1987).

The quantities of the soluble carbohydrate in soybean seeds are about 10%, with approximately 5% sucrose, 1% raffinose and 4% stachyose. One of two valuable components of the soybean is its oil. Most of the crude oil is triglyceride, but minor components are present to some extent, depending on the extraction system. For example, newly developed and experimental techniques for extraction soy oil with carbon dioxide under pressure have shown that the extraction oil has less phospholipid than normally extracted oil. Also the amount of oil extracted from the soybean will influence the composition. The final portion extracted is rich in phospholipids (Synder and Kwon, 1987).

Protein is the second major chemical component of the soybean that has commercial value. Soybean protein is particularly valuable, because it has an amino acid composition that complements that of cereals. Soybeans are limiting in sulfur-containing amino acids for most animal species, including humans, but contain sufficient lysine to help overcome the lysine deficiency of cereals. Table 1.9 shows the essential amino acid composition of soybeans, wheat gluten, milled rice, corn, and

broad beans, another legume. A soybean-rice combination is complementary for lysine and methionine and helps to explain the successful use of soy protein products such as soybean curd in the rice-eating cultures of Asia (Synder and Kwon, 1987).

This large quantity of protein in soybeans along with excellent quality increases their value as a feedstuff and is one of the reasons for the economic advantage of soybean. The quality of soy protein is not equal to that of animal protein, it is considerably better than cereal protein. Also, soybeans contain more protein than cereals. Proteins in soybeans are often deficient in sulfur-containing amino acids that are present in excess in cereal. Most of the diets in developing countries, where protein rich foods and their mix are needed, have the disadvantage of being low in total protein and deficient in lysine. Thus, a logical supplement (bulgur, soybean etc.) for such diets is an economical protein abundant in essential amino acids (lysine and tryptophan). Generally these essential compounds are lacking in cereals. Therefore, soybean is used in formulae to enrich the foods such as macaroni, pasta, bread and baked goods etc. or is consumed alone as traditional foods (tempeh, tofu, ang-kak, hamanotta etc.) (Arslan Bayram *et. al.*, 1998; Snyder and Kwon, 1987; Paulsen, 1961; Irvine, 1971). Additionally, soy foods can be used for gluten-intolerant people instead of cereal based food products.

Soybeans used in protein-rich food mixtures are generally in the form of defatted or full-fat flours with adequate heat treatment. These flours may be obtained from a large soybean mill in defatted form. Recognizing the many advantages of properly processed soy flour as a protein supplement, considerable effort has gone into formulation of blends of soy flour with cereals. These mixtures, when suitably fortified with vitamins and minerals, have great potential for the feeding of infants, children, and people of all ages in developing areas of the world.

Table 1.9 Essential amino acid compositions (g/16 g N) (Snyder and Kwon, 1987)

	Soybean	Wheat Gluten	Rice	Milled corn	Broad beans
Isoleucine	5.1	3.9	4.1	3.7	4.5
Leucine	7.7	6.9	8.2	13.6	7.7
Lysine	6.9	1.0	3.8	2.6	7.0
Methionine	1.6	1.4	3.4	1.8	0.6
Phenylalanine	5.0	3.7	6.0	5.1	4.3
Threonine	4.3	4.7	4.3	3.6	3.7
Tryptophan	1.3	0.7	1.2	0.7	-
Valine	5.4	5.3	7.2	5.3	5.2
Histidine	2.6	1.8	-	2.8	2.8

1.6. Cereals-Rye

Rye (*Secale cereale*) tends to be grown on land just outside the belt which gives the most satisfactory return for wheat, such as areas of northern and eastern Europe that have a temperate climate. As a bread grain, rye is second only to wheat in importance and is the main bread grain of Scandinavian and Eastern European countries. Although nutritious and palatable to some people, rye bread is not comparable with wheat bread as regards crumb quality, large loaf volume or taste. Cultivated rye was derived in about 4000 BC from the rye grass that occurred as a weed in wheat and barley crops. Rye is particularly susceptible to infection by the fungus *Claviceps purpurea*, which can also attack barley, oats and wheat. The sclerotia of this fungus are known as ergot. Ergot is a toxic contaminant of cereals, which has a maximum limit of 0.05% in wheat and rye traded within the European Union. The grains of rye are longer and thinner than those of wheat and have a greenish-grey color. Rye milling differs from wheat milling and usually involves the use of eight or more break rolls and comparatively few reduction rolls. Rye meal and flour have a characteristically high amylase activity and its protein produces little gluten, which limits its use in bread production. The high pentosan content of rye allows batters to be whipped from water and rye meal, which form stable foam. These stable foams can be baked at high temperature into crisp bread. In order to avoid excessive amyloytic breakdown of the starch in breadmaking, the pH of the rye dough is lowered by acid modification in a "sour dough" process. A starter 'sour dough' is prepared by allowing rye dough to stand at 25°C for several hours to induce a natural lactic acid fermentation caused by species of *Lactobacillus*. Although rye bread is still not popular in the United Kingdom, the successful new range of 'soft grain'

breads, such as Mighty White, contain presoaked kibbled wheat and rye grains (Ranken *et. al.*, 1997).

Only a small amount of work has been done making strict comparisons between rye varieties except for plot yields. Instead, composite samples of rye have been examined for chemical and physical characteristics. Morrison (1956) gave the overall chemical compositions of rye grain, flour, and middlings as shown in Table 1.10. He also compared the chemical composition of wheat and barley. Protein and fat composition of rye, wheat, and barley grains were generally similar, ranging close to 13 and 1.8%, respectively. Fiber percentages of wheat and rye grain are essentially similar as is true of nitrogen-free extract and minerals. Rye was somewhat lower in total digestible nutrients than barley or wheat. Total digestible nutrients of rye flour and middlings were lower than that of the grain. The flour was lower than rye grain in protein, fat, fiber, and minerals. However, middlings had higher protein, fat, fiber, and mineral percentages, but lower nitrogen-free extract than either the grain or flour.

Koz'nima *et. al.* (1956) demonstrated the presence of wedge and adhesive protein in the rye endosperm. Vones *et. al.* (1964) observed 8 or 9 migrating components in a moving boundary electrophoresis study of wedge proteins gave essentially the same mobility values. With preparation of rye flour lacking wedge proteins, Vones *et. al.*, (1964) produced bread with dry, crumbling, and cracking crumbs that lacked coherence. This demonstrated the need of wedge proteins for formation of normal dough. They believed that wedge proteins and gums did not interact for increased viscosity. Higher than expected viscosity values were observed in solution of gums and glutes, thus suggesting complex formations. Korkman and Linko (1966) placed much emphasis on the role of starch in making good loaves and gave less credit to the interactions between soluble high molecular gums with protein factions, including wedge proteins. Schopmeyer (1962) stated that fine particles separated by air had 14.4% protein; high coarse particles contained only 7.3% protein.

Rohrlich and Rasmus (1956) compared the proteins of rye and wheat after manually separating small quantities of the germ, aleurone, and endosperm. In the rye aleurone (and pericarp) they found almost equal quantities of albumin, globulin, and

prolamine. In contrast, wheat had a much higher proportion of albumin in the aleurone and a much lower proportion of prolamine. The rye was tetraploidform, presumably tetra pukes. Paper chromatography was used in determining the amino acids present in the aleurones, germs, and meal or flour from wheat and rye. They were able to identify 18 amino acids as follows in Table 1.11.

Table 1.10 Nutritional composition of rye and its derivatives (Morrison, 1956)

Product	Total Digestible Nutrients	Protein (%)	Fat (%)	Fiber (%)	Nitrogen-free extract	Total (%)	Ca (%)	P (%)	K (%)
Rye grain	76.5	12.6	1.7	2.4	70.9%	1.9	0.10	0.33	0.47
Rye flour	74.5	11.2	1.3	0.6	74.6%	0.9	0.02	0.28	0.46
Rye middlings	72.0	16.6	3.4	5.2	61.2%	3.8	0.06	0.63	0.63
Wheat	80.0	13.2	1.9	2.6	69.9%	1.9	0.04	0.39	0.42
Barley	77.7	12.7	1.9	5.4	66.6%	2.8	0.06	0.40	0.49

Table 1.11 Amino acid content of rye (Rohrlich and Rasmus, 1956)

Alanine	Histidine	Proline
Arginine	Leucine	Serine
Aspartic Acid	Lysine	Threonine
Cystine	Isoleucine	Tryptophan
Glutamic Acid	Methionine	Tryosine
Glycocol	Phenylalene	Valine

These workers did not find qualitative differences between the amino acids of germ and the aleurone. They noted, however, that the wheat endosperm was lower in arginine and lysine when compared to that the rye endosperm.

Orr and Watt (1957) summarized the data available on 14 amino acids expressed in terms of amino acids content per gram of nitrogen present in whole grain and flours of different extractions as well as amino acid content for 100 gram of bread from light and medium rye flours. More amino acid content was found in bread from medium flour than bread made from light flour. Of the amino acids listed above, they did not present data for alanine, aspartic acid, glycocol and proline. Glutamic acid, leucine, valine, arginine, and phenilalene were among those that had the highest percentages.

In studying higher molecular gums of cereals, Preece and Hobkirk (1955) found that rye was rich in water-soluble pentosans with very little if any contamination with beta-glucosane. Pure pentosans were more readily obtained from rye than from other cereals. The measure units of gums identified from rye were glucosan, xylan, araban, and galactane. These workers later separated rye and oat polysaccharides by electrophoresis. Rye had clear separation in to bands, while oat had three bands. They were able to recognize the following sugar unit in hydrolysates of rye: glucose, xylose, galactose, and arabinose.

The physical properties of the rye grain are concerned with bushel weight, and other characteristics. Though the legal weight for rye is 56 lb per bushel, only plump rye of the diploid type frequently reaches this weight. The kernel weight of rye is about 26 mg while the tetraploid forms are nearer 40 mg per kernel. As already suggested, rye kernels vary a good deal in color and most of them tend to be “rough” in appearance because of wrinkled pericarp. Further, rye tends to sprout before harvest according to many European reports. Rye samples with ruptured pericarp above the embryo are frequently observed; this suggests incipient sprouting (Matz, 1970).

Ljung (1948) noted differences in germination of rye varieties immediately after harvest; one reaching 22.6% while another had only 9.0% after being placed under favorable germination conditions for 4 to 5 days.

1.6.1 Flavor of rye

On a worldwide basis the rye grain is used to great extent in making bread, and to a lesser extent for feeds and distilled products. The importance of rye for user is the flavor, which means different things to different people. This is especially true for the taste of rye bread.

1.6.2 Rye “Glutens”

Johnson and Bailey (1925) studied the gluten and gas-retaining capacity of rye flour dough. They found that the rate of gas production in the dough was high, but that the gas-retaining capacity was low and was probably responsible for the dense compact loaves that are ordinarily baked from pure rye flour. Cunningham *et al.* (1955) extracted “glutens” from rye, wheat, barley, and oats by use of formic, oxalic, and

citric acids. The formic acid gluten of rye absorbed 70.3% water while that of wheat, barley, and oats absorbed 65.0, 55.2, and 50.2%, respectively. These workers thought that carbohydrate gums might have caused differences in water absorption rather than variations in the protein moiety. A judging panel thought that rye gluten was intermediate in elasticity and cohesiveness when compared to wheat gluten, which was quite elastic and cohesive.

1.6.3 Palatability of rye as feed

In feeding rye, palatability is thought to be important. Many workers consider rye unpalatable, and it is probably this reason that promoted Delwiche *et al.* (1940) to suggest mixtures of rye in the grain portion of cattle rations. Wilson and Wright (1932) in South Dakota noted that cattle did not eat large quantities of rye when fed free choice. They further noted that the finish of the cattle lacked luster. In their feeding experiments with hogs, daily gains with rye were greatly improved when it was mixed with corn or barley. Vitamins in rye are shown in Table 1.12.

Rye is also used as a feed instead of a food in Turkey. Therefore, its economical value is low.

Table 1.12 Distribution of vitamins in rye (Matz, 1970)

Product	Individual B Vitamin Readings			
	Thiamine ($\mu\text{g/g}$)	Nicotinic acid ($\mu\text{g/g}$)	Riboflavin ($\mu\text{g/g}$)	Pantothenic acid ($\mu\text{g/g}$)
Whole rye	2.4	12.9	1.5	10.4
Rye germ	9.3	27.0	4.46	13.9
Middlings from whole rye degermed	3.3	16.7	2.5	23.1
Middlings from degermed rye	3.3	17.7	2.0	23.1
Dark flour from whole rye	3.2	12.2	1.7	13.4
Dark flour from degermed rye	3.6	12.5	1.8	14.9
White rye flour from whole flour (not bleached)	1.5	7.1	0.76	7.1
White flour from whole rye (bleached)	1.6	7.3	0.69	7.25
White flour from degermed rye (bleached)	1.4	7.3	0.68	6.5

1.7. Bulgur

Bulgur can be defined as dry and wet cleaned, cooked, dried, peeled then grinded and classified wheat product (in general made from *Triticum durum*) (Bayram *et. al.*, 1996; Bayram, 1997). It is an ancient wheat food (its history back to 4000 years ago) of Near Eastern, Mesopotamia and Mediterranean origin that referred as “Arisah” in the Old Testament and it is the major source of both protein and calories in the ancient world. The Roman word for bulgur is “*cerealis*”, after Ceres, the goddess of harvest; Israelites called it “*dagan*”, a word meaning "bursting kernels of grain"; other Mid-Easterners called it “*arisah*”, and it is a mainstay in the diet which is how it was referred to in the Bible Biblical scholars translate “*arisah*” as "the first of the coarse meal" and, according to Biblical archeologists, was a porridge or gruel prepared from parboiled and sun-dried wheat.

In Turkey, for example, the number of bulgur plants is nearly 500 and about 1 million ton of bulgur is produced annually (250 000 tones in America). This consumption is 2.5 times greater than macaroni (pasta) production, with an average consumption 12 kg per person (Bayram and Öner, 1996; Bayram and Öner, 2002).

Bulgur is also coming into commercial prominence in the United States, as large amounts are being shipped overseas under government assistance programs, and its availability in domestic food channels is growing. Because, it is a whole grain food and popular in the health foods sector, and its hearty flavor lends itself to be included frequently in vegetarian meals (Bayram and Öner, 2002).

Processing steps during the bulgur production cause the gaining of the some functional characteristics on the finished product as follow; (i) resistance to mold contamination, (ii) resistance to insect attacks, (iii) enzymes are inactivated due to cooking operation, (iv) microorganisms are inactivated due to the cooking and drying (pasteurised), (v) numerous nutritional benefits (original wheat kernel nutrients are encapsulated during the processing), (vi) low fat, high protein (whole grain food), (vii) appealing taste, (viii) easy preparation without reducing to take time to cook (since semi or ready to eat food), (ix) inexpensive and economical, (x) does not absorb radiation, (xi) long shelf-life (starch is gelatinised and the kernel is almost cooked during processing therefore bulgur is more stable than wheat in hot and

humid environments), (xii) consumable as individually due to its nutritional properties and it is a good source for folic acid, (xiii) the best processing method to decrease the available phytic acid content in contrast to increasing the bran content (cellulosic part, high mineral), (xiv) stored for military purpose (bulgur is one of the wheat products in countries, and it is included in the special list of food rations in nuclear fallout shelters), (xv) prevent intestinal cancer risk due to its fiber content, (xvi) has no respiration activity during storage due to inactivation of enzymes, microorganism and insects larvae (Bayram, 1997; Bayram and Öner, 2002; Bayram *et. al.* 2003a; b; c).

In order to solve the declining consumption of legumes, alternative methods should be considered to process the legumes into new forms, such as bulgur. A combination of the bulgur production procedure with soybean and rye as the raw material could supply humans with a new type food product (calling as soybulgur and ryebulgur) and may solve some nutritional and consumption problems. Additionally, soybulgur can be used for gluten-intolerant people instead of wheat-bulgur.

1.8. Processing Operations

Bulgur production method is a good processing method for the production of semi-ready-to-eat (pilaf etc.) and ready-to-eat food product (köfte, kısır etc.) (Bayram and Öner, 2002; Bayram *et. al.* 2003a; b; c). The most important processing steps of bulgur production are soaking, cooking and drying.

1.8.1. Soaking and cooking operations

For human consumption, heat treatment is a major operation. Especially, cereals and legumes are cooked before eating. Sometimes, soaking operation is used before cooking operation. For legumes and cereals, other preconditioning operations have not been used except soaking. Under atmospheric conditions, cooking of legumes is too hard, that's why pressure-cooking is recommended. In addition, microwave can be used to cook legumes and cereals.

During processing the food material is affected in many ways including changes in the protein, fat and carbohydrate portion with both positive and negative results for quality and nutritional status (Dagerskog, 1977).

It has been shown that for legumes and cereals, a soaking operation prior to cooking is necessary while heat processing improves protein digestibility (Ellenrieder *et. al.*, 1980; Silva and Leite, 1982; Rockland and Radke, 1981) and eliminate completely the toxic factors contained in the raw seed. In order to obtain the maximum protein quality, a much shorter cooking time was needed for the soaked samples than for the unsoaked ones (Molina *et. al.*, 1975; Wang *et. al.*, 1979). To improve protein digestibility and reduce the processing time, soaking above ambient temperature might be recommended. The aim of the heating processes is to obtain a palatable and digestible food product with a minimum quality loss.

The effect of soaking temperature on the rate of hydration of cereals and legumes is pronounced and well documented (Bakski and Singh, 1980; Abu-Ghannam and McKenna, 1997; Kubota, 1979; Singh and Kulshrestha, 1987; Sopade *et. al.*, 1992; Sopade and Obekpa, 1990; Becker, 1960; Verma and Prasad, 1999; Hsu, 1983; Hung *et. al.*, 1993).

Soaking occurs together with leaching. Rates of soaking and leaching increase theoretically with increase in temperature theoretically. In the leaching of soluble materials from inside a particle (by water), the following general step can occur in the overall process. Water is transferred to the surface of the solid. Next, water penetrates or diffuses into the solid. The solute dissolves in the water. The solute diffuses through the solid-water mixture to the surface of the particle. Finally, the solute is transferred to the bulk solution. In general, the rate of transfer of the water from the bulk solution to the solid surface is quite rapid and the rate of transfer of the water into the solid can be either fast or slow (Geankoplis, 1983).

The transfer of nutrients from bran and aleurone structures to endosperm during parboiling of wheat is well-known in bulgur production. Water diffuses through hull and bran; most of the water-soluble nutrients in these parts of the kernel are transported into the endosperm. During soaking of soybean, vitamins and nutritional compounds diffuse into the kernel. In turn, the nutritional values of the bulgur increase.

When legumes and cereals are put into soaking water to produce bulgur, water soluble substances (encapsulated ingredients inside the cells) are solubilized initially. Mass transfer continues during soaking from products to water or vice-versa. Solubilized substances in the water are then re-absorbed during subsequent soaking (Bayram, 1997).

Some of the remaining substances in water after the soaking operation are important for nutritional properties of finished food product and environmental pollution (as discharge). Also, discharged soaking water might be re-used for the next soaking operation to recover energy and water, practically. Therefore, the properties of soaking of legumes and cereals should be investigated to understand the leaching of the substances from soybean and rye into the water.

The main requirement during soaking and cooking, moisture content should be larger than 40%. If the moisture content of kernel is less than this limit, white spots can occur into kernel. This white spots shows the ungelatinized starch. The gelatinization of wheat starch start at 67.5°C. During gelatinization, shape of the wheat starch does not change but swell (Çömde, 1986; Ökte, 1984; Seçkin, 1968). During cooking, temperature should be below 95°C to prevent denaturation of the nutritional compounds (Çömde, 1986; Ökte, 1984; Tahsin, 1964).

The basic objective when cooking cereals is to convert their starch content to a digestible form by gelatinization. However, commercial cooking processes pursue additional aims: to change the cereal's properties, e.g. as in the case of parboiled rice or bulgur; to prepare the cereal for further processing, e.g. corn flakes or rice crispies; and to shorten subsequent preparation stages, e.g. for "instant groats" or "1 minute rice" in each case with only partial gelatinization of the starch and with minimum changes to product texture and consistency (Vorwerck and Oeding, 1992).

Cooking conditions must be selected to give complete gelatinization without darkening the product or making it so sticky as to interfere with subsequent drying. Conditions for the precook treatment and for the drying must be selected carefully to balance the costs of these treatment with the quality characteristics of the product.

Cooking equipment varies from atmospheric batch kettles to continuous pressure cookers (Haley and Pence, 1960). In some factory, screw conveyer cooking system is applied. In batch system, 1.5-2 times water is added into kettle then 1-1.5 hours boiled. At the end of cooking all of the water should be absorbed by kernel to prevent nutritional losses (Çömnden, 1986). But, practically it is impossible.

Industrially, water addition and cooking processes are made simultaneously with designed steam jacket helezonic conveyor. At each helezonic section, temperature and water content are different. Helezons have slope. This slope supplies that, at half of helezon, wheat will be immersed into water and at other half part, will not be immersed into water during conveying (Çömnden, 1986; Öktem, 1984). This design supplies that, wheat absorbs water during immersion, and then at the other part; water will diffuse into wheat homogeneously. Temperatures are 80 and 95°C respectively in first and second conveyors (Çömnden, 1986; Öktem, 1984). Temperatures are controlled by thermocouples and check valves. Addition of water is important for nutritional content. If water content is high, solubilized vitamin B will be decanted at the end of the cooking (Çömnden, 1986). At Maktas Co., this process is used and capacity is 5 tones/day (Çömnden, 1986; Öktem, 1984). At sufficient water addition, solubilized vitamin B will be diffused into kernel. Therefore, nutritional value and color quality will be high. In addition, energy recovery will be increased. Total retention time in the helezons is 72 minutes (Çömnden, 1986).

Pressure parboiling technique developed for paddy is used for producing wheat bulgur. Wheat is cleaned by circulating water, steamed at 12.5 kg/cm² for 10 minutes in a specially developed vessel, and then steamed for 10-15 minutes with a constant pressure of 1.4 kg/cm² (gauge) for 20-25 minutes. The wheat is then dried to 12.5-14.0% moisture, polished with 5% rice husk in a rice huller and milled. Maximum time for producing bulgur is 55-60 minutes. A recently developed pressure parboiling process involves soaking paddy in water for a few minutes, followed by steamed at atmospheric pressure for 10-15 minutes and at about 17 kg/cm² (gauge) for 5 minutes. The process, which possesses several advantages in terms of operating costs, times and product quality. Brief mention is also made of a pressure parboiling system for use in rural areas; such a system may be used for freshly harvested paddy

and does not require a boiler. Pressure parboiling may also be successfully applied to bulgur wheat (Iengar *et. al.*, 1979; Iengar *et. al.*, 1980). In small batch system, cooking step is made in tank. Wheat absorbs water and then gelatinizes. In this system labor and energy cost are high, but investment cost is less.

Cooking operation is one of the most important steps for the bulgur production process. A big problem to produce bulgur is the dispersion of the kernel during the cooking operation. Dispersed wheat kernel causes product loss, stickiness (leaching of starch), changing of the kernel size, color and quality losses. These problems also affect the subsequent operations (drying, conveying system, peeling and quality loss of the finished product). During the cooking operation, the crease of the wheat kernel is opened and the widths of the kernel increase. The crease of the wheat kernel can be disrupted due to the excess cooking operation and, inner part and gelatinised starch leach. Traditionally, the cooking of wheat to produce bulgur is controlled using the change of the size (crease side) of the wheat kernel. Therefore, determination of the behavior of the wheat kernel during cooking is of practical importance since it governs the subsequent operations and quality of the final product. Hence, modeling the dimensional changes during cooking has attracted considerable attention. During the cooking operation, water diffuses into the kernel, thereby increasing the size of the kernel during the cooking. The expansion may be different in the radial and axial directions. Cooking time and temperature affect the wheat kernel due to water absorption. The effects of the processing variables and the modeling of the cooking operation are necessary to systematically design of cooker and to understand the effects of cooking on bulgur production. Kinetics deal with the changes in a system, their associated levels, the rate at which the changes occur and the mode and mechanism by which the changes are affected. Understanding behaviors of wheat kernel during cooking is of practical importance since it governs the subsequent operations and quality of the final product. Hence, modeling the dimensional changes during cooking has attracted considerable attention. Determination of the cooking mechanism and the prediction of the dimensional changes of kernel are also essential to the control of the cooking operation.

Kinetic models and thermodynamics or physicochemical equations have been used to understand water absorption of cereals and legumes (Bakshi and Singh, 1980; Abu-

Ghannam and McKenna, 1997; Kubota, 1979; Singh and Kulshrestha, 1987; Sopade *et. al.*, 1992; Sopade and Obekpa, 1990; Becker, 1960; Verma and Prasad, 1999; Hsu, 1983; Hung *et. al.*, 1993; Heldman and Singh, 1980; Fasina *et. al.*, 1999; Rizvi and Benado, 1984; Iglesias *et. al.*, 1976; Mazza, 1980; Benado and Rizvi, 1985; Fasina *et. al.*, 1997). According to the studies of Fasina *et al.* (1997; 1999), some approaches were used to understand the properties of water and calculate the energy requirements associated with the transfer of heat and mass in biological systems.

Different legumes and cereals were examined with various operational conditions by some researches as follows;

For example, chick peas, lentils, broad beans and 3 cv. of beans (*Phaseolus vulgaris*, *Mexican white*, *Pinto* and *Black*) were soaked in distilled water at 25°C for 8 h (1:10 wt./vol. ratio), cooked in distilled water at 95, 90, 85 and 80°C for 300 minutes. Samples was taken at 0, 5, 10, 15, 20, 30, 45, 60, 75, 90, 120, 150, 180, 240 and 300 minutes and a 2 mm diameter cylindrical punch was driven through the samples at 5 mm/s in a Texture Analyzer TA.XT2. Data for the 3 bean cv. cooked at 95°C and the force vs. cooking time curves for the other legumes and cooking temperature (90, 85 and 80°C) was found as similar. Results showed that the effects of both cooking temperature and cooking time was highly significant ($P < 0.0001$). A rapid initial a slower softening, both followed softening corresponding to a pseudo first order mechanism. The effect of temperature followed an Arrhenius' pattern (Anzaldua *et. al.*, 1996).

Water absorption characteristics of 2 cowpea var. (IITA-2246 and IFE-BPC) was studied by Taiwo *et. al.* (1997), when soaked at different temperatures (27 $\pm$ 2, 45, 60 and 75°C) and for varying lengths of time (0.25, 0.5, 0.75, 1, 2, 3, 4, 5 and 6 h). Effect of different soaking conditions on cooking rate, texture and percent split of the 2 cowpea var. when cooked for different lengths of time was also investigated. Cooking tests was carried out on 3 sets of samples: unsoaked beans; beans soaked at room temperature for 1 h; and beans soaked at 45°C for 1 h before cooking. Beans was heated at atmospheric pressure for 30, 45, 60, 75, 90, 105 and 120 min after an initial heating time of approx. 5 min. Soaking prior to cooking had an effect only on cookability, while the amount of water absorbed and penetration depth of a

penetrometer head increased with cooking time. IITA-2246 was noticeably softer in texture than IFE-BPC. For both var., splitting of seeds increased with cooking time for all the pre-cooking treatments studied. A positive correlation was found between texture indices (penetration depth) and splitting tendency. Max. percentage splits recorded for IFE-BPC and IITA-2246 were 63 and 92%, respectively (Taiwo *et. al.*, 1997).

In addition, parboiling, a popular technology used to protect rice from nutrient loss during milling and to increase rice shelf-life, was applied to barley kernels, and its effect on nutrient retention and chemical composition were evaluated. In the period leading up to 36 days after ear emergence, barley kernels had water content of greater than 40%, and parboiling without presoaking resulted in at least 43% degree of gelatinization. This implies that soaking, an important step in rice parboiling were dispensable for barley at the milky stage. Parboiling had little effect on appearance of the kernel 31 days after ear emergence. Pearling led to a decrease in crude protein, fat, fiber and minerals of barley sampled and parboiled on the 36th day after ear emergence. Free sugars in the parboiled barley were also reduced with increasing pearling rate. Vitamin B1 content of the parboiled barley were 260 µg/100 g (dry basis) at 50% pearling rate, compared to 36 µg for raw barley at the same pearling rate. Thus parboiling appeared to be very effective in the retention of vitamin B₁ during pearling (Seog *et. al.*, 1993).

For preparation of a quick-cooking rice product, rice were first cooked also at atmospheric pressure in an amount of water suitable to hydrate rice to moisture content of 60-75% by wt., at a temperature of 90-100°C for approx. 1-10 min. The rice were then steam pressure cooked in water with agitation, at a pressure of 250-2500 mm Hg for 1-50 min, for further hydration and gelatinization. A cooked rice results with moisture content of 60-75% by wt. and which were 85-100% gelatinized. After steam pressure-cooking, the pressure were gradually released in order to avoid puffing the cooked rice. It was then dried at 140-205°C (Baz *et. al.*, 1992).

In order to manufacture of a quick-cooking barley; moisture content of pearled barley were raised to 55-60% by cooking, the barley were then subjected to ambient pressure in an atmosphere saturated with steam and sprayed with hot water to

achieve a drained moisture content of 70-80%. The barley was then drained and dried to moisture content of 12% or less. The barley product was cooked by hydration in an equal volume of boiling water for 5-15 min, followed by 5 min standing in the cooking liquor. Texture of the cooked barley was 75-90 lb/force when measured by shear press value (Messick, 1995).

A specially designed experimental unit were used to cook various types of groats (rice, barley, buckwheat) in superheated steam at atmospheric pressure, using a fluidized bed, solid bed, stirred solid bed or pulsating bed combined with mechanical stirring. Operating parameters were: steam consumption 10-120 kg/h; water consumption 0.1 m³/h; specific load on perforated carrier tray 10-85 kg/m²; temperature of sprayed water 293-353 K; steam temperature 373-400 K; initial moisture content of groats 0.1-0.4 kg/kg; groats temperature during cooking, 353-383 K; steam pulsation rate, 1-8 Hz; and steam feed rate, 0.1-5 m/s. The pulsating bed with mechanical stirring was found to be the most effective variant (Kretov *et. al.*, 1989). Physically, to understand the effect of cooking operation; cutting force, degree of cooking, cooking loss and absorbance of cooking solution of 3 cv. of Korean kidney beans, pink (PKB), red (RKB) and white (WKB), were examined. The cutting force of raw kidney beans were 23 500-27 000 g. Optimum soaking conditions for kidney beans, to give the same cutting force was 10 h at 10°C, 8 h at 20°C, 6 h at 30°C and 3 h at 40°C. Under optimum soaking conditions, the degree of cooking of the cotyledons was determined by measuring the maximum cutting force. The terminal points for cooking at 98°C was 23 min for PKB, 25 min for RKB and 27 min for WKB. Absorbance of cooking solution showed a similar pattern in all samples, except PKB soaked at 10°C for 10 h (Hee and Eun, 1995).

In the study of Gandhi and Bourne (1991), soybean was soaked or/and cooked at oriental region to produce tempeh, hamanotta etc. In addition to this traditional procedures, whole soybeans and dehulled soybean cotyledons was soaked in water at ambient temperature for 0, 8 and 12 h then cooked in boiling water at atmospheric pressure for 6 h (in order to investigate effect of soaking time and cooking time on thermal softening). In every case there was an initial rapid rate of softening followed by progressively slower softening until, after about 3 h, there were little change in firmness. Kinetics of softening of every sample was consistent with the 2 substrate

theory of thermal softening. Firmness ranking, in descending order after 15 min cooking, was no soak, whole beans greater than 12 h, soak cotyledons greater than no soak, cotyledons greater than 8 h, whole beans greater than 12 h soak, whole beans. This ranking was maintained for the entire cooking period. For whole beans, soaked sample was less firm than unsoaked samples while for cotyledons, soaked samples was more firm than unsoaked. This reversal in behavior may be caused by the seed coat (skin) retarding the inhibition of water in the whole beans thus delaying the onset of enzyme activity in bean tissue.

Microwaves are being used to a limited extent in a number of industrial food processing operations such as baking, blanching, cooking, dehydration, pasteurization, sterilization and tempering. An increasing consumer demand for foods that offer greater convenience and time savings in preparation has led to a microwave oven saturation level of more than 70%. This demand is providing a strong marketing incentive to the food manufacturing and foodservice industries to consider innovative approaches in food formulation and packaging design to develop new and improved microwavable consumer products for oven use.

In addition, improvements in the design of high-powered microwave ovens offer rapid and economic methods for manufacturing food products of high organoleptic and nutritional value. However, the development of industrial processes has been rather disappointing. With a few notable exceptions, e.g., "tempering" of frozen foods, precooking of poultry and pork products, and drying of pasta and onions, there are not many large-scale microwave installations in the food industry. Many of these combine conventional and microwave heating to raise surface temperature to improve browning and crisping, accelerate drying rates, or reduce microbial surface counts (Mudgett, 1989).

Microwaves are generated by a magnetron-a device that converts electrical energy at low frequencies, e.g. 60 cycles/sec (Hertz, (abbreviated Hz), into an electromagnetic field with centers of positive and negative charge that change direction billions of time each second. Penetration and heating of foods by microwave energy sources are instantaneous. In contrast, conventional heating methods transfer thermal energy from product surfaces toward their center 10-20 times more slowly. As the

microwaves enter the product, they interact with regions of positive and negative charges on water molecules, (electrical dipoles) that rotate the molecules in the electrical field by forces of attraction and repulsion between oppositely charged regions of the field and the dipoles. This results in the disruption of hydrogen bonds between neighboring water molecules and generates heat by "molecular friction" (Mudgett, 1989).

Positive and negative ions of dissolved salts in foods, such as common table salt, sodium chloride, also interact with an electrical field by migrating toward oppositely charged regions of the electrical field and disrupt hydrogen bonds with water to generate additional heat. Magnetic field interactions are negligible, since foods contain only trace amounts of magnetic minerals such as nickel, cobalt, and iron. The heat generated within a product by the electrical interactions is then transferred throughout the product by conventional thermal conduction. Microwave penetration depths within the product are determined by its electrical and physical properties and can vary significantly with chemical composition and temperature of the product and the processing frequency (Mudgett, 1989).

The electrical and physical properties of foods, which determine microwave penetration depth, conventional heat transfer, and overall heating rate are the dielectric constant and loss factor, heat capacity (specific heat), and density. The dielectric constant of a product reflects its ability to store electrical energy, and the loss factor its ability to dissipate electrical energy as heat. The dielectric properties and some related electrical properties which affect the transmission and absorption of microwave energy are rigorously defined in classic references on the nature of electromagnetic waves and applications of dielectric materials by Von Hippel (1954a; b). Values of the dielectric properties for a large number of agricultural and food products are available in bibliography (Kent, 1987).

Food dielectric properties are primarily determined by moisture and salt contents (Mudgett, 1974; Swami and Mudgett, 1981). Generally, the greater moisture and salt contents, the shallower the microwave penetration depth and, consequently, the less uniform the heating rate throughout the product. While alcohols and dissolved carbohydrates are active ingredients in some foods and beverages, their effects are

negligible in most food products, except for high-carbohydrate foods, such as bakery products or syrups, and alcoholic beverages. The effects are related to stabilization of hydrogen bonding patterns through hydroxylwater interactions (Buck, 1965; Roebuck et al., 1972). Food solids do not absorb microwave energy in high or intermediate moisture products, although dried food solids do absorb energy, as illustrated by microwave ignition of a marshmallow, by transfer mechanisms that are not well understood at this time.

On the other hand, low-moisture products heat more uniformly because of their low heat capacities (Schiffman, 1986). Moisture content and temperature of product also affect rates of conventional heat transfer (internal conduction and surface convection) which are determined by thermal diffusivity (ratio of thermal conductivity to heat capacity and density). Heat is also lost from the product to the microwave oven as a result of surface cooling by moisture evaporation.

Values of thermal properties that affect rates of conventional heat transfer in foods are given in reviews by Heldman (1982), Polley et al. (1980), and Singh (1982). Further details on the mechanisms of microwave and conventional heat transfer are given by Holman (1976), Metaxas and Meredith (1983), and Mudgett (1985a; b; 1986a; b). It should also be noted that food electrical and physical properties that affect microwave heating change dramatically at temperatures below freezing.

Energy absorption and transmission in foods are determined by mutual interactions between the microwave power source and the food product. Some energy may be reflected from product surfaces without being absorbed, causing standing wave patterns of nodes and antinodes. These cause high and low incident power levels in the microwave cavity that result in uneven energy distribution at product surfaces and hot and cold spots within the product. This problem can be minimized by using wave stirrers, which distribute microwaves more uniformly at product surfaces, or by rotating the product in the microwave oven. More uniform heating can also be obtained in ovens with multiple feed systems. Power transfer is efficient for high-moisture products of some minimum volume, but less efficient for low-moisture products of small volume. Unreflected, i.e., transmitted, power is absorbed by interaction with active food constituents and decreases within the product with

increasing penetration. Power penetration in the product is about 2-3 times greater at 915 megahertz (MHz) than at 2,450 MHz (the two microwave frequencies most commonly used in the United States), although at higher temperatures the differences in some cases may be insignificant. In general, product thickness must be limited to power penetration depth, i.e., the depth at which about 67% of transmitted power is absorbed, to obtain uniform heating (Mudgett, 1989).

The slow rate of development of microwave energy for industrial processes is related to historically unfavorable equipment and energy costs and to a lack of basic information on the electrical properties of foods and their relationships to the heating characteristics of foods. In terms of energy cost differentials, industrial microwave food processing has become more economically attractive in recent years, as costs of gas and oil have risen and use of coal and nuclear energy sources for generating electrical power has increased. Capital costs of industrial ovens have also been reduced by modular designs using magnetrons of high reliability that are manufactured in bulk quantities. Installed costs of microwave equipment in the 100-200 kW range are about \$2,000/kW (Mudgett, 1989).

Edgar (1986) shows favorable cost advantages for tempering frozen foods and precooking meats in modular processing systems. These advantages result from reduced product loss and increased throughput energy savings, and product quality. Costs are evaluated in differential cash flow and investment analysis by economic models based on simple payback, net present value, and internal rate of return that can be more generally applied to microwave process evaluation in a variety of applications. Recent advances in equipment design, trends in electrical energy costs, and research on food properties which has provided a basis for modeling microwave heating patterns should stimulate the development of new and improved commercial food processes.

Decareau and Peterson (1986) reported that 254 microwave installations were in industrial operation upto 1986; 200 for tempering frozen foods, primarily meats and fish; 16 for precooking bacon, poultry, and meat patties; 30 for dehydration of pasta, onions, and snack foods; 5 for vacuum drying of citrus juices, grains, and seeds; and

3 for pasteurization of bread and yogurt in USA. Many of these processes combine microwave with conventional heating methods.

Microwave installations generally employ frequencies of 2,450 MHz or 915 MHz (Rosenberg and Bögl, 1987). The lower frequency penetrates a product to a depth of up to 30 cm, while the higher frequency penetrates only up to 10 cm (Anon, 1968; Minett, 1976). The tempering, pasta drying, and bacon precooking processes use 915 MHz to obtain deeper penetration of microwave energy, while precooking of meat patties, bread pasteurization, fish sterilization, and vacuum drying to concentrate fruit juices use 2,450 MHz (Mudgett, 1989).

In combination ovens, microwaves are used to achieve internal heating, and conventional heat sources are used to produce the desired surface browning or crispness as well as reduction of microbial counts at product surfaces. The most highly developed commercial applications include dehydration of low-moisture solids, e.g., pasta; precooking of meat products, e.g., bacon, poultry, or beef patties; and tempering of frozen foods, e.g., frozen meat and fish blocks (Decareau, 1986). Decareau estimates annual growth of these applications at 1.0-1.5 MW/year with an annual growth of 2.5 MW for microwave food processing equipment on a worldwide basis. Other microwave operations such as vacuum drying, freeze drying, pasteurization, sterilization, baking, roasting, blanching, and rendering are in pilot-scale development (Decareau and Peterson, 1986).

Microwave cooking operations have been increasingly successful for precooking bacon, meat patties, and poultry parts for institutional and retail markets. Hot air is used in the bacon process to aid in moisture removal, while saturated steam is used in poultry operations to reduce the risk of *Salmonella* contamination. Some of the advantages indicated for such operations include increased yields, shorter preparation times for institutional users, reduced labor costs, and high product quality. It has been reported that the microwave bacon process results in yield increase of 25-38%, since none of the product is lost by overcooking. The poultry process reportedly provides a 10% increase in yield, with reduced moisture loss. Since larger, thicker poultry parts require more energy and longer processing times than thin parts, thighs and breasts are processed at a higher power level than legs and wings. Power levels

at 2,450 MHz are more limited in penetration depth and thus are better suited for processing of thinner products while 915 MHz is more suitable for thicker products. Processes at either frequency may be combined with conventional heating to achieve surface browning or crisping (Mudgett, 1989).

Microwave precooking of meat patties at 2,450 MHz in the Swedish "Inpro" process yields 1 ton of cooked patties/hr and uses a novel method for browning involving temperature-controlled, Teflon coated aluminum platens prior to passage through a microwave tunnel (Decareau, 1985). This process is reportedly widely used in Sweden and Japan (Sanio and Michelussi, 1988).

1.8.2 Drying

Drying is another the most important step in bulgur production. Successful drying is practiced varying from simple tunnel dryers to huge dryers (Haley and Pence, 1960). In some plants, cooked bulgur is dried in tunnel dryer with ventilation of hot air at 60°C until 10-12% of moisture. For industrial drying, fluidized bed dryer and a cascade tower are also used (Certel *et. al.*, 1989).

A fluidized bed dryer system was explained by Çömüden (1986). In this system; moisture content of kernel is 52% after cooking which is decreased with fluidized bed dryer using 80°C of hot air to 10-13%. The shape of fluidized bed dryer is perpendicular with 4 sections. Three sections are used for drying and one is for cooling. Pressure drop changes at each section because of moisture differences. Cooling section is used for decreasing the kernel temperature to 30-40°C at the end of drying. Some part of used hot air is recycled in drying. Density of dried wheat is higher than cooked wheat because of shrinkage of wheat during drying. Therefore, fluidized bed dryer is not suitable for drying. Yield of fluidized bed dryer at first section for mass transfer is higher than second and third sections. Fluidized bed dryer can be used until hardness of wheat surface increases for efficient heat transfer. Then, belt type dryer may be used. Also, high ventilator force is needed, so consumption of electricity will be high because of high pressure drop in fluidized bed dryer. Also, tower dryer can be used to dry bulgur instead of this system.

Another drying method is sun drying. Vitamin B loss is high (Çömüden, 1986). Loss of riboflavin is 28% and 64% with hot air dryer and sun drying respectively (Saraçoğlu and İbiş, 1985). Industrially, drying can be made by fluidized bed, rotary dryer, sun drying, tower and tunnel. But, tower dryer is the most popular system which is used by bulgur producers due to capacity, low energy consumption and good air usage (Bayram and Öner, 2002).

1.9. Texture-Hardness-Chemical Fortification

Hardness of legumes is the most important factor and sometimes it can be problem during processing. Hardness and texture are related with some chemical compositions of legumes. Also, chemical fortifications that are used either texture or nutritional purposes.

Storage of legumes at high temperature and low humidity sometimes generates the 'hardshell' condition. The level of water that hard-to-cook (HTC) seeds imbibe is approximately the same as that of normal seeds, but HTC beans do not soften during cooking because the cotyledon cells do not separate. Hardshell beans have a defective seed coat and fail to soften during cooking because they do not imbibe sufficient water.

The hard-to-cook defect were partitioned into reversible and irreversible components using common beans [*Phaseolus vulgaris* L. cv. *Blackhawk* and *Ex Rico* 23], previously stored under a range of temperature (15, 30 and 45°C) and a_w (0.59, 0.75 and 0.86) that were soaked and cooked in distilled water or a 5% (w/v) aqueous solution of Na₂(EDTA). Results of phytate analysis and fluorescence microscopy showed that these components reflect the pectin-phytate mechanism or reversible hardening, and the lignification mechanism or irreversible hardening (Valle and Stanley, 1995).

A study has been undertaken by Garcia Vella and Stanley (1989) to assess protein denaturation and starch gelatinization in ground samples of common black beans exhibiting the hard-to-cook (HTC) defect. Using differential scanning calorimetry, no significant differences in either gelatinization or denaturation temperature were found between hard and soft beans, but tropical storage conditions produced

significant increases in gelatinization enthalpy and reductions in denaturation enthalpy. Endotherms of cooked samples showed that as little as 34% of the protein had denatured in HTC beans vs greater than 85% in soft beans. Micrographs indicated that the ground raw material was composed of clumps of cotyledon cells; cooking soft beans produced cell separation, but this did not occur in HTC samples. These data supported the idea that bean hardening accompanied by limited water availability inside cotyledon cells, which could reduce cell swelling, starch gelatinization and protein denaturation, leading to textural toughness (Garcia Vella and Stanley, 1989).

In order to study the effect of various salts on the hard-to-cook phenomenon, black beans (*Phaseolus vulgaris*) were stored by Garcia Vela *et. al.* (1991) under tropical conditions to induce the defect and soaked in various aqueous sodium salt solutions prior to cooking. Statistical analyses of hardness data showed that storage conditions and pH of soaking solutions did not produce significant effects but anion type were important in inducing softness as follows: CO_3^{-2} greater than EDTA^{-2} = NO_3^- greater than SO_4^{-2} = Cl^- . Softening were also promoted by increasing the ionic strength of the soaking solution. Treated beans indicated that storage conditions contributed more to degree of cell separation after cooking than salt treatment, which had little effect. These results bring a mechanism based on chelation and ion exchange into question. Differential scanning calorimetry data was interpreted as meaning that soaking beans in salt solution caused a major reduction (10-15°C) in temperature of protein denaturation. This suggests that aqueous salts influence storage proteins, perhaps by solubilization and rendering them more thermally labile (Garcia Vela *et. al.*, 1991).

Effect of using salt solutions to soak fresh and hard-to-cook beans (*Phaseolus vulgaris*) on cooking time and protein quality (PER and digestibility); sensory analysis were also carried out after soaking and cooking by Leon *et. al.*, (1992). They found that by increasing the ratio of monovalent (Na^+ and K^+) to divalent ions (Ca^{+2} and Mg^{+2}) in the salt solutions, cooking time of both fresh and hard-to-cook beans decreased significantly ($P < 0.05$). Protein quality was lowered by researchers significantly at lower (0.30) and higher (9.80) monovalent to divalent ion ratios. Although cooked bean flavor was slightly affected by salt treatment, taste was

improved by discarding the salt solutions after soaking and cooking with water. Cost analyses showed an energy saving of more than US \$0.19/kg of beans during cooking with a ratio of 8.30 of monovalent to divalent ions of salt solution. Data obtained indicated the feasibility of implementing this process at industrial or population levels in order to decrease cooking time of both fresh and hardened beans. The most effective solution evaluated had a salt composition of 0.5% NaHCO₃ and 2.5% K₂CO₃ (w/v) (a ratio of 8.30 of monovalent to divalent ions.). Therefore, the recommended cooking method is to soak beans with this salt solution, discard the soaking solution and cook with fresh water (Leon *et. al.*, 1992).

Effects of degree and type of salinity on characteristics of faba beans were studied by Shehata *et. al.* (1988) in a randomized complete block design experiment with 5 irrigation water salinity levels and 6 replicates. Control irrigation water had a salinity level (as measured by electrical conductivity) of 0.5 mmho/cm. The same water plus NaCl, CaCl₂ and MgCl₂ (2:1:0.5) were used to obtain 30 and 60 m-equiv./l and other irrigation waters were prepared by adding CaCl₂ at 30 and 60 m-equiv./l. Plants were irrigated 6 times, dried for 5 days after harvest and properties of dry seeds and cooked beans (autoclaving in distilled water at 115.5°C for 2 h) were studied. The linear effect of Ca (CaCl₂ treatments) on dry seeds were significant for yield, swelling coefficient, seed wt., % seed coat and hydration coefficient; linear effect of salt (mixture) was significant for yield and swelling coefficient only. Salinity had no effect on seed germination. Cooked faba beans were examined for texture, hydration coefficient, and specific gravity, volume and weight. of cooking liquor. Effects of salt (mixture) were not significant, but effects of Ca were significant for all properties except specific gravity of the cooking liquor. Cooked faba beans from the Ca treatments were harder in texture and had lower hydration coefficient than those from other treatments. Phytate, pectic substances and mineral contents of dry faba beans and cooking liquor were affected by soil ions but there were no significant correlation with the texture of cooked beans except in the case of K content and some pectic fractions. Ash content of dry beans was significantly correlated with texture of cooked beans and soil ions. Texture of cooked faba beans was correlated negatively with soil pH and HCO₃ but correlated positively with electrical conductivity, Cl, total anions, total cations, Ca and Mg. Results indicate that effects of soil ions on cooking

properties of faba beans may be due to changes in functional, biochemical or other properties of chemical constituents (Shehata *et. al.*, 1988).

For comparison of the effects of processing with solutions of CaCl_2 , MgCl_2 , NaHCO_3 and a local [Nigerian] tenderizer known as Kanwa (sodium sesquicarbonate) on pectin losses and cooked texture of the cowpeas were processed in double distilled water and local tap water. Analysis included total pectin, calcium and magnesium content, leached solids, texture and water absorption. The results show that CaCl_2 , MgCl_2 and the local tap water increased firmness, Ca and Mg content in the cooked beans compared to distilled water; however, water absorption, leached solids and pectin solubilization were decreased by these salts. Kanwa and NaHCO_3 increased water absorption, leached solids and softness in the cooked beans and also increased pectin solubilization but decreased Ca and Mg when compared to distilled water or the other salts (Uzogara *et. al.*, 1990).

In another study, model aqueous systems were used by Kyriakidis *et. al.* (1997) for the study of the cooking quality of beans (*Phaseolus vulgaris*). These systems were created using graded contents of calcium and magnesium ions, in a ratio of 4:1, to prepare aqueous media with cation content corresponding to 0-400 mg/liter of calcium carbonate. The model systems were used to measure the quality of boiled beans in water of low and high divalent cation content. A boiling time of 60 min was used and an Instron Universal Testing Machine measured the hardness of the boiling beans. Cooking of beans in water of low divalent cation content equivalent to 0-50 mg/litre CaCO_3 resulted in well-boiled beans for both types (easy-to-cook and hard-to-cook) of beans. Boiling in water of high divalent cation content led to the formation of very hard beans for both types of bean, while boiling in water of moderate divalent cation content (normal drinking water: 150-250 mg/liter CaCO_3) differentiated between the two categories of beans. These results were further tested by adsorption experiments with divalent cations, on beans boiled (a) in different proportions of boiling water, and (b) in model aqueous systems. The divalent cation content of boiling water and the phytic acid content of the beans proved to be the crucial factors in the hard-to-cook phenomenon of beans (Kyriakidis *et. al.*, 1997).

In order to determine the synergistic effects between salt and hydrogen ion concentration (acidity or alkalinity) on softening during cooking were tested by Buren *et. al.* (1990) with modifying solutions in which pods of snap beans (*Phaseolus vulgaris*) were heated. Ca displacement was minimized by soaking heated pods in 0.2M CaCl₂ before measuring firmness. Softening was increased independently by the presence of salts and when pH was raised from 5.2 to 6.2. Cations decreased firmness in the order Li greater than Na=K greater than NH₄ and Ca greater than Mg. Anions decreased the firmness in the order SO₄ greater than acetate greater than Cl greater than NO₃. Firmness differences persisted at long heating times. Results support the hypothesis that pectin beta-elimination were the principal softening reaction (Buren *et. al.*, 1990).

Two common bean (*Phaseolus vulgaris*) var. was seeded in the same location, harvested and cleaned. Three hardening procedures were used (soaking in acetate buffer, pH 4.1 at 37°C for 5 h; storage at 37°C, 100% RH for 28 days; and storage at 31-33°C, 76% RH for 120 days) to have seeds in a hard-to-cook (HTC) state. The adverse effects of HTC condition, in terms of cooking time as assessed by a Mattson bean cooker, was eliminated by soaking seeds in salt solutions (1% NaCl + 0.75% NaHCO₃, and 0.75% NaHCO₃) instead of only water. Ultrastructural changes of cotyledon cells from fresh, HTC and softened seeds were observed. Results of this study may be used for the development of a technological procedure to utilize properly HTC beans generated by inefficient storage systems (Parades *et. al.*, 1991). In addition, winged bean (*Psophocarpus tetragonolobus* (L.) DC) seeds were soaked for 24 h in distilled water, 30 or 50 g/l rice husk ash suspension or solutions of 10 or 20 g/l baking soda, or 5 or 10 g/l NaHCO₃, then boiled for 30 min in these solutions, either was held and resoaked in distilled water, or peeled, washed for 24 h and resoaked for 24 h in distilled water. pH and level of leached solids increased during boiling. Boiling in distilled water or rice husk ash suspensions did not render the bean sufficiently soft, whereas boiling in the alkaline solutions produced adequately soft seeds. There was no significant difference in tenderness of beans given further processing by resoaking or peeling and resoaking, compared with boiling. Nature of the cooking liquid had no significant effect on the protein content of the seeds (Buckle and Sambudi, 1990).

Effect of alkali treatments on the stability of antinutritional factors (tannins, phytates and trypsin inhibitors), vitamins (niacin and riboflavin) and on protein quality of kidney beans (*Phaseolus vulgaris*) were studied by Jyothi and Sumathi (1995). Samples were processed by soaking for 24 h, in alkali solutions of sodium hydroxide (0.005 and 0.01M), sodium carbonate (0.025 and 0.05M) and sodium bicarbonate (0.05 and 0.01M). At low temperature sodium carbonate, and at high temperature sodium bicarbonate were found to be the most effective treatments for the extraction of tannins. At both low and high temperature sodium carbonate were found to be more efficient for the destruction of phytates. Extraction of trypsin inhibitors at both low and high temperature with sodium bicarbonate was the most effective alkali treatment. Retention of niacin and riboflavin in beans were greatest with sodium hydroxide treated beans. With all treatments pressure-cooking further reduced levels of antinutritional factors and vitamins (Jyothi and Sumathi, 1995).

1.10. Bulgur From Different Raw Materials

1.10.1. Corn bulgur

Corn bulgur was investigated by Elgün *et. al.* (1990). In study, effects of the maturation stage (milk, yellow or ripe) and cooking form (on the cob or shelled) of Narman sweet corn on some selected parameters obtained in the bulgur-making process were studied. Physical and chemical properties of corn bulgur, were also investigated. The results obtained at statistically significant levels were as follows. During cooking at less than 95°C for approximately 60 minutes, there was an increase in the dry matter content and color intensity of cooking wastewater. As the grain matured, the amount of material diffused into the cooking wastewater decreased. The yellow stage corn provided the hardest and most vitreous endosperm texture to the bulgur after drying and showed the highest resistance to grinding, whereas the milky stage corn bulgur showed the lowest resistance. On a raw material basis, the yields of pilaf bulgur (greater than 1.5 mm) and total bulgur (greater than 0.5 mm) increased sharply with grain maturation, especially in the ripe stage. In either total or yellow color intensity of the bulgur fractions, the yellow stage corn bulgur showed the highest values with amberlike yellowness and brightness. Increasing in particle size of the bulgur decreased with maturation, but fat content increased. In general, the finer the corn bulgur fraction contained the higher the ash, fiber, protein and fat contents. In conclusion, the best stages were, yellow corn for

bulgur color, appearance and functionality; milky corn for nutritional value; and ripe corn for bulgur yield.

1.10.2. Triticale bulgur

Bulgur at acceptable quality was prepared from 2 commercially available cv. of triticale by boiling 10 minutes and cooking for 3 minutes or 10 minutes at 15 lb/in² and 120°C. Moisture contents of 32-41 % were needed to achieve a desirable level of gelatinization of starch. Compared to triticale whole meal, bulgur had almost similar amounts of protein, amino acids and gross energy but lower amounts of crude fat, thiamin, riboflavin, folic acid, Vitamin E, Ca, Fe, Cu, P, Mn, Zn, K, Na and Mg (Singh and Dodda, 1979).

1.10.3. Barley bulgur

Barley bulgur was studied by Köksel *et. al.* (1999) that three barley cultivars (*Hordeum vulgare L.*) were processed into bulgur by pressure or atmospheric cooking methods. The effect of processing on levels of thiamine, riboflavin, minerals (Fe, Cu, Zn, Mn, Ca, Mg) as well as the phytic acid and β -glucan was investigated. Significant decreases ($P < 0.05$) were observed in ash, riboflavin and thiamine contents during bulgur processing. Neither the cooking methods nor the dehulling process had significant influence on the content of Fe, Cu, Zn or Mg. However, the Mn and Ca content of the bulgurs were significantly lower compared with the corresponding raw barleys. For all cultivars total P and phytate P contents of the bulgurs were significantly lower compared with the corresponding raw barleys. In contrast, levels of β -glucan were significantly higher in processed bulgur vs. raw barley. Protein contents of the samples did not change significantly during bulgur processing. Bulgur processed from barley appeared to retain most of the nutritional value of raw barley in particular it showed high levels of soluble dietary fibre.

1.11. The Aim of This Study

New food products should be developed to increase the production and consumption of legumes and cereals due to decline in their consumptions overall the world, recently. Legumes and cereals can be processed as bulgur because of its processing, economical and nutritional properties.

In the present study, soybean and rye were selected due to their physical (size and shape), chemical (protein, ash and starch contents) and economical values (soybean is very famous legumes, but rye is less used as a food) as legume and cereal, respectively. Bulgur processing operations were applied and tried to increase the economical and nutritional values of soybean and rye with processing to new bulgur-like food products.

Since, the aim of this study was to;

- study the soaking of soybean and rye at 30, 50 and 70°C at each of pH values of 5, 7 and 9,
- determine the effect of the soaking time, temperature and pH on the change of the dimensions (x, y and z), weight, volume, density, moisture content, color and texture of soybean and rye,
- determine the effects of the soaking time, temperature and pH on the change in pH, turbidity, soluble solids content and color of the soaking water of soybean and rye,
- determine the optimum soaking conditions of soybean and rye,
- study the atmospheric, pressure and microwave cooking of soybean and rye at various temperatures (87, 92 and 97°C); pressures (10, 15 and 18 psig) and microwave power levels (350, 490, 700 W), respectively,
- determine the effect of the cooking time, cooking temperature (for atmospheric cooking), cooking pressure (for pressure cooking) and microwave power level (for microwave cooking) on the change of the dimensions (x, y and z), weight, volume, density, moisture content, color and texture of soybean and rye,
- determine the cooking degree of soybean and rye during the atmospheric, pressure and microwave cooking operations,
- determine the effect of the cooking time, temperature during atmospheric cooking on the change of pH, turbidity, soluble solids content and color (L, a, b and YI-values) of the soaking waters of soybean and rye,
- determine the optimum cooking method and parameters for soybean and rye,
- study the column-type drying of cooked soybean and rye at 70, 80 and 90°C,

- determine the drying rate and drying periods of cooked soybean and rye during the drying operation,
- determine the effects of the drying time and temperature on color, drying rate, outlet air dry and wet bulb temperatures,
- determine the hectoliters of soybean and rye at optimum conditions,
- determine the energy consumptions of soaking, cooking and drying operations,
- produce the soy and rye bulgur from soybean and rye



CHAPTER II

MATERIALS AND METHODS

2.1. Materials

2.1.1. Samples

Special pure cultivars of soybean and rye were used in experiments. They were pure and homogeneous in their physical (size, dimension, color etc.) and chemical properties. Soybean (Code 613-2001) was obtained from Çukurova Agricultural Research Institute (Adana, Turkey). Rye (Aslın 95-2001) was obtained from Acıpayam Government Agriculture Administration (Denizli, Turkey). Both sample were free of dust, foreign material, broken and small kernels.

2.1.2. Chemicals

Citric acid and sodium carbonate were used to adjust the pH of soaking water and purchased from Merck Chemical Company (Germany). To determine the amount of starch in samples, HCl (Merck, Germany) and Phosphore-Wolfram acid “Phosphotungstic acid, $2\text{H}_3\text{PO}_4 \cdot 24\text{WO}_3 \cdot n\text{H}_2\text{O}$ ” (Carlo Erba, Italy) were used.

2.1.3. Instrumentations

Soaker and atmospheric cooker were specially designed (Figure 2.1) as an insulated and closed system. In atmospheric cooker, peristaltic pump was used to circulate hot water in contrast to centrifugal pump for soaking system to safe pump. Circulation rate of 60 ml/s was sufficient to maintain constant temperature and homogeneity of soaking and cooking water.

An autoclave (Armfield Ltd. Portable Ref No:7777, England) was used for pressure cooking. A programmable microwave cooker (Arçelik, ARMD 580, Turkey) with maximum output of 700 W at 2450 MHz was used for microwave cooking of soybean and rye. Microwave cooker had adjustable power (wattage) and the time controllers, and was fitted with a turntable.

Existing fluidized-bed dryer (Gateshead Sherwood Sci. Co., MKII, England) was converted to column-type dryer (Figure 2.2) and used for drying operation. During drying, an anemometer (Airflow Inst., LCA6000, England) was used to measure flow rate and linear velocity of air were calculated. Dry and wet bulb temperatures of ambient and outlet air during drying were measured and recorded.

Micrometer (Mutitoyo No=505-633, Japan) and analytical balance (with a sensitivity of ± 0.0001 , Shimadzu, Japan) were used to determine dimensions and weight of sample, respectively. Voltage, ampere and power of systems were measured using designed PAV system.

Color and texture of samples were measured using Hunter Lab colorimeter (A60-1010-615, Colorflex, USA) and Texture Analyzer TA-XT2i (Texture Technologies Corp, Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) equipped with a Texture Expert software program (Version 2.03).

Automatic steam distilling unit (UDK 130 A, Velp Scientifica Milano, Italy) was used for digestion of proteins during Kjeldahl procedure. Polarimeter (Carl-Zeiss Jena, Dr 21949, Germany) was used in Ewers's method to determine starch content in samples. Oven dryer (Nüve, Turkey) and ash oven (Nüve, Turkey) were used to determine moisture and ash content, respectively.

Cooking degree of soybean and rye were evaluated from a Differential Scanning Calorimeter (DSC) (Perkin-Elmer DSC-6, USA).

pH-meter (Jenway-3010, UK), spectrophotometer (Pharmacia LKB-Novaspec II, UK), Abbe-refractometer (Opton-F.G.Bode&Co., Germany), conductometer (Orion, USA) and HunterLab colorimeter (Colorflex, USA) were used to measure pH, turbidity, soluble solids content, conductivity and color of soaking and atmospheric cooking waters, respectively.

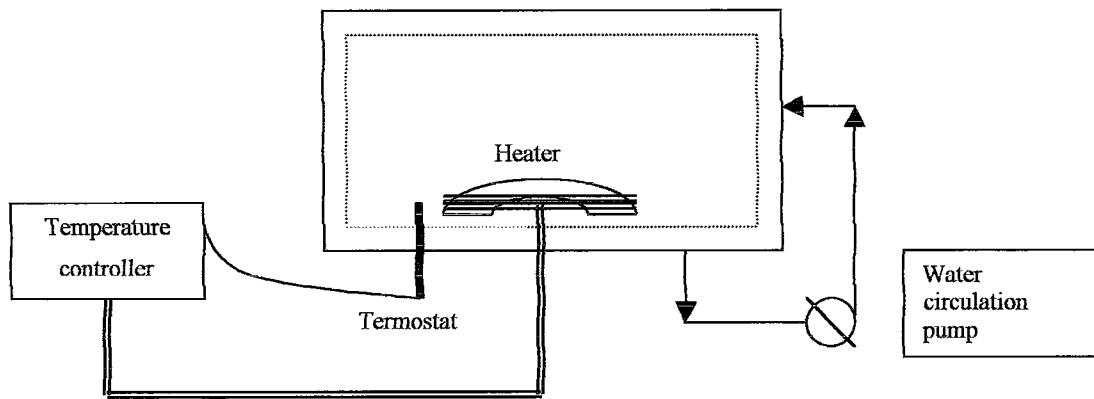


Figure 2.1 Illustration of soaking and cooking system

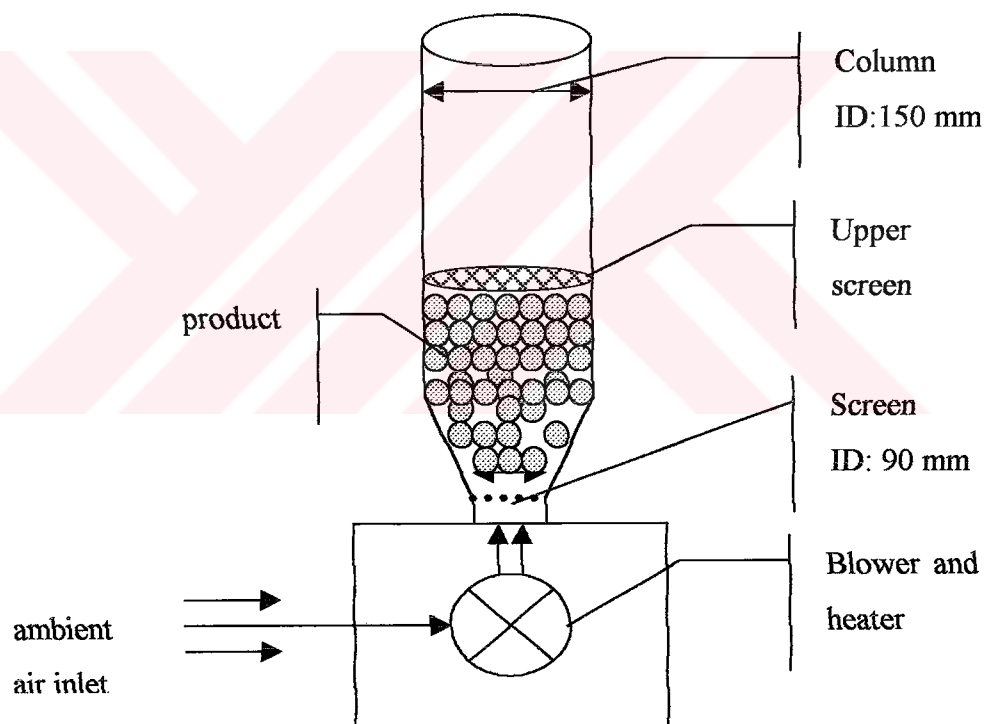


Figure 2.2 Illustration of drying system

2.2. Methods

2.2.1. Summary of experimental set-ups during production of semi-ready-to-eat food product

Overall operation steps and experimental set-ups used in this study to produce semi-ready-to-eat food products using soybean and rye as a raw material were given in

Figure 2.3. For each system, voltage, ampere, power and energy consumption were determined using PAV system. Hectoliter-weight values of samples were measured at the optimum point.

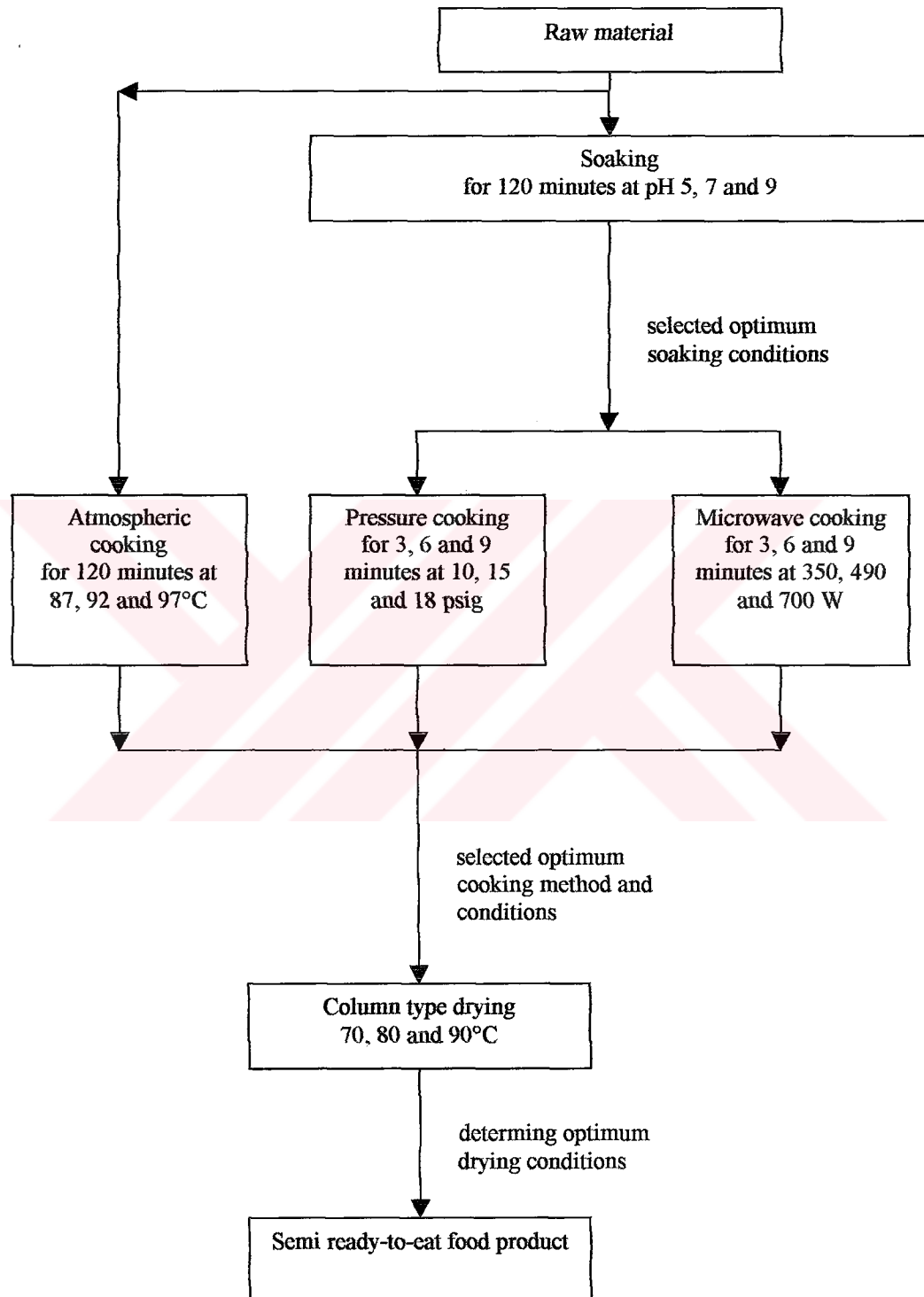


Figure 2.3 Summary of experimental set-ups during production of semi-ready-to-eat food product

2.2.2. Soaking operation

Soaking of soybean and rye was performed at 30, 50 and 70°C at 3 different pH levels (5, 7 and 9). pH of the soaking water (de-ionized water) was adjusted to 5, 7 and 9 using citric acid and sodium carbonate at 25°C.

When the temperature of the soaking water (3 liters) reached to specified temperatures, 500 g of soybean or rye (1:6 ratio) and marked 16 soybean or rye were separately placed into the same soaking chamber (no contact with each other). Fifteen grams of sample, 90 mL of soaking water (1:6 ratio) and one of the marked samples were collected at 10 minutes intervals during 120 minutes of soaking operations. Fifteen grams of soybean was used to determine moisture content and color. The marked samples were used to determine the changes in the dimensions, weight, volumes, densities and textural properties of samples. Ninety millimeters of soaking water was used to determine pH, absorbance (at 500 nm), soluble solids content (Brix), conductivity (μ S) and color (L, a, b, YI) at 25°C.

Optimum temperature, pH and soaking time (based on 40% final moisture content) were selected. Optimum soaking parameters were used on samples before pressure and microwave cooking of samples.

2.2.3. Cooking operations

Cooking of soybean and rye was carried out using atmospheric, pressure and microwave cooking operations. After optimization, cooking method and parameters were selected and column type drying was continued.

2.2.3.1. Atmospheric cooking

Atmospheric cooking of soybean and rye was performed at 87, 92 and 97°C in pH-adjusted water as 7. When the temperature of the cooking water (3 liters) reached these specified temperatures, 500 g of soybean or rye (1:6 ratio) and marked 16 soybean or rye were separately placed into the same cooking chamber (no contact with each other). Fifteen grams of sample, 90 mL of cooking water (1:6 ratio) and one of the marked samples were collected at 10 minutes intervals during 120 minutes of cooking operations. Fifteen grams of sample was used to determine moisture content and color. The marked samples were used to determine the changes in the

dimensions, weights, volumes, densities, cooking degree and textural properties of samples. Ninety millimeters of cooking water was used to determine pH, absorbance (at 500 nm), soluble solids content (Brix), conductivity (μS) and color (L, a, b, YI) at 25°C.

2.2.3.2. Pressure cooking

Soybean and rye were pressure cooked after soaking operation. Pressure cooking was performed at 10, 15 and 18 psig for 3, 6 and 9 minutes. Before the pressure cooking operation, pressure cooker was preheated to 97°C, then sample and marked kernel were placed into cooker (no contact with each other). Before reaching to operating pressures i.e. 10, 15 and 18 psig, cooker was heated for 280, 360 and 505 seconds, respectively. Then, pressure cooking was carried out at these pressures for 3, 6 and 9 minutes (as holding or cooking time). Three marked samples and 500 g of bulk sample were used for pressure cooking. At the beginning and the end of the pressure cooking operation, dimensions, weights, volumes, densities, textural properties of the marked samples were determined. The marked sample was also used to determine the cooking degree. Moisture contents and colors were measured using the bulk samples. During pressure cooking, samples were not in contact with water to prevent excessive moisture uptake of samples which was important for semi-ready-to-eat food product production like bulgur to produce high quality product with lesser drying requirement. After pressure cooking, pressure was reduced immediately with turning on vent.

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DOKÜMANTASYON MERKEZİ

2.2.3.3. Microwave cooking

Soybean and rye were microwave cooked after soaking operation. Microwave cooking was performed at 50, 70 and 100% microwave power levels (350, 490 and 700 W) for 3, 6 and 9 minutes. Three marked samples (no contact with each other) and 500 g of bulk sample were used for microwave cooking. Sample was placed into original container of microwave system that was made from teflon. The depth of sample used was arranged with thickness of the kernel. In other word, one layer sample was used. This layer thickness was nearly 7 and 3 cm for soybean and rye, respectively. At the beginning and the end of microwave cooking, dimensions, weights, volumes, densities, textural properties of marked samples were determined. The marked sample was also used to determine the cooking degree. Moisture

contents and colors were measured using the bulk samples. During microwave cooking, samples were not in contact with water to prevent excessive moisture uptake of samples and benefit from drying effect of microwave system to evaporate water from samples.

2.2.4. Column-type drying

After determination of the optimum cooking operation and parameters, cooked soybean and rye were dried at 70, 80 and 90°C using column-dryer. Column type drier has a similar operational principal as the packed bed and the tower drier used in the bulgur production. Initially 752 g of cooked grain was loaded into dryer. Dry bulb and wet bulb temperature of ambient air were 20 and 16°C, respectively (RH% was about 55%). The velocities of air were 4.31 and 1.55 m/s at inlet (near screen, where the diameter was 90 mm) and in drying column (diameter of drying column was 150 mm), respectively. Volumetric flow rate of air was 98.56 m³/h (Figure 2.3). Weight loss, outlet dry and wet bulb temperatures and color (L, a, b and YI values) were measured during drying. Drying rate, free and equilibrium moisture contents were calculated.

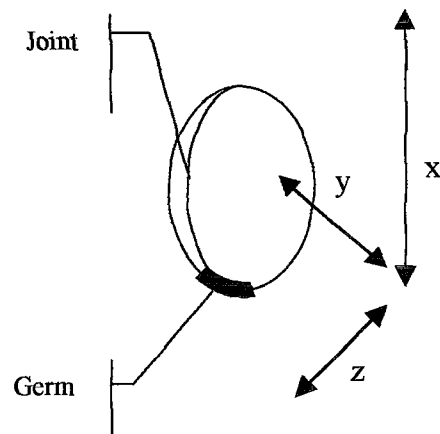
2.2.5. Determination of dimensions, weight, volume and density of the soybean and rye kernels

Shapes of soybean and rye were simulated as an ellipsoid (Figures 2.4 and 2.5). Certain amounts of soybeans and rye were marked and their dimensions and weights were determined before and after soaking and cooking operations. Dimensions of soybean and rye [length, x (mm); crease side width, y (mm); secondary width, z (mm)] and weight, W (g) were measured by using a micrometer and an analytical balance (± 0.0001), respectively. Measured dimensions of soybean and rye were used to calculate the volume V (mm³) of the soybean kernel with Equation [1].

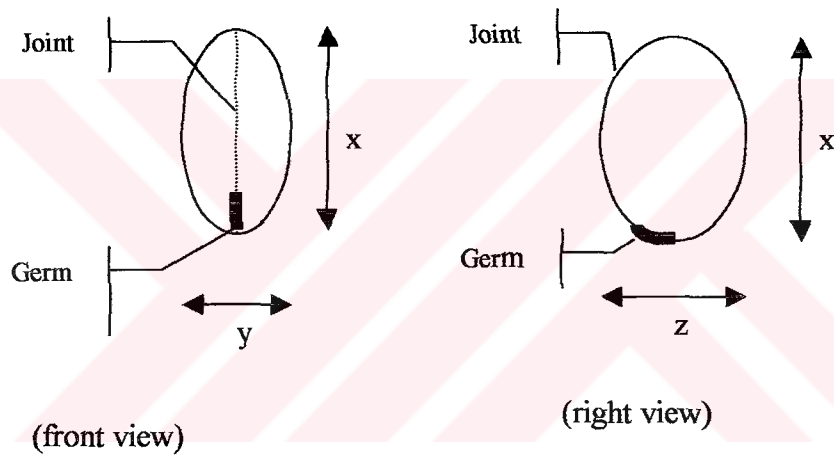
$$V = (4/3) * (\pi) * (\text{radius of width}) * (\text{radius of width}) * (\text{radius of elongation}) \quad [1]$$

In order to find the density ρ (g/mm³) of kernels, Equation [2] was used.

$$\rho = W/V \quad [2]$$



(oblique view)



(front view)

(right view)

Figure 2.4 Simulated shape of a soybean kernel

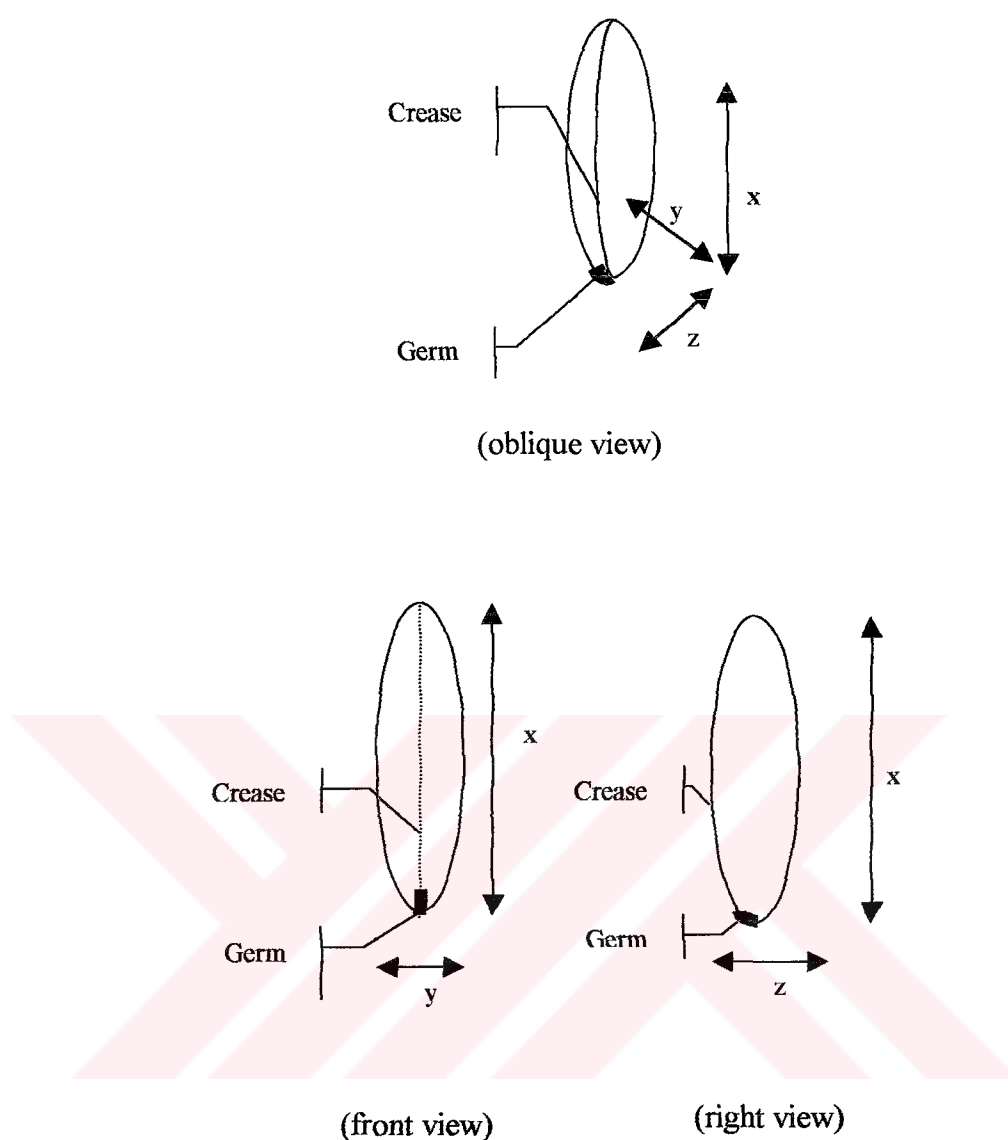


Figure 2.5 Simulated shape of a rye kernel

2.2.6. Determination of moisture content

Moisture determinations were carried out by drying 3-4 g of sample in an oven at 105°C until constant weight reached (AOAC, 1990).

2.2.7. Determination of protein content in samples

Kjeldahl method was used to determine protein content of samples (AOAC, 1990).

2.2.8. Determination of ash content and pH of samples

Analytical method was used to determine the ash contents of samples at 900°C (AOAC, 1990). pH of the unprocessed sample was measured at 25°C using 25 g of ground sample was mixed with 150 mL of deionized CO₂-free water (ratio was same with the soaking and atmospheric cooking operations i.e. 1:6).

2.2.9. Determination of starch content in samples (Ewers's method)

Sample (1.25 g) was put into 25 ml of baloon and mixed with 12.5 ml of 1% of HCl solution. Mixture was kept while it was being shaken for 15 minutes in water bath at 95-100°C. Then, 7.5 ml of distillated water was added and cooled. Then, to precipitate free nitrogenous matter, 2.5 ml of 4% of phosphore-wolfram acid was added and solution was diluted to 25 ml. Solution was filtrated to obtain clear solution. Filtrate was poured into 2 dm³ of polarization tube and polarization value was measured by using the polarimeter. Following formula was used: (Elgün and Certel, 1987)

$$\% \text{Starch} = [(V_{TS} * a_p) / (\alpha_D^{20} * L_p * W_s)] * 100 \quad [3]$$

V_{TS} : Total volume of sample = 25 ml

a_p : Polarization value

L_p : Length of polarization tube = 2 dm

α_D^{20} : Conversion factor (specific rotation)

of Ewers method for starch = 182.7 / (dm x g/ml)

W_s : Weight of sample = 1.25 g

2.2.10. Measurement of color of samples

Color of soybean and rye (L, a, b and YI) were measured with Hunter Lab Colorimeter (Colorflex, USA). Before each of the color measurement, white standard tile was used to calibrate colorimeter (L=93.01, a=-1.11, b=1.30)

The opponent-color scales give measurements of color in units of approximate visual uniformity through out the color solid. Therefore, in the Hunter scale, L measures lightness and varies from 100 for perfect white to 0 black, approximately as the eye could evaluate it. The chromatically (a and b values) gives understandable

designation of color as follows; “a measures redness when positive, gray when zero and greenness when negative. b measures yellowness when positive, gray when zero and blueness when negative. YI (yellowness index) visually; yellowness associated with scorching, soiling, and general product degradation by light chemical exposure, and processing. Yellowness indices are used chiefly to measure these types of degradation”.

2.2.11. Measurement of textural properties of samples

The texture properties ($F_{\max}$ and A_p) of soybean and rye were measured using Texture Analyzer with penetration (needle) tests (Figure 2.6). Penetration test was used to predict the force required to push a needle into the sample and related with the structural properties inside the sample and space between the cells (Figure 2.7).

Graphical results were examined as $F_{\max}$ (maximum force, N), and A_p (partial area under the curve till maximum force, N.s) (Figure 2.6). Each one was used to explain the hardness of samples. Texture Analyzer project parameters were also given in Tables 2.1 and 2.2 for soybean and rye, respectively. Settings for soybean and rye were same except distance value due to differences in size of soybean and rye. The needle was applied on the kernel along y-side.

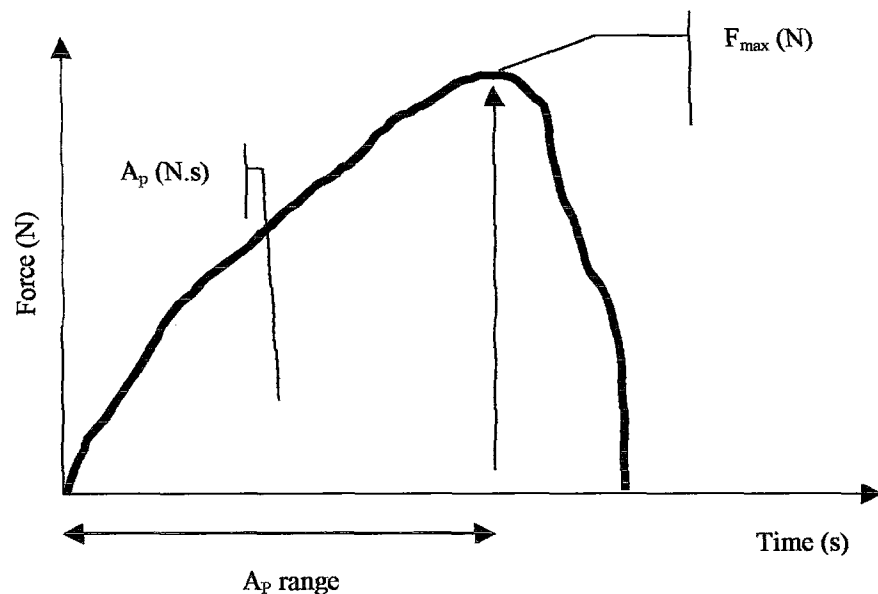


Figure 2.6 Illustration of graphical results of texture analyzer

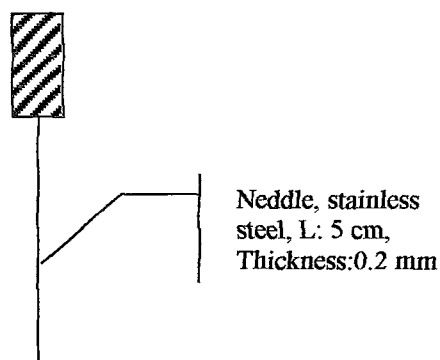


Figure 2.7 Probe of penetration test

Table 2.1 TA-XT2i settings for soybean

Pre-test speed	:	2 mm/s
Test speed	:	1 mm/s
Post test speed	:	2 mm/s
Distance	:	4 mm
Load cell	:	25 kg
T	:	25°C

Table 2.2 TA-XT2i settings for rye

Pre-test speed	:	2 mm/s
Test speed	:	1 mm/s
Post test speed	:	2 mm/s
Distance	:	2 mm
Load cell	:	25 kg
T	:	25°C

2.2.12. Determination of cooking degree during cooking operations

Standard uncooked (0% cooking degree) soybean and rye were prepared by grinding and sieving through a 200 mesh screen and standard cooked (100% cooking degree) soybean and rye were prepared by autoclaving at 15 psig for 1h, and drying in a forced air oven at 40°C and grinding to pass a 200 mesh screen (Birch and Priestly, 1973).

For determination of linear relationship between the cooking degree and measured ΔH values for soybean and rye, cooked and uncooked samples were mixed at different ratios.

In order to determine the ΔH values for mixes, Differential Scanning Calorimeter measurement (DSC) was conducted using a Perkin-Elmer DSC 6. Temperature was increased from 10-20°C to 180-220°C, and dry N₂ (~3 bar) was used as the purging gas. Calibration was performed with indium at the experimental heating rate of 2°C/min for cooking degree studies (Riva *et. al.*, 2000; Biliaderis *et. al.*, 1980). Sealed 20 μ L aluminum DSC pans were used for all the studies. ΔH values were measured from instrument versus degree of cooking of mixes.

2.2.13. Measurements of pH, conductivity, turbidity/absorbance and soluble solids content in soaking and atmospheric cooking water

pH, absorbance (at 500 nm), soluble solids content (Brix) and conductivity (μ S or mS) of the soaking and cooking water were measured at 25°C using pH-meter (Jenway-3010, UK), spectrophotometer (Pharmacia LKB-Novaspec II, UK), Abbe-refractometer (Opton-F.G.Bode&Co., Germany) and conductometer (Orion, USA), respectively.

Electrical conductivity (EC) estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water. The sensor simply consists of two metal electrodes that are exactly 1.0 cm apart and protrude into the water. A constant voltage (V) is applied across the electrodes. An electrical current (I) flows through the water due to this voltage and is proportional to the concentration of dissolved ions in the water - the more ions, the more conductive the water resulting in a higher electrical current which is measured electronically. Distilled or deionized water has very few dissolved ions and so there is almost no current flow across the gap (low EC). The basic unit of measurement of conductivity is the mho or siemens. Conductivity is measured in micromhos per centimeter (μ mhos/cm) or microsiemens per centimeter (μ S/cm).

2.2.14. Measurement of colors of soaking and atmospheric cooking water

Colour (L, a, b, YI) of the soaking and cooking water were measured at 25°C using HunterLab colorimeter (Colorflex, USA). Before each color measurement, a white standard tile was used to calibrate the colorimeter (L=93.01, a=-1.11, b=1.30). Sample was put into cell as it has 3 cm thickness.

2.2.15. Measurements of T_{wb} , T_{db} , and air flow rate of drying air

Wet bulb, dry bulb temperatures and airflow rate were measured during drying operation at inlet and outlet of dryer using wet and dry thermometers, and anemometer.

2.2.16. Measurements of voltage, ampere and power (PAV) of systems

To determine the energy consumption, PAV system was used (Figure 2.8). In addition, PAV system was used to adjust the voltage and ampere for electrical field.

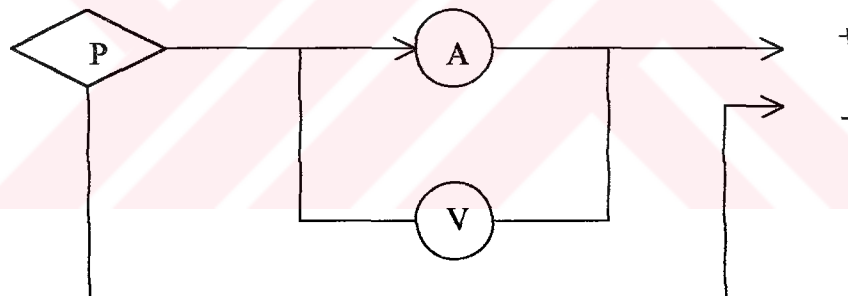


Figure 2.8 PAV system diagram

2.2.17. Measurement of hectoliter-weight of samples at the optimum conditions

Hectoliter-weights of samples were measured using a graduated chamber and analytical balance.

2.2.18. Preparation of drying curve

Drying curve was prepared for each drying system individually. Equations [4 and 5] were used to determine rate of drying.

$$R=(-Ls/A)(dx/dt) \quad [4]$$

$$R=A.R \quad [5]$$

where

L_s : Dry solid (kg)

A : Drying area (m^2)

x : Moisture content in drying rate equation

R : Drying rate (kg/m^2 hr)

R : Drying rate (kg/hr)

2.2.19. Statistical analysis

An ANOVA analysis was performed for all data to determine significant differences ($P<0.05$). Duncan's multiple range test was carried out to determine the effect of parameters on all responses.

CHAPTER III

RESULTS AND DISCUSSION

In this study, soybean and rye as a member of legumes and cereals were processed into semi-ready-to-eat food product like bulgur. Basic processing steps were studied. Firstly, soybean and rye were soaked in water of pH 5, 7 and 9 at 30, 50 and 70°C. Then, they were cooked using atmospheric, pressure and microwave cooking systems and finally dried at 70, 80 and 90°C in a column-type dryer. Their hectoliter-weight values were determined at the optimum processing parameters. Energy consumption of systems was also evaluated as well as physical and chemical properties.

The initial moisture (w.b.), ash (d.b.), starch (w.b.) and protein contents (d.b.) of soybean and rye were determined and were found as 8.2, 4.84, 0.47 and 37.7% for soybean; 11.7, 1.53, 60.6 and 10.4% for rye, respectively. It was found that ash content of soybean was higher than rye due to its dense and tough bran layer. Also, protein content in rye was lower than that in soybean in contrast to starch content. Due to these distinct properties, soybean and rye were good choices to compare for the production of semi-ready-to-eat food product like bulgur.

3.1. Soaking of Soybean and Rye

Soaking operation was carried out to supply enough water absorption (40% of moisture, w.b.) into soybean and rye before pressure and microwave cooking (Bayram, 1997). Soaking of soybean and rye were performed in pH-adjusted water to 5, 7 and 9 at 30, 50 and 70°C for 120 minutes. Changes in dimensions, volume, density, moisture content, color and texture of the soybean and rye kernels were determined within 10 minutes interval during soaking. pH, conductivity, absorbance, soluble solid and color measurements were carried out in soaking water at every 10 minutes.

Changes in the physical attributes of soybean and rye (dimensions, weight, volume, density, moisture content, color and texture) and in properties of their soaking waters (pH, conductivity, turbidity/absorbance, soluble solids content and color) were analyzed statistically using ANOVA and Duncan's multiple range test at $\alpha=0.05$ level.

3.1.1. Soaking of soybean

3.1.1.1. Changes in the physical attributes of soybean

a. Changes in the dimensions of the soybean kernel

Percent changes in length of the soybean kernel at 30, 50 and 70°C and pH 5, 7 and 9 were illustrated in Figures 3.1-3.3. Statistical analysis was performed to determine the effect of time, temperature and pH on the change of the x-value. It was found that, time and temperature had significant effect ($P<0.05$) on the change of the x-value of the soybean kernel during soaking. However, change in x-value due to pH was not statistically significant ($P>0.05$). In addition, there were no significant interaction between pH, t and T ($P>0.05$).

The percent change in x-values increased ($P<0.05$) with temperature during soaking. Significant fluctuations occurred at 30°C at all the pH levels however, small fluctuations were observed during soaking at 50 and 70°C. It may be due to the rate of diffusion of water into the soybean kernel at 50 and 70°C were greater than that of 30°C during first 40 minutes of soaking. There was an increase ($P<0.05$) in the length of the soybean kernel at 50 and 70°C. The percent change in x-values reached to 60-80% of initial value at the end of the soaking at each condition.

It was found from the multiple range tests and 3-way ANOVA that the percent change in the length increased of the soybean kernel significantly ($P<0.05$) when soaking temperature was increased from 30 to 50°C. But, there was no significant ($P>0.05$) difference observed in the x-values of soybean that soaked between 50 and 70°C. As expected, due to gelation and cooking effects, the length of soybean kernel increased more at 50 and 70°C than the 30 and 50°C ($P<0.05$).

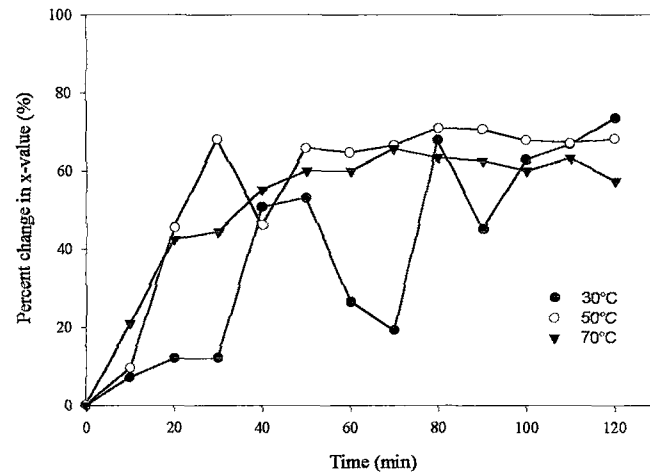


Figure 3.1 Percent change in x-value of the soybean kernel during soaking at pH 5

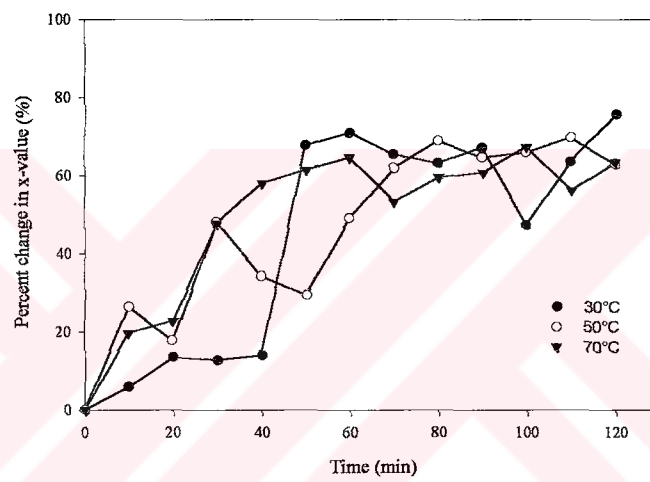


Figure 3.2 Percent change in x-value of the soybean kernel during soaking at pH 7

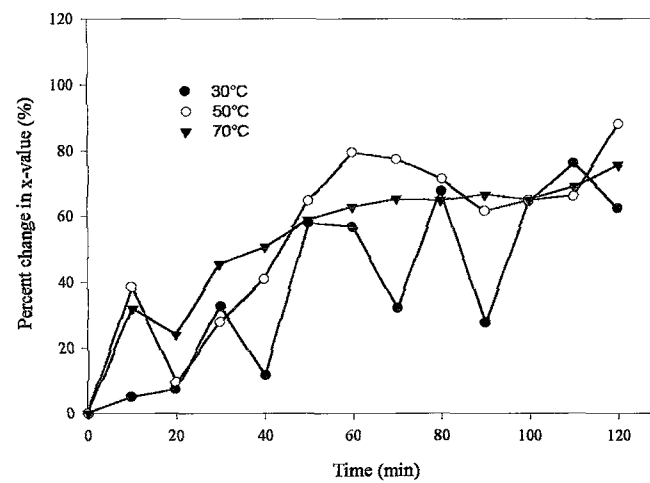


Figure 3.3 Percent change in x-value of the soybean kernel during soaking at pH 9

The percent change in the length was a positive value as it was predicted, because length of soybean increases during the soaking operation and there was no shrinkage. In contrast, Bayram *et. al.* (1998) reported that, the wheat kernel has crease which protect the kernel against the external forces, therefore, percent change in the length of the wheat kernel decreases. This decrease in length may also be explained with increase in the y and z-values for the wheat kernel (Bayram *et. al.* 1998, Bayram *et. al.* 2003a). Soybean has only joint side but not crease. Increase in y and z-values are not effective on length of the soybean kernel in contrast to the wheat kernel.

Percent change in the y-value (crease side) of the soybean kernel was determined at different pH and temperature during the soaking operation (Figures 3.4-3.6). According to ANOVA, soaking time had significant effect ($P<0.05$) on the change in the y-value of the soybean kernel in contrast to soaking pH and temperature. The percent change in y-value increased ($P<0.05$) sharply during first 10 minutes at all pH and temperatures (Figures 3.4-3.6), then slightly decreased. During the final stage of the soaking operation (between 70 and 120 minutes), the percent change in the y-value decreased very slowly (Figures 3.4-3.5) except soaking pH 9 (Figure 3.6) probably due to alkaline effect of the pH 9 to soften the tissue.

Change in y-value is important because it prevents the separation of the soybean kernel from the joint into two parts. If the kernel is separated from the joint during soaking, the bran will not be able to keep the kernel intact during further operations (e.g. cooking), and it will lead to some quality losses (leaching, stickiness, losses of color and processing ability etc.).

It is well known that, $\text{pH}>7$ has both gelation and alkaline (softening) effects on the food products. It was observed that softening effect of pH 9 on the y-value of the soybean kernel is more important than the gelation effect.

Changes in the z-value (secondary width) of soybean were given in Figures 3.7-3.9 at pH 5, 7 and 9. pH and temperature had no significant ($P>0.05$) effect on z-value that similar with y-value. It may be explained that both y and z-values were widths of the soybean kernel. Therefore, they may be showed similar behaviors against the soaking pH and temperature.

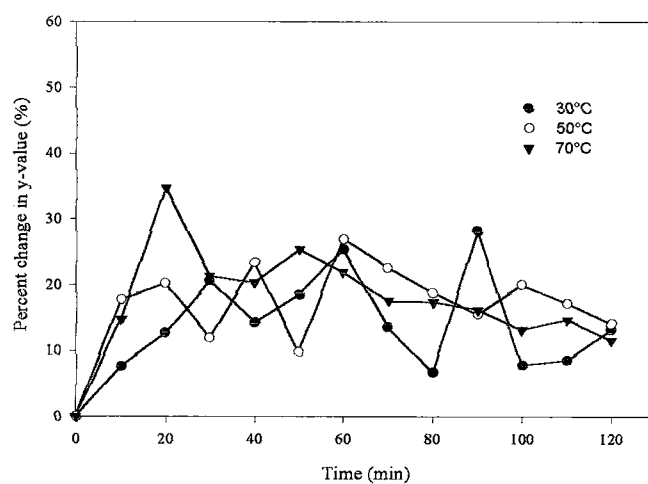


Figure 3.4 Percent change in y-value of the soybean kernel during soaking at pH 5

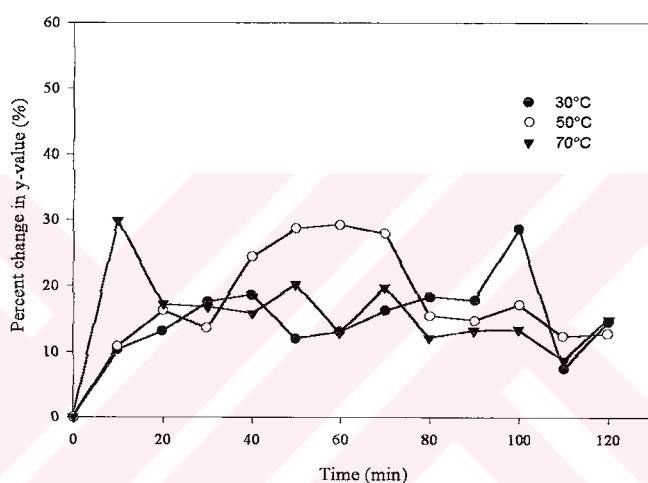


Figure 3.5 Percent change in y-value of the soybean kernel during soaking at pH 7

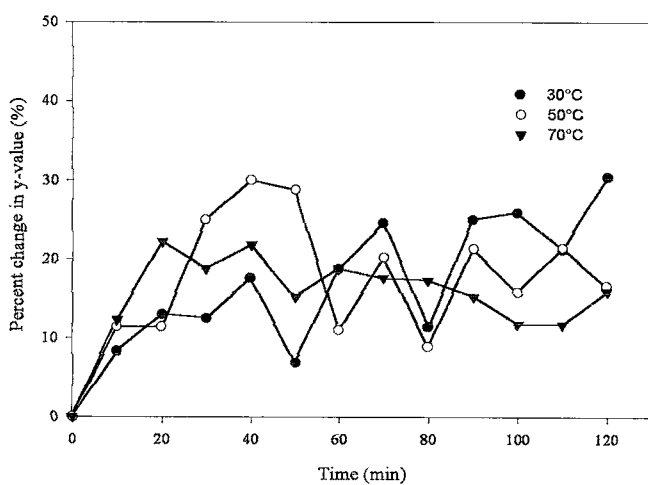


Figure 3.6 Percent change in y-value of the soybean kernel during soaking at pH 9

Joint side is important for the soybean kernel (Figure 3.10). Two half parts of a kernel combine to form the whole soybean kernel attached with germ part. There are also two bran layers covering the soybean kernel where outer part is dense and thick, and inner is thin. Although, bran layers supply force to hold together and provide the strength of the whole soybean kernel, they act as a barrier for the water penetration. It was observed that when water diffused through bran layers, water first entered easily through two half parts, then the rate of the soaking increased (Figure 3.10). But, strength of the joint side of the soybean kernel is less than the crease side of the wheat kernel (Bayram *et. al.* 1998). Therefore, x, y and z-values of the soybean kernel increased, independently.

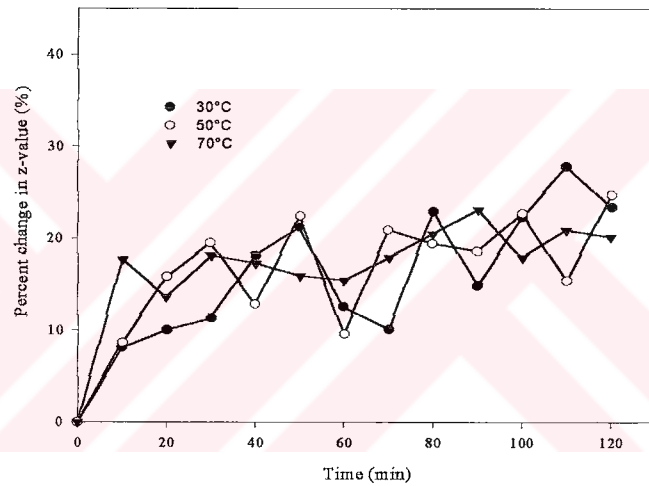


Figure 3.7 Percent change in z-value of the soybean kernel during soaking at pH 5

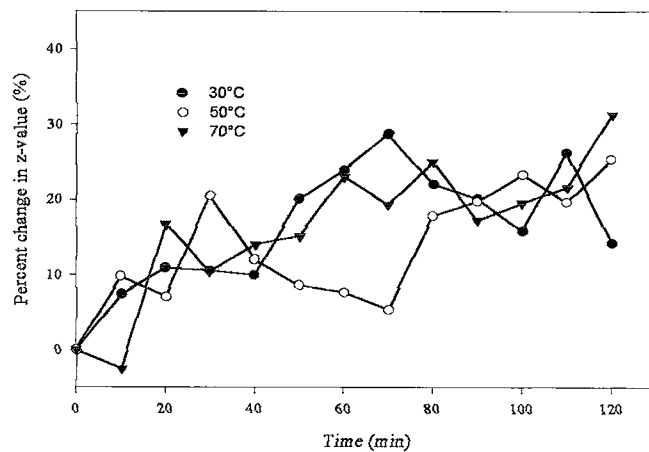


Figure 3.8 Percent change in z-value of the soybean kernel during soaking at pH 7

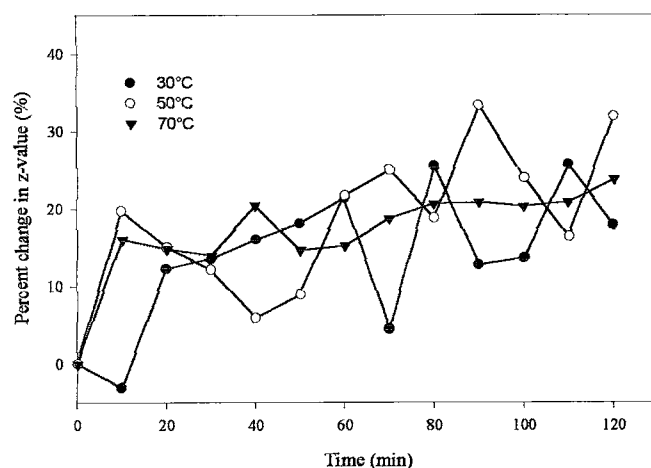


Figure 3.9 Percent change in z-value of the soybean kernel during soaking at pH 9

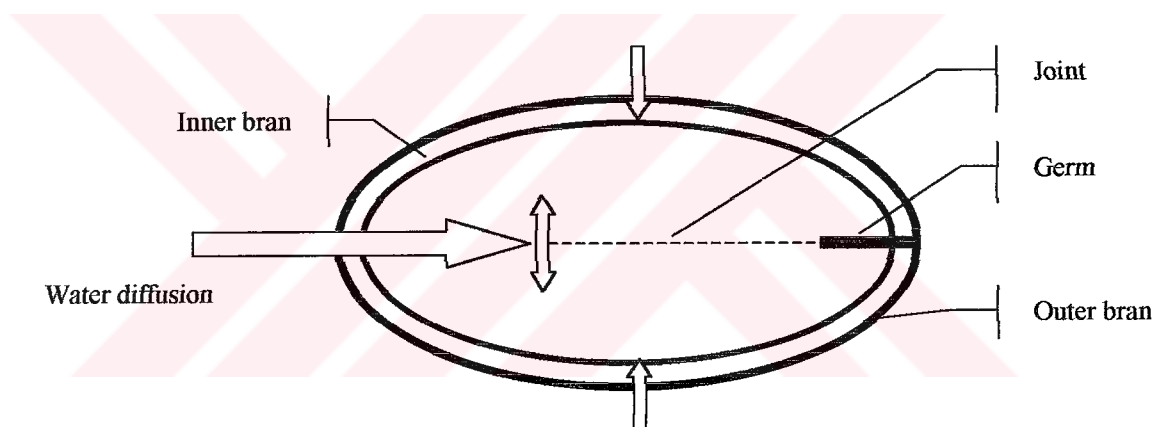


Figure 3.10 Illustration of water diffusion into soybean kernel

b. Changes in weight, volume and density of the soybean kernel

Percent change in weight (W) and volume (V) of soybean kernel were given in Figures 3.11-3.13 and 3.14-3.16, respectively. The weight and volume of the soybean kernel increased during the soaking operation at all of the soaking temperatures and pH. Soaking time and temperature significantly ($P < 0.05$) affected the change in weight and volume of the soybean kernel. It was found that there was no significant effect ($P > 0.05$) of pH of the soaking operation on weight and volume of soybean.

The density of the soybean kernel depends on the weight and volume of the soybean kernel. According to the results of the 3-way ANOVA, soaking time and temperature significantly ($P<0.05$) affected the change of density of the soybean kernel however; pH had no effect ($P>0.05$) on the density of soybean.

Increase in the weight and volume of the soybean kernel is important for design of the soaking system (dimensions, size, head space over the soaker etc.). The change in the volume was higher than that of the weight due to excessive swelling of the soybean kernel (Figure 3.11-3.16). Therefore, a negative percent change in density was obtained during soaking (Figures 3.17-3.19) and the change in the density of the soybean kernel increased negatively. A similar negative result has been reported by Bayram *et. al.* (1998) for the density of the wheat kernel.

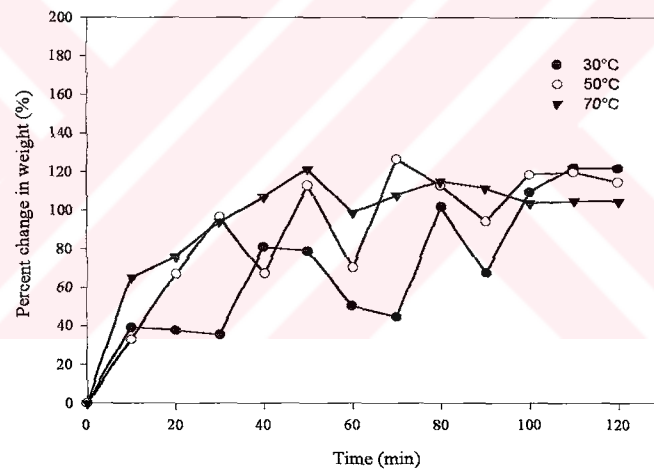


Figure 3.11 Percent change in weight of the soybean kernel during soaking at pH 5

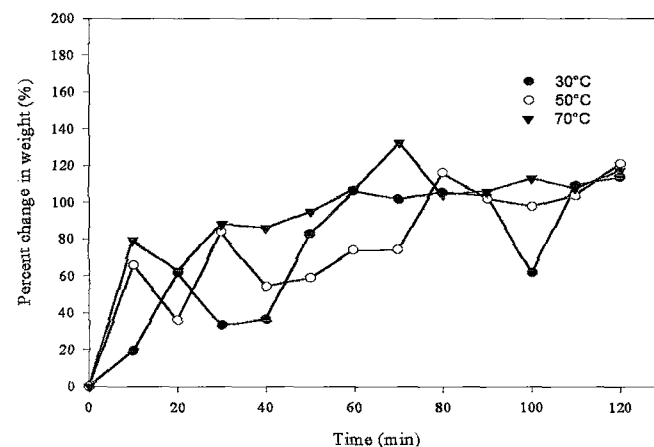


Figure 3.12 Percent change in weight of the soybean kernel during soaking at pH 7

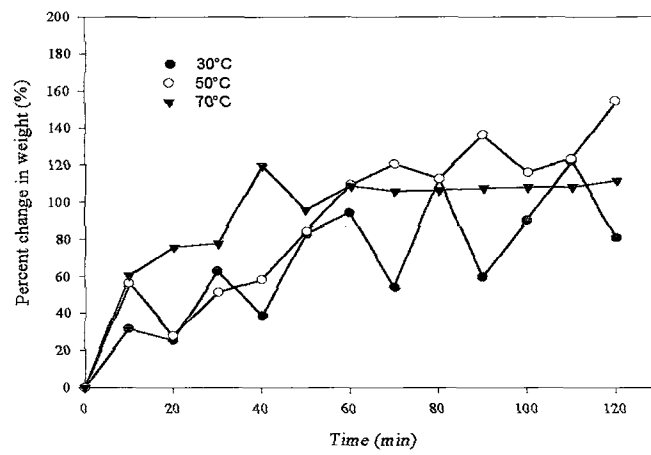


Figure 3.13 Percent change in weight of the soybean kernel during soaking at pH 9

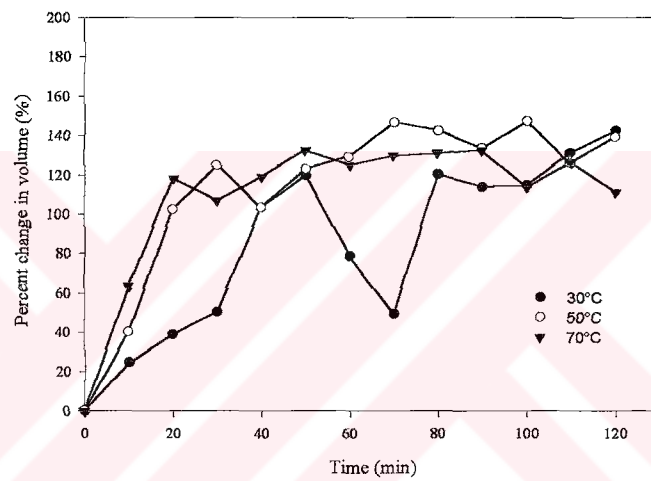


Figure 3.14 Percent change in volume of the soybean kernel during soaking at pH 5

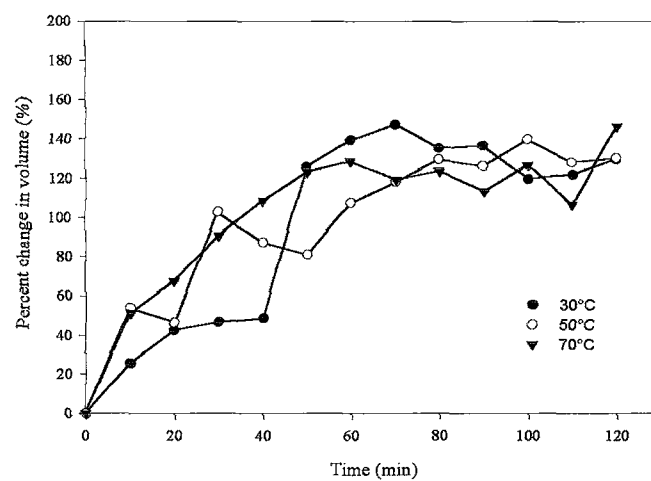


Figure 3.15 Percent change in volume of the soybean kernel during soaking at pH 7

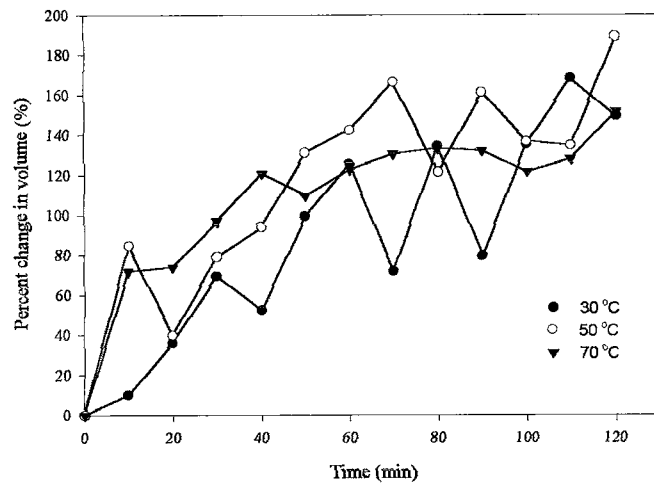


Figure 3.16 Percent change in volume of the soybean kernel during soaking at pH 9

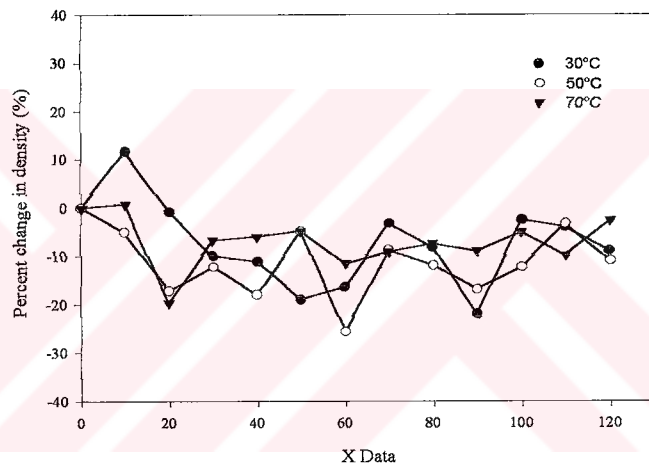


Figure 3.17 Percent change in density of the soybean kernel during soaking at pH 5

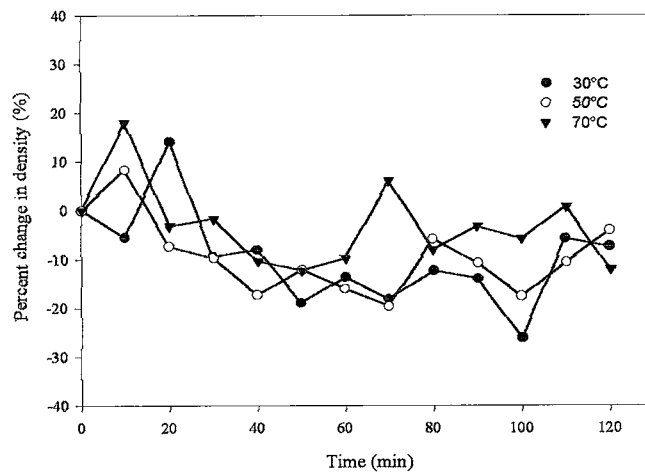


Figure 3.18 Percent change in density of the soybean kernel during soaking at pH 7

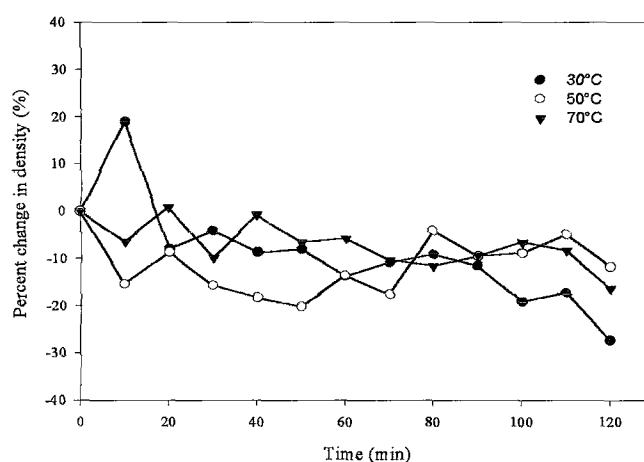


Figure 3.19 Percent change in density of the soybean kernel during soaking at pH 9

c. Change in moisture content of soybean during soaking

The most important property for soaking of soybean is the moisture content to achieve the proper cooking operation. If the moisture content of soybean is less than 40%, pressure-cooking operation could not be carried out properly (Bayram, 1997).

Moisture content of the unprocessed soybean was determined as 9.6% (w.b.). Soaking pH, temperature and time affected the moisture content significantly ($P < 0.05$). Moisture content of soybean increased ($P < 0.05$) with soaking time up to 55 %. Then, percent moisture content of soybean became nearly constant around 60 % i.e. equilibrium was established. Increasing soaking pH and temperature increased ($P < 0.05$) moisture content due to softening effect of the high pH and temperature.

Optimum moisture content (40%) was reached within 10 to 20 minutes at 30, 50 and 70°C and at the pH values of 5, 7 and 9. Soaking was also continued after 40% moisture during 120 minutes to determine changes in moisture and other properties. It was found that optimum moisture content could easily be reached for soybean using high soaking pH and temperature (Figure 3.22) within 10 minutes of soaking.

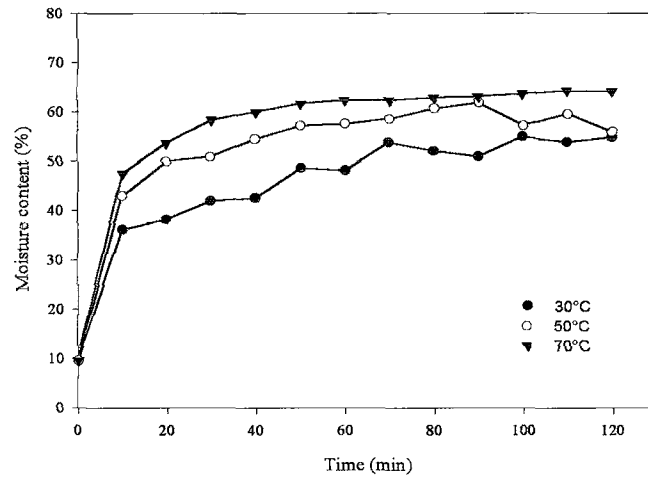


Figure 3.20 Change in moisture content of soybean during soaking at pH 5

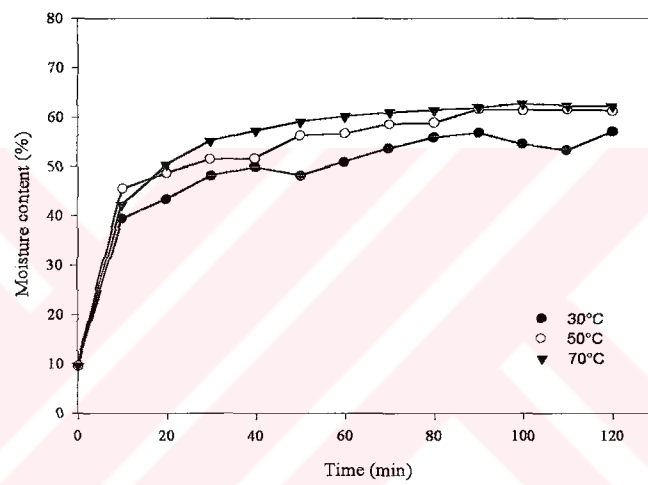


Figure 3.21 Change in moisture content of soybean during soaking at pH 7

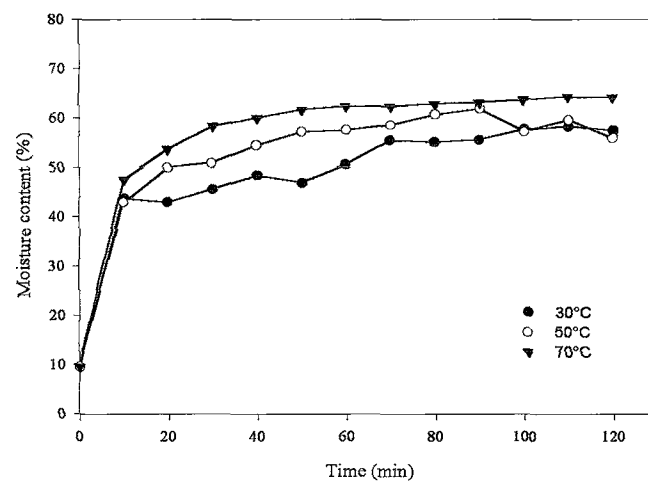


Figure 3.22 Change in moisture content of soybean during soaking at pH 9

d. Change in color of soybean during soaking

It has been reported that many reactions can affect the color during the processing of the foods. Among them, the most common are pigment degradation, (especially carotenoids and chlorophyll), browning reactions (such as Maillard condensation of hexoses and amino components) and change of ingredient distribution and structure (swelling, salt or sugar distribution), recrystallization of some compounds (sugar, salt etc.), phenol polymerisation and oxidation of ascorbic acid (Barreiro *et. al.* 1997; Lozano and Ibarz, 1997; Lee and Coates, 1999; Maskan, 2001a; Maskan *et. al.* 2002; Sherkat and Luh, 1976; Okitani *et. al.* 1983; Petropakis and Montgomery, 1984; Resnik and Chrife, 1979; Cornwell and Wrolstad, 1981; Reynolds, 1965; Abers and Wrolstad, 1979, Kaya, 2002; Aguilera *et. al.* 1987). Other factors affecting color include acidity, processing temperature and time, cultivar and heavy metal contamination (Abers and Wrolstad, 1979; Skrede 1985; Garcia-Viguera *et. al.* 1999).

The first quality judgment of a food product made by a consumer at the point of sale and acceptability is its visual appearance. Therefore, color of bulgur is the most important parameter for acceptability of the final product for wheat bulgur. A common problem with the processing of wheat bulgur is the color loss (generally darkening) of the finished product, which in turn affects the consumer acceptability. Addition of color additives to give good yellowness is forbidden by laws and regulations; namely, wheat bulgur should have a natural color. Similar properties will be required for acceptability of the soy-bulgur. Therefore, the color of the soybean was monitored during the soaking operation in the present study.

Bulgur in acceptable quality should have a light yellow color. Therefore, “L” and “b” values should be high in contrast to low values of “a” and “YI”. Color measurements (L, a, b and YI-values) at pH 5, 7 and 9 during the soaking operation were given in Figures 3.23-3.34.

Statistical analysis illustrated that time and temperature had a significant ($P<0.05$) effect on the L, a, b and YI-values. The L-value (lightness) was 51.96 initially for the unprocessed soybean and it decreased during first 10 minutes sharply at all soaking pH and temperature. Then, the L-value during soaking steadily increased ($P<0.05$).

This rising value indicates that the samples turned light with increasing soaking time and temperature (Figures 3.23-25). The a-value also decreases gradually ($P<0.05$) at all pH and temperature during soaking (Figures 3.26-3.28). It was also significantly ($P<0.05$) affected by soaking time and temperature in contrast to pH. The variation in the brightness of the treated samples can be taken as a measure of the degree of brownness (Labuza *et. al.* 1992). Therefore, this statement positively correlated the obtained results.

Lightness had a higher value due to high water absorption and pigment denaturation during the soaking. The main pigments of soybean fall into the carotenoid class although some amounts of chlorophyll also are present. Also, some vitamins (riboflavin, thiamine, niacin etc.) are found in soybean (Synder and Kwon, 1987). The effect of temperature on the lightness of soybean was also related to the change in the structure and the color of the soybean due to the water penetration and the gelation of compounds (protein, starch etc.) in the soybean. This dominant color change affected the appearance of the soybean. During the thermal processing, the food material may be exposed to temperatures which have an adverse effect on quality and which make these products susceptible to color deterioration (Barreiro *et. al.* 1997; Lozano and Ibarz, 1997; Avila and Silva, 1999; Ibarz *et. al.* 1999; Rhim *et. al.* 1989).

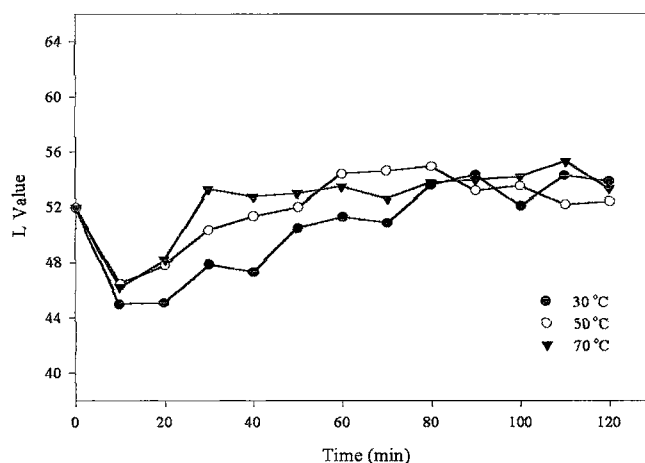


Figure 3.23 Change in L-value of soybean during soaking at pH 5

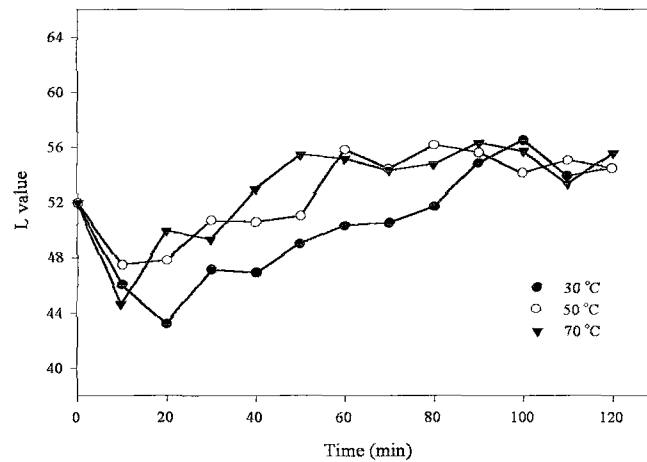


Figure 3.24 Change in L-value of soybean during soaking at pH 7

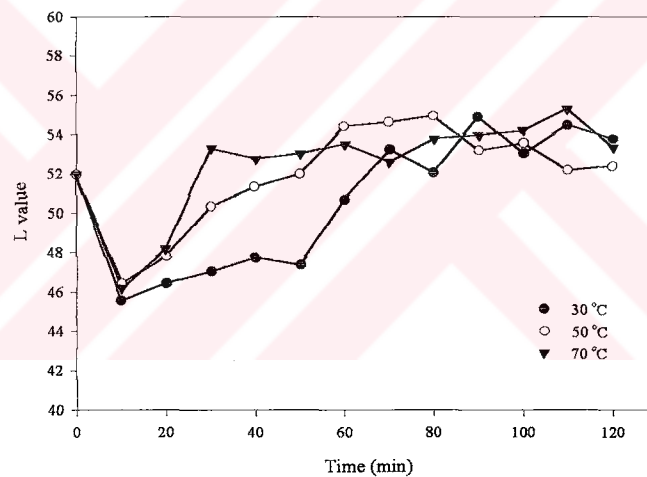


Figure 3.25 Change in L-value of soybean during soaking at pH 9

Change in the color of the soybean can be explained by the combinations of the L, a and b values. Browning reactions are very limited or do not occur during the soaking of the soybean, which only showed an increase in the L-value (lightness) and a decrease in the a-value (redness). The redness decreased due to the degradation effect of temperature on the long chemical structure of carotenoid. Therefore, the broken reddish carotenoids turn to a light yellowish color (short chemical structure). Increase in lightness with temperature could be explained by the absorption of water into the soybean, and degradation of carotenoid pigments in the soybean.

Other researchers obtained an increase in the a-value (e.g. drying, heat concentration and cooking etc. processes), however, increase in the L and decrease in the a-values that observed in this study. It was explained as the formation of the some reaction products (Lozano and Ibarz, 1997; Avila and Silva, 1999; Ibarz *et. al.*, 1999; Skrede, 1985). Increase in the a-value during processing has been correlated with decrease in the L-value (Lopez *et. al.* 1997; Lozano *et. al.* 1994). But, these studies were carried out for a low quantity of free water and at high temperatures (drying, heat concentration, cooking etc.). Therefore, formation of browning was expected for these types of the heat processes, in contrast to the soaking operation (mild process with a high water quantity and low temperature).

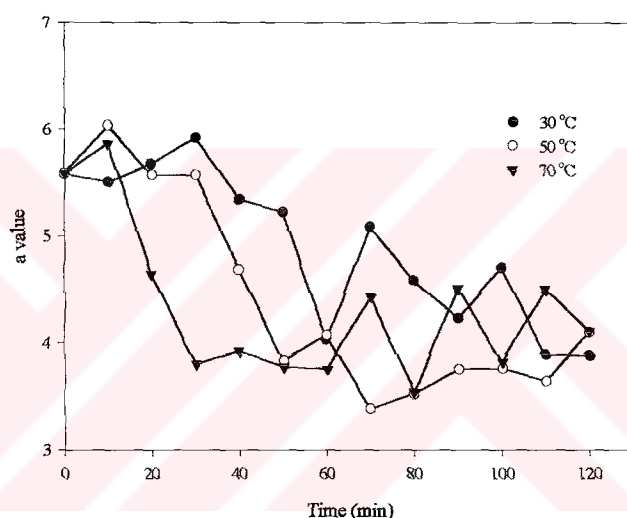


Figure 3.26 Change in a-value of soybean during soaking at pH 5

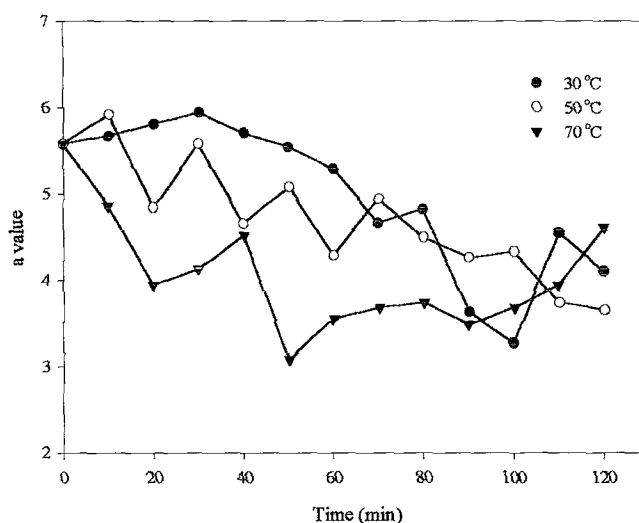


Figure 3.27 Change in a-value of soybean during soaking at pH 7

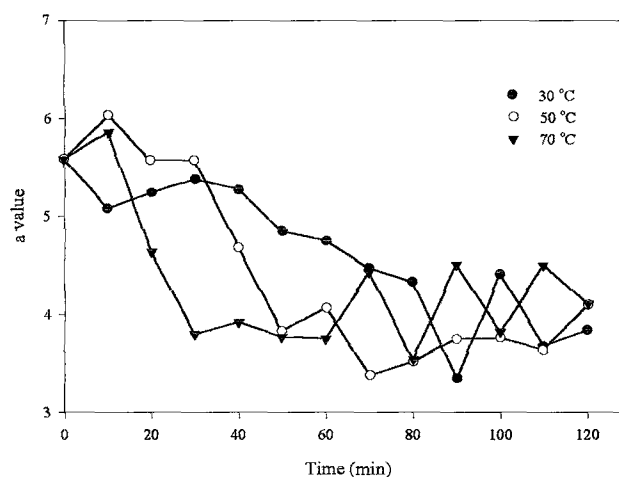


Figure 3.28 Change in a-value of soybean during soaking at pH 9

The b-value (yellowness) increased during soaking (Figures 3.29-3.31) and was affected significantly by soaking time and temperature ($P < 0.05$) but not pH. Increase in the b-value might be explained as the degradation of red pigments into a yellow color, and yellowish pigments and vitamins participate in the soybean. Gelation of protein could also affect the appearance.

Avila and Silva (1999) presented a literature survey and list of published data for the kinetics of color degradation of some foods. Measurement and evaluation of the YI-values of foods had not been reported previously. The YI-value is important for the water treated (soaking, cooking, blanching etc.) food materials to understand the clarity effect of the water on food color. YI (Yellowness Index) visually; yellowness is associated with scorching, soiling, and general product degradation by light, chemical exposure, and processing. Yellowness index is used chiefly to measure these types of degradation. Yellowness index (YI) is a numerical representation of how yellow a material is in comparison with a “clear” water-white standard (indicates the degree of departure of an object color from colorless or from a preferred white). Lower YI values indicate greater clarity (cleanness or clearness).

During first 10-20 minutes, clarity or clearness of soybean decreased then increased (decrease in the YI-value) during the soaking ($P < 0.05$). The decrease in clarity during first period may be due to reaching of moisture to optimum level i.e. 40%. When the evaluation of clarity is done using the L and b-values, the appearance of

the soybean turns to a light-clarity degree. Additionally, the application of the high temperature (e.g. 70°C) for the soaking causes a decrease in the clarity (it might be explained by gelation of proteins, function of carbohydrates and water content in the soybean).

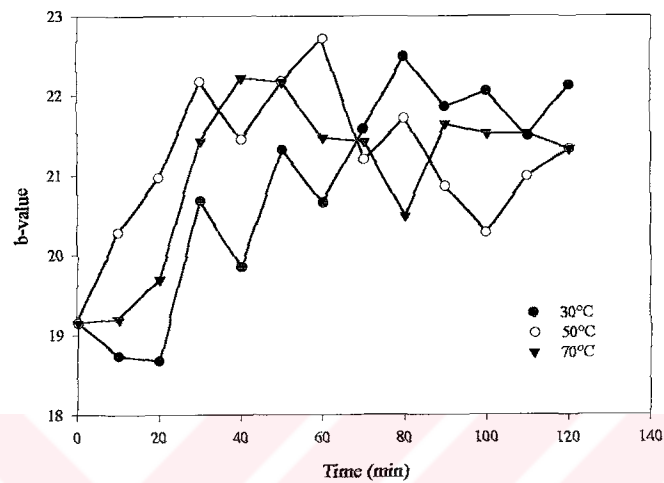


Figure 3.29 Change in b-value of soybean during soaking at pH 5

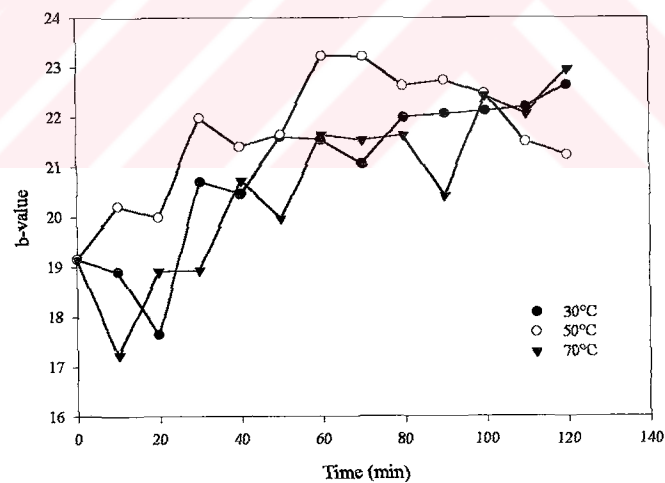


Figure 3.30 Change in b-value of soybean during soaking at pH 7

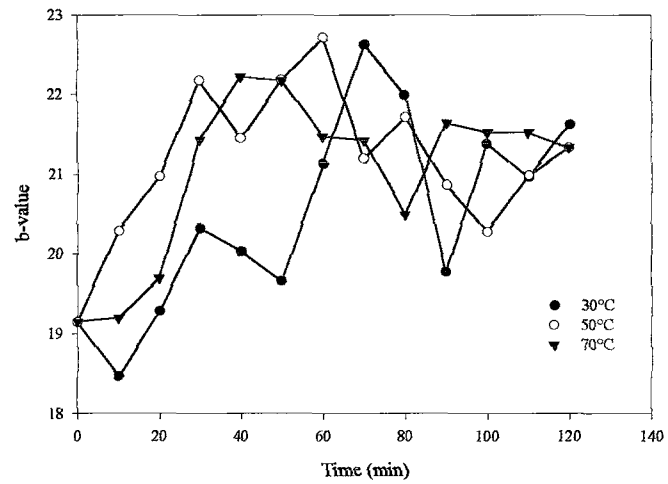


Figure 3.31 Change in b-value of soybean during soaking at pH 9

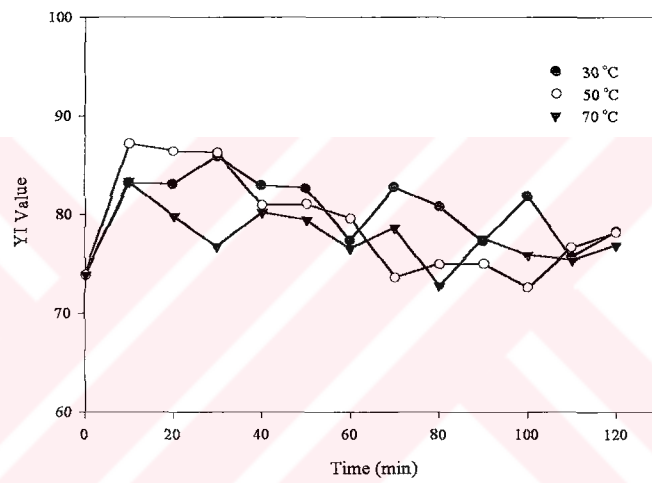


Figure 3.32 Change in YI-value of soybean during soaking at pH 5

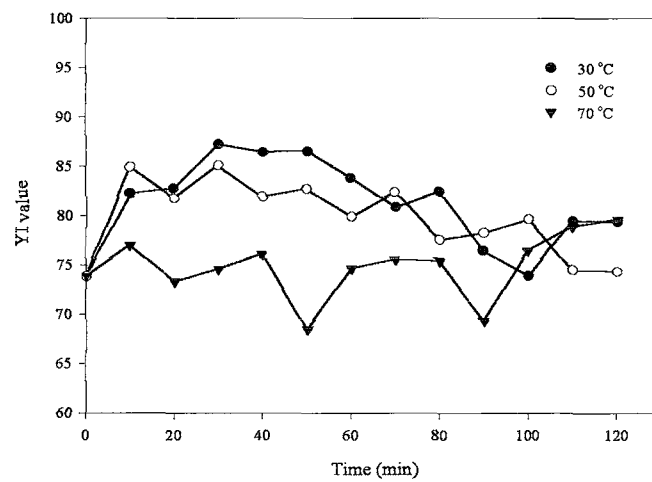


Figure 3.33 Change in YI-value of soybean during soaking at pH 7

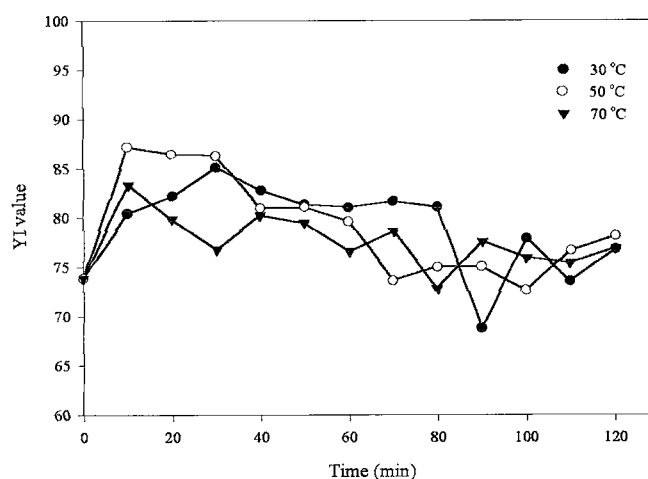


Figure 3.34 Change in YI-value of soybean during soaking at pH 9

e. Change in texture of soybean during soaking

Texture of the soybean was analyzed using $F_{\max}$ and A_P values. $F_{\max}$ and A_P values are used to determine the degree of hardness of soybean during soaking and their values were illustrated in Figures 3.35-3.37 and 3.38-3.40 at pH 5, 7 and 9, respectively.

Soaking time and temperature had significant effect on $F_{\max}$ and A_P values ($P < 0.05$). Traditionally, alkaline treatment e.g. carbonate addition is used during soaking and cooking operation to soften legumes. It was interesting that there was no significant effect of pH on texture of soybean ($P > 0.05$).

The $F_{\max}$ and A_P values decreased significantly ($P < 0.05$) during soaking. The huge change occurred in first 10 minutes and then textural properties changed up to 20 minutes steadily. This change indicated the soft texture in soybean. After that, they changed slightly until the end of the soaking operation (i.e. 120 min). This change was also correlated with moisture content of soybean. Optimum moisture content value (40%) for the bulgur production was reached after 10-20 minutes and the changes of the textural properties was also completed at that soaking time (Figure 3.35-3.40).

It was found that increasing soaking temperature decreased the $F_{\max}$, and A_P values ($P<0.05$) significantly, in other words softening increased (decreasing hardness) with increasing temperature as expected.

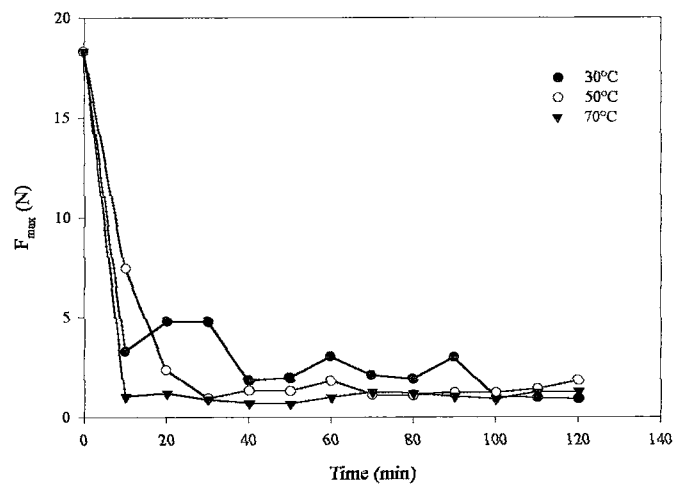


Figure 3.35 Change in $F_{\max}$ of soybean during soaking at pH 5

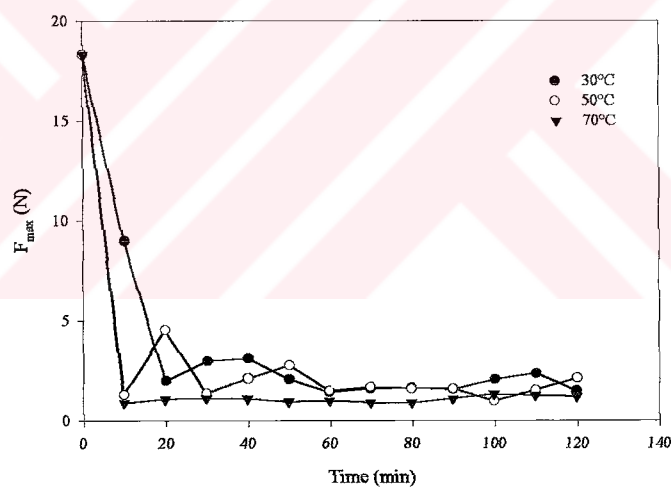


Figure 3.36 Change in $F_{\max}$ of soybean during soaking at pH 7

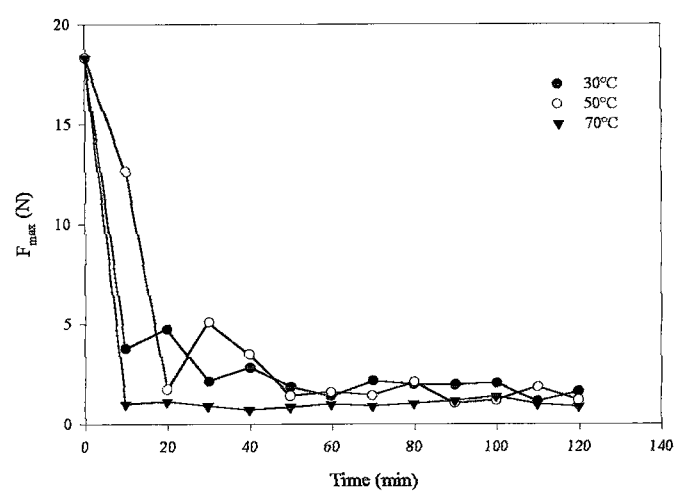


Figure 3.37 Change in F_{max} of soybean during soaking at pH 9

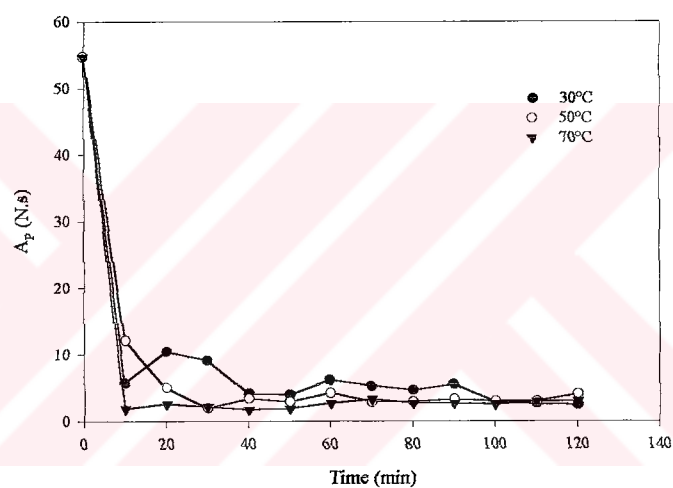


Figure 3.38 Change in A_p of soybean during soaking at pH 5

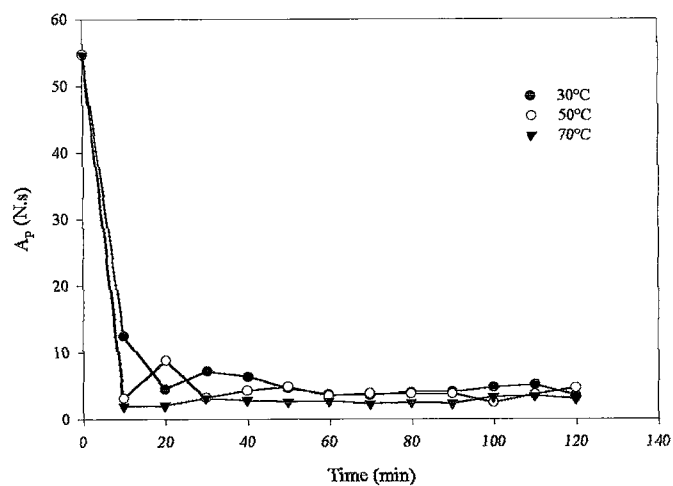


Figure 3.39 Change in A_p of soybean during soaking at pH 7

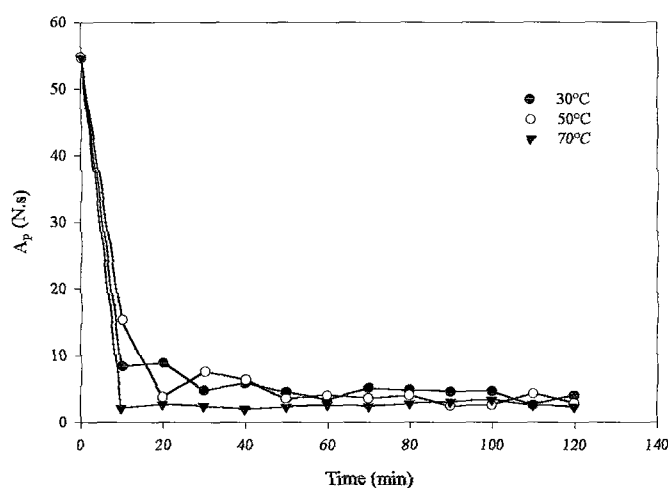


Figure 3.40 Change in A_p of soybean during soaking at pH 9

3.1.1.2. Changes in soaking water

Leaching of solubles occurs during soaking process. Rates of soaking and leaching increase with increase in temperature theoretically. The following general steps occur during the leaching process in water. Water is transferred to the surface of the solid. Then, water penetrates or diffuses into the solid. The solute dissolves in the water. The solute diffuses through the solid-water mixture to the surface of the particle. Finally, the solute is transferred to the bulk solution. In general, the rate of transfer of the water from the bulk solution to the solid surface is quite rapid and the rate of transfer of the water into the solid can be either fast or slow (Geankoplis, 1983).

The transfer of nutrients from bran and aleurone layers to endosperm during parboiling of cereals is well known in bulgur production. Water diffuses through the hull and the bran; the most of the water-soluble nutrients in these parts of the kernel are transported into the endosperm. During soaking, vitamins and nutritional compounds diffuse into the kernel. In turn, the nutritional values of the bulgur increase.

When the soybean was put into soaking water to produce soy-bulgur, water soluble substances (encapsulated ingredients inside the cells) are solubilized initially, mass transfer continues during soaking from soybean to water or vice-versa between these two macro-systems. Solubilized substances in the water are then re-absorbed during subsequent soaking.

Some of the remaining substances in the water after the soaking operation is important for nutritional properties of soy-bulgur and environmental pollution (as discharge). Also, discharged soaking water might be re-used for the next soaking operation to recover energy and water as well as increasing nutritional value of grain, industrially. So, the properties of soaking water of soybean should be investigated to understand the leaching of the substances from soybean into the water.

During soaking operation, vitamins, amino acids, pigments, minerals, carbohydrates and other water-soluble substances might leach into the water. In order to determine the overall dissolved substances; pH (to measure the dissolved acidic compounds), absorbance (to measure the turbidity causing substances, such as starch, proteins etc.), conductivity (to measure the minerals and ionic compounds), soluble solids content (as Brix; to measure the soluble organic and inorganic compounds) and color (to measure the soluble pigments, vitamins and coloring compounds) can be used.

a. Change in pH value of soaking water of soybean

Measurement of the change in the pH-values during soaking is the most important parameter that can be used to predict the rate of leaching of the acidic, basic and buffering compounds from soybean to water and to understand the chemical and physical changes in the water due to acidity, basicity or buffering property (initial pH's of the soaking water were 5, 7 and 9, Figures 3.41-3.43). The initial pH of soybean was measured as 6.44 before the soaking operation.

The experimental results of pH of soaking water during soaking were illustrated in Figures 3.41-43. The change in the pH of soaking water during soaking operation was analyzed using ANOVA at $\alpha=0.05$. According to statistical analysis soaking time, temperature and pH affected significantly ($P<0.05$) the pH of soaking water during soaking.

The pH of soaking water at pH 5 increased sharply to nearly 6.20-6.80 at 30, 50 and 70°C during first 10 minutes, then changed slightly. pH of soaking water at pH 7 and 9 decreased to 6.20-6.80. It was very interesting to note that, regardless of the starting soaking water pH, after, approximately 10 minutes of soaking process,

soaking water pH becomes constant around 6.20-6.80. This could be explained by the leaching of the buffering compounds e.g. amino acids, proteins, from soybean into soaking water and/or reaching to original pH of soybean at the end of the soaking operation. This evidence may explain why the changing of the pH of soaking water, as 5, 7 and 9 had no significant effect on the physical attributes of soybean e.g. dimensions, weight, volume, density etc. except moisture content during initial period of soaking process..

Increasing temperature increases ($P < 0.05$) the leaching of the compounds from soybean to water. pH value of soaking water decreases. Hardening effect of low pH was reported by Ordonez *et. al.* (1999), Abu-Ghannam (1999), Hsu (1983), and Garruti and Bourne (1985), but in present study hardening effect of low pH on textural property of soybean was lesser than the softening effect of temperature.

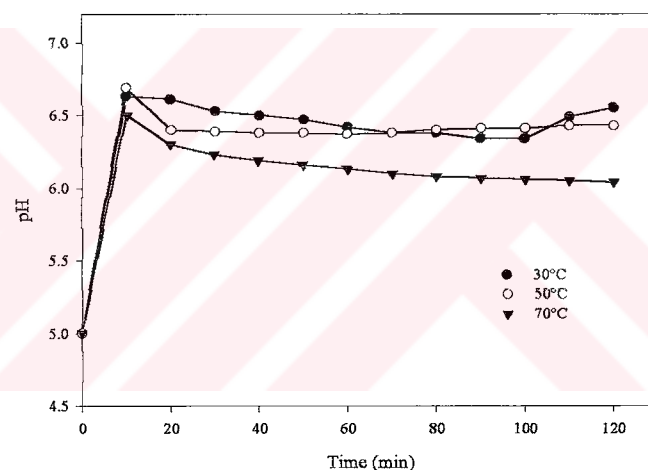


Figure 3.41 Change in pH value of soaking water during soaking of soybean at pH 5

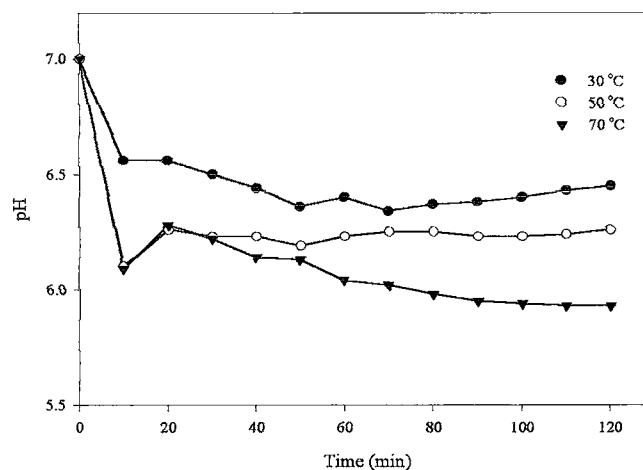


Figure 3.42 Change in pH value of soaking water during soaking of soybean at pH 7

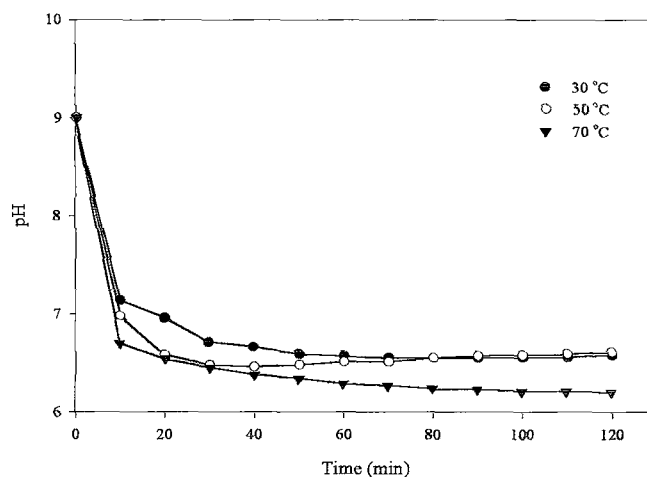


Figure 3.43 Change in pH value of soaking water during soaking of soybean at pH 9

b. Change in conductivity of soaking water of soybean

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of dissolved inorganic solids such as ions that carry a negative (chloride, nitrate, sulfate, and phosphate anions) or a positive (sodium, magnesium, calcium, iron, and aluminum cations) charge. Organic compounds like oil, phenol, alcohol, and sugar do not conduct electricity very well and they will have a low conductivity in water. The major minerals of soybean are potassium, sodium, calcium, magnesium, sulphur and phosphorus (Synder and Kwon, 1987).

Conductivity of soaking water was measured to determine overall rate of leaching of soluble compounds e.g. inorganic into water (Figures 3.44-3.46). Soaking time, pH and temperature had significant effect on conductivity ($P < 0.05$). The initial conductivity values of soaking water were 28.1, 6.5 and 43.3 μS at pH 5, 7 and 9, respectively.

There was a regular increase ($P < 0.05$) in conductivity during soaking at all soaking conditions. In turn, it decreased ($P < 0.05$) with increasing soaking pH due to gelation effect of high pH (i.e. preventing the leaching of the electrolytes). Acidic condition (pH 5) has higher conductivity value than pH 7 and 9. Change in conductivity value at 70°C was also higher than 30 and 50°C of soaking. According to these results, dissolved inorganic compounds (such as chloride, nitrate, sulphate, phosphate,

sodium, magnesium etc.) might have leached into the soaking water. Therefore, to minimize the mineral loss, soaking should be carried out at low temperature and high pH medium.

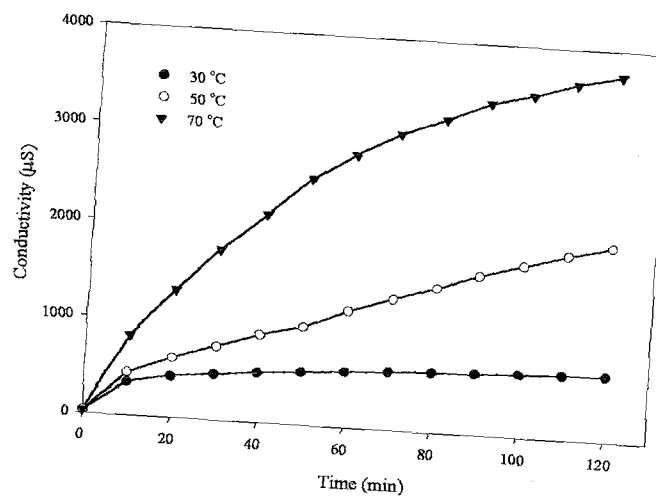


Figure 3.44 Change in conductivity of soaking water during soaking of soybean at pH 5

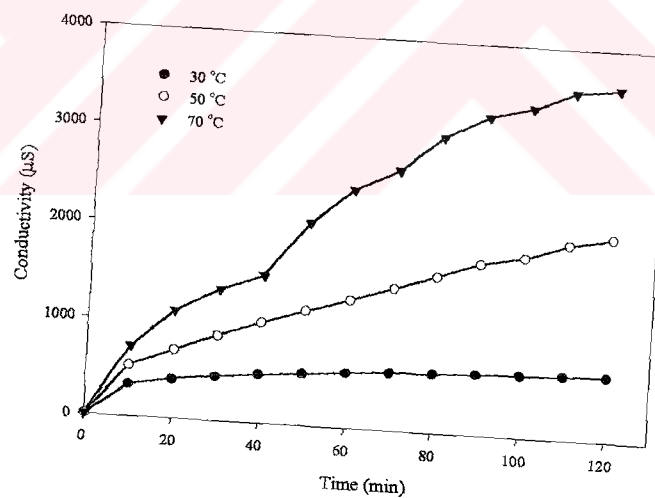


Figure 3.45 Change in conductivity of soaking water during soaking of soybean at pH 7

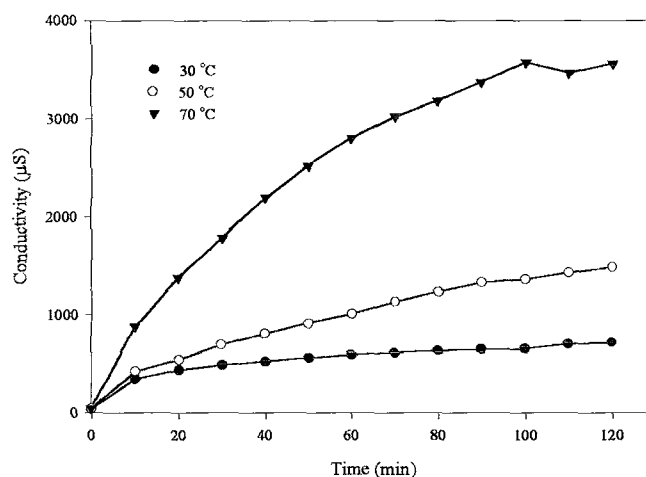


Figure 3.46 Change in conductivity of soaking water during soaking of soybean at pH 9

c. Change in turbidity/absorbance of soaking water of soybean

Turbidity of water is an important parameter in soaking and it can be used to decide the re-use of the water for next soaking operation. This may prevent environmental problems caused by discharging the water. Turbidity can occur due to leaching of some organic compounds (e.g. organic compounds, pigments, protein, sugars, starch and vitamins) into the water during soaking. Solubility of protein and sugar frame of soybean was described by Snyder and Kwon (1987) and Wang *et al.* (1979) with respect to pH and ionic strength. For the water treatment operations of the food processing, absorbance at 500 nm was used to obtain the turbidity value.

They found that, soaking time, pH and temperature had significant effect on the absorbance/turbidity ($P < 0.05$). Absorbance/turbidity of the soaking water increased ($P < 0.05$) during soaking at each soaking temperature and pH (Figures 3.47-3.49). Maximum absorbance/turbidity was obtained at pH 7. Acidic and basic soaking operations decreased the leaching of organic compounds. It can be explained as the coagulation and gelation effects of acidic and basic conditions on proteins and starch.

The change in absorbance/turbidity at 30°C was lower ($P < 0.05$) than at 50 and 70°C due to the lower temperature effect on leaching at all pH 5, 7 and 9. Increase in the leaching rate was expected with increasing temperature, but it is of interest that absorbance values at 50°C were higher than the others ($P < 0.05$, Figures 3.47-3.49), which could signify as the beginning of the gelations of starch and protein after 50°C

(organic compounds were retarded by soybean structure). Therefore, turbidity (and leaching) is low at higher temperature (70°C). But, as explained previously, conductivity is higher at this temperature due to leaching of minerals easily. It could be because of the particle size of minerals and migration mechanisms.

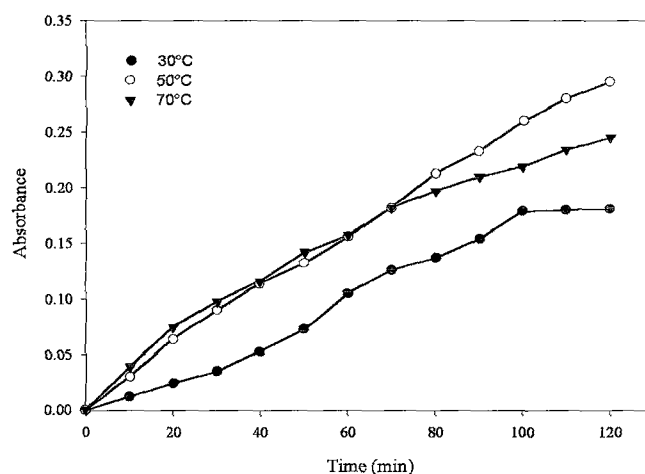


Figure 3.47 Change in absorbance of soaking water during soaking of soybean at pH 5

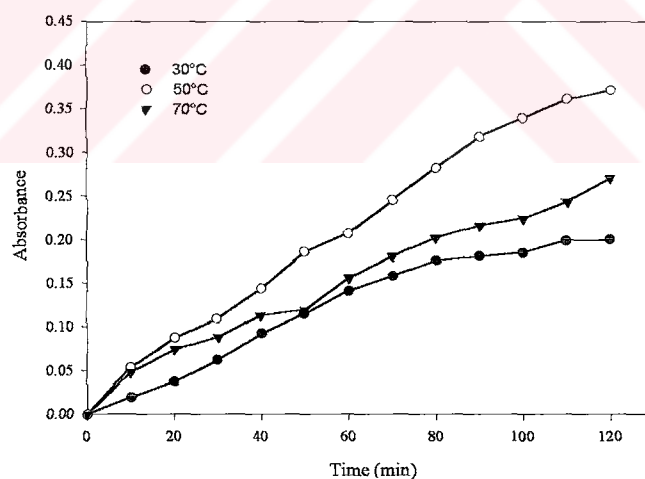


Figure 3.48 Change in absorbance of soaking water during soaking of soybean at pH 7

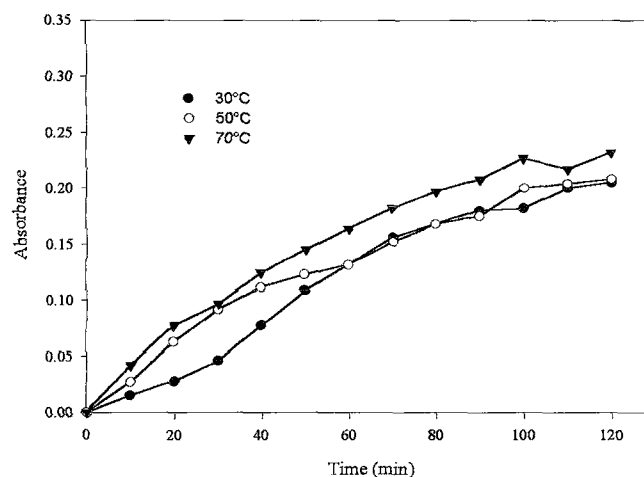


Figure 3.49 Change in absorbance of soaking water during soaking of soybean at pH 9

d. Change in soluble solids content of soaking water of soybean

Solubilized solids from soybean into water at different temperatures, pH and time were monitored (Figures 3.43-3.45) and all of the soaking parameters affected the leaching of compounds from soybean to soaking water significantly ($P < 0.05$).

Leached solid for different grain products have been reported to be phytic acid, non-protein nitrogenous compounds, sugars, minerals (Fe, Cu, Zn, Mn, P, Ca, Mg), pigments, starch, protein, water soluble vitamins such as thiamine, riboflavin and niacin (Kon, 1979; Wang *et al.*, 1979; Synder and Kwon, 1987).

It was observed that, at all soaking condition, soluble solids content orderly increased ($P < 0.05$). These results parallel the results of Wang *et al.* (1979) where soaking of soybean for 2 hours resulted in a loss of 0.7-1.25% (total solids) as the temperature increased from 20°C to 37°C and the results of Kar *et al.* (1999) on parboiling of dehusked rice where leaching losses ranged from 0.5 to 1.0 %. On the other hand, the bran layer of soybean while resisting ingress of water resisted leaching to a greater degree (Singh and Kulshrestha, 1987).

As can be seen from Figures 3.50-3.52, soluble solids values show a similar trend with conductivity values. Similar results were found by Evranuz and Gürtaş (1992) and Maskan (2001b). It has been noted that electrolytes found in the leached solids

cause the conductivity of the solution to increase and determine the structure of the soaked/cooked product (Bhatty, 1989).

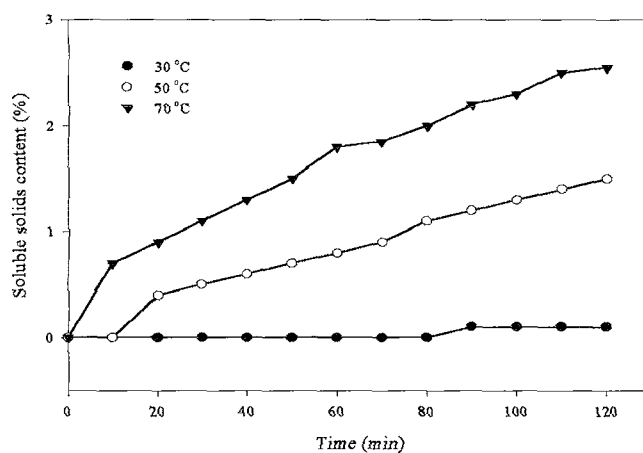


Figure 3.50 Change in soluble solids content in soaking water during soaking of soybean at pH 5

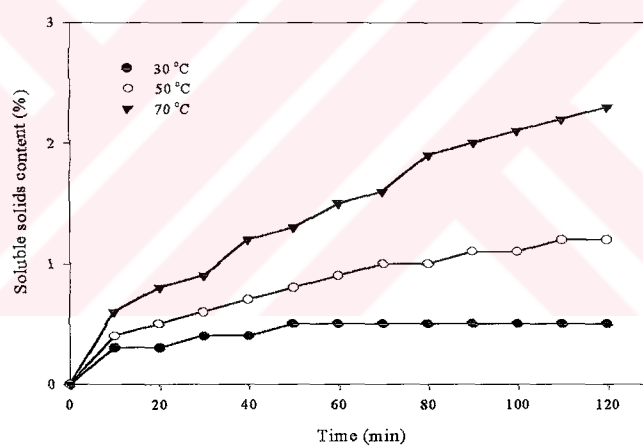


Figure 3.51 Change in soluble solids content in soaking water during soaking of soybean at pH 7

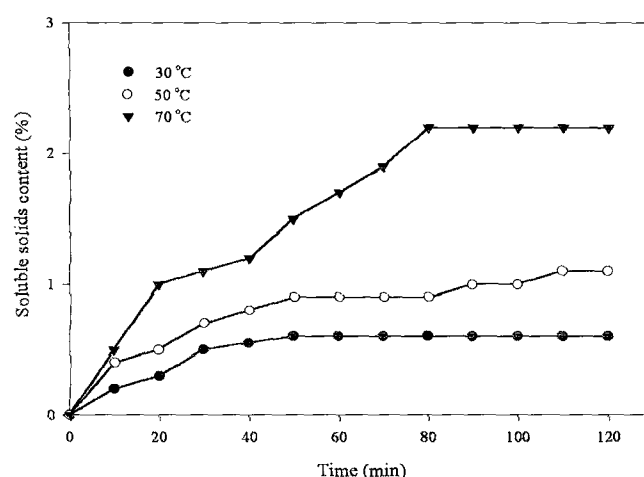


Figure 3.52 Change in soluble solids content in soaking water during soaking of soybean at pH 9

e. Change in color of soaking water of soybean

During the soaking, measurement of color could give an idea about the overall leaching of pigments and water-soluble vitamins into the water from the soybean. The main pigments of soybean fall into the carotenoids class although often small amounts of chlorophyll are also present. Water-soluble vitamins present in mature whole soybeans are thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folic acid, inositol, cholin and ascorbic acid (Synder and Kwon, 1987).

Figures 3.53-3.64 show the change of L, a, b and YI values during soaking at 30, 50 and 90°C and at each of 5, 7 and 9. All color values (L, a, b and YI) significantly affected ($P < 0.05$) by soaking time and temperature. Soaking pH was only effective ($P < 0.05$) on a-value.

Lightness of water (L-value) decreased during soaking (Figure 3.53-3.55). The pH did not affect ($P > 0.05$) the lightness of the soaking water. Increasing the soaking temperature decreased ($P < 0.05$) the lightness of the water (Figure 3.53-3.55). The L-value at 30°C was greater ($P < 0.05$) than at the other two temperatures at all soaking pH values. Therefore, the samples were observed as darker at higher temperatures. The variation in the brightness of the treated samples was taken as a measurement of degree of browning of the fruit juice by Labuza *et. al.* (1992). Additionally, the decreasing L-value with increasing the temperature has been explained as being due

to different reactions (Lozano and Ibarz, 1997; Avila and Silva, 1999; Ibarz *et. al.* 1999; Skrede, 1985). These studies carried out using a low quantity of free water and high temperatures (drying, heat concentration, cooking etc.). Therefore, formation of browning was expected for such heating processes. In turn, leaching of substances mainly causes the loss of the lightness of the soaking water. Darkening of the soaking water could also result in a lightening of the soy-bulgur due to increased leaching of the dark compounds.

The a-values were found to be negative, which means that greenness (e.g. green pigments) is present in the soaking water (Figure 3.56-3.58). All soybeans are green early in maturity due to chlorophyll. As the beans mature, chlorophyll disappears and the residual flavonoid pigments predominant. In some varieties chlorophyll is not lost, and hence they have green seed coats. The cotyledons are invariably light yellow unless soybeans are harvested before full maturity (Synder and Know, 1987). Most of the chlorophyll in the chloroplasts is bound with proteins and carbohydrates. The colloidal dispersion of chlorophyll is also affected by immersion of the plant material in boiling water and this destroys the chlorophyll to form phaeophytin. Also, the action of water in improving the extraction efficiency is postulated to be because of the effect it has on the colloidal dispersion of the chlorophyll in the chloroplasts. The crude phaeophytin extract is then further processed to give either the water-soluble or oil-soluble with chlorophylls (Humphrey, 1980).

Additionally, carotenoids (nearly red pigment, non-polar “water-insoluble”) that found in soybean were not solubilized in the soaking water (it remained in the soybean) in contrast to water-solubilized green pigments and their derivatives. Therefore, only greenness was determined in the soaking water due to leaching of green pigments.

Degree of greenness increased ($P < 0.05$) (negative a-value) at 50 and 70°C until nearly 40-50 minutes and then decreased (Figures 3.56-3.58). This may be due to decomposition of chlorophyll (Kostaropoulos and Saravacos, 1995; Lee and Coates, 1999; Weemaes *et. al.* 1999) and mixing with the other leached coloring compounds. Mixing of different colors cause the formation of a gray or darker color.

Increase in turbidity, soluble solids content and yellowness (b value) correlated well with the leaching of other coloring compounds and loss of the greenness in water (Figures 3.47-3.52 and 3.59-3.61).

Studies on a wide variety of plants indicate that the chlorophyll pigments are the same in all of them and that apparent differences in color are due to the presence and variable distribution of other associated plant pigments. In particular, these are the xanthophylls and carotenes, which always accompany the chlorophylls. Although the ratio of the yellow pigments to the chlorophylls is very variable, the absolute amount of chlorophyll in a given tissue remains constant for a given environment (Humphrey, 1980). The pigments found in the seed coat of soybeans are water-soluble and are flavonoids in nature (Synder and Kwon, 1987).

The degree of yellowness (b value) increased with time and temperature ($P < 0.05$). b-values were determined as positive, which means that yellowness was present in the soaking water (Figure 3.59-3.61). At 70°C, high yellowness was observed at pH 5, 7 and 9. Also, at each temperature, different homogeneous groups were obtained. This increase in yellowness could be explained as the leaching of yellow color pigments and vitamins with the temperature effect during soaking.

The yellowness index also increased with temperature during soaking ($P < 0.05$, Figures 3.62-3.64). When the temperature of soaking was increased from 30 to 50 or 70°C, YI-value increased sharply. This increase in YI-value was opposite to decreasing the lightness (L-value) and in parallel with the b-value. Namely, a change of YI-value was correlated with L and b-values, which means that the soaking water losses its clarity and brightness. Additionally, losses of clarity and lightness could be correlated with the leaching of the soluble solids (pigments, organic materials etc.) and causes the darkness in water.

It was interesting that, at pH 9, graphical results of L, a, b and YI-values illustrated the smooth change. It may be due to alkaline effect.

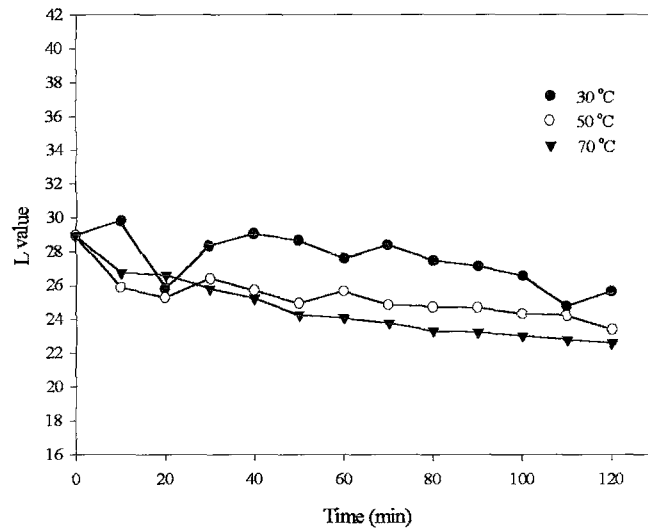


Figure 3.53 Change in L-value of soaking water during soaking of soybean at pH 5

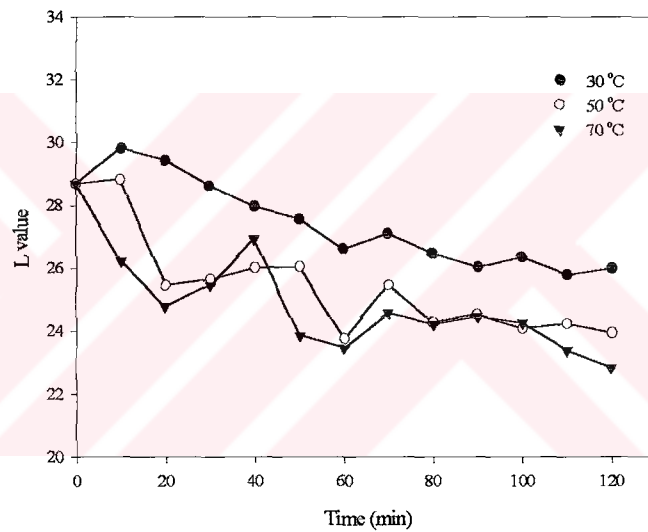


Figure 3.54 Change in L-value of soaking water during soaking of soybean at pH 7

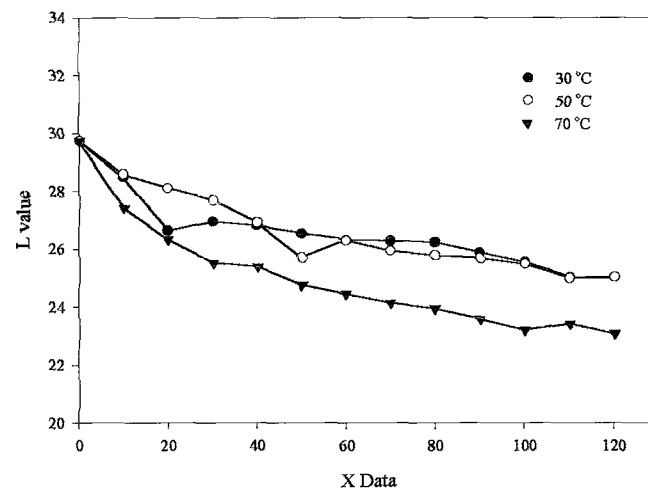


Figure 3.55 Change in L-value of soaking water during soaking of soybean at pH 9

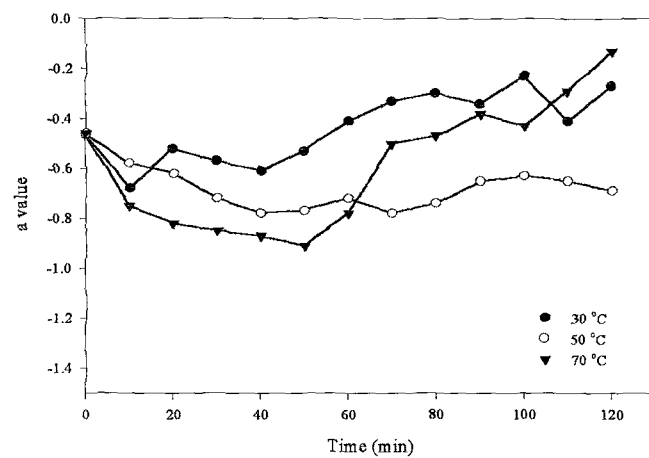


Figure 3.56 Change in a-value of soaking water during soaking of soybean at pH 5

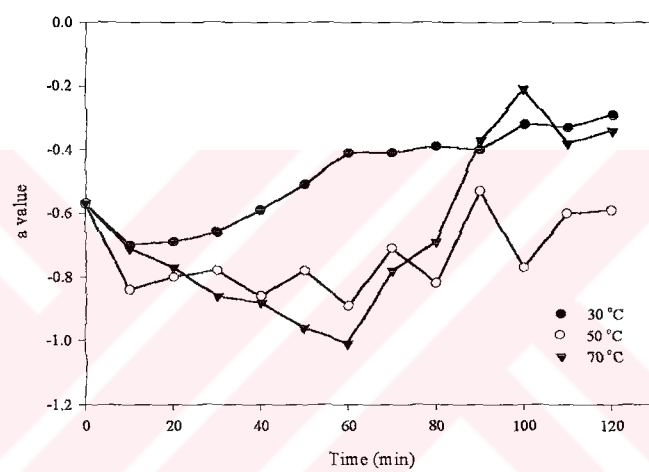


Figure 3.57 Change in a-value of soaking water during soaking of soybean at pH 7

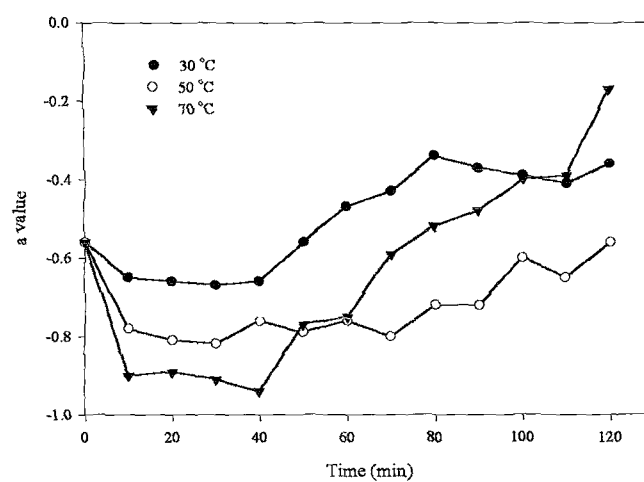


Figure 3.58 Change in a-value of soaking water during soaking of soybean at pH 9

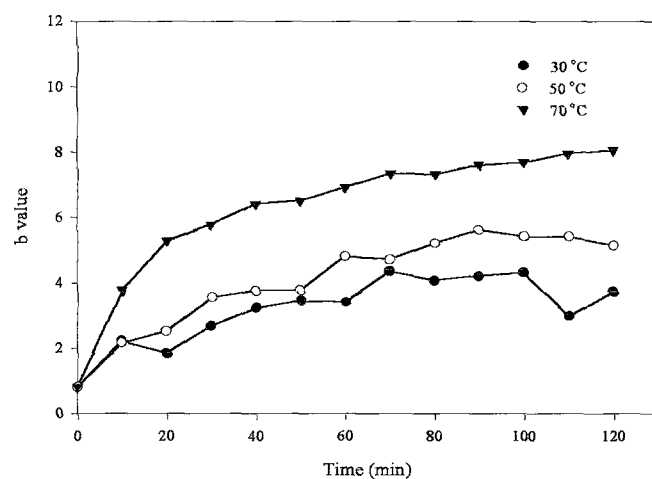


Figure 3.59. Change in b-value of soaking water during soaking of soybean at pH 5

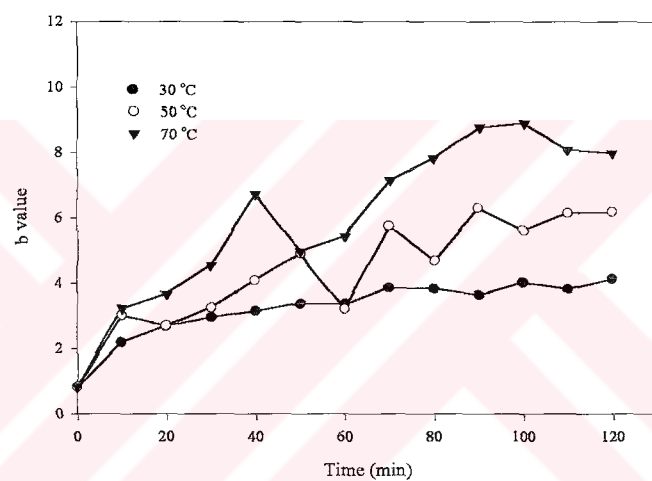


Figure 3.60 Change in b-value of soaking water during soaking of soybean at pH 7

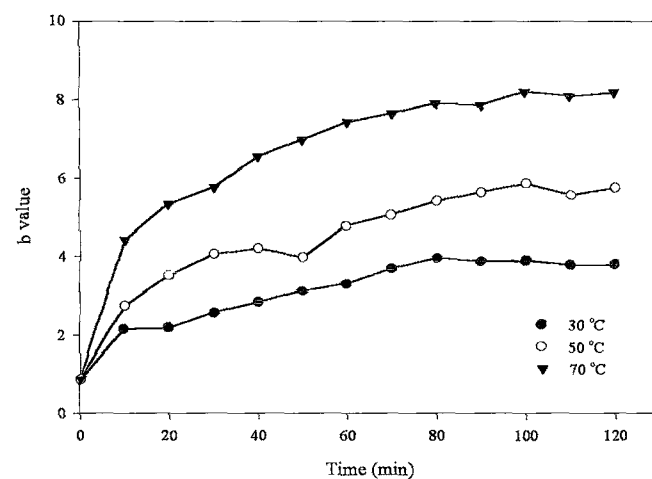


Figure 3.61 Change in b-value of soaking water during soaking of soybean at pH 9

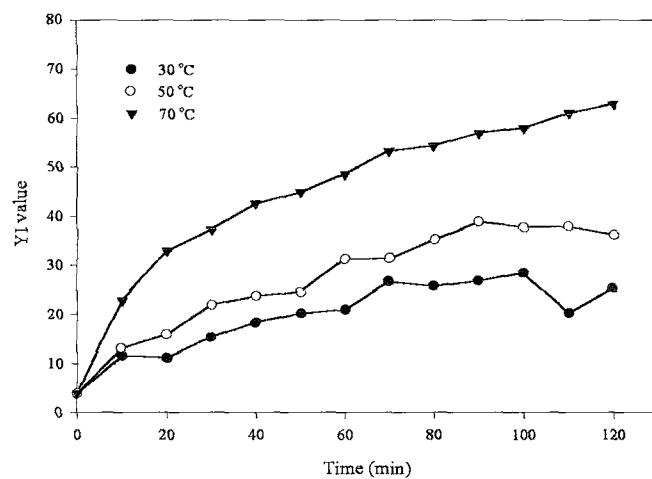


Figure 3.62 Change in YI-value of soaking water during soaking of soybean at pH 5

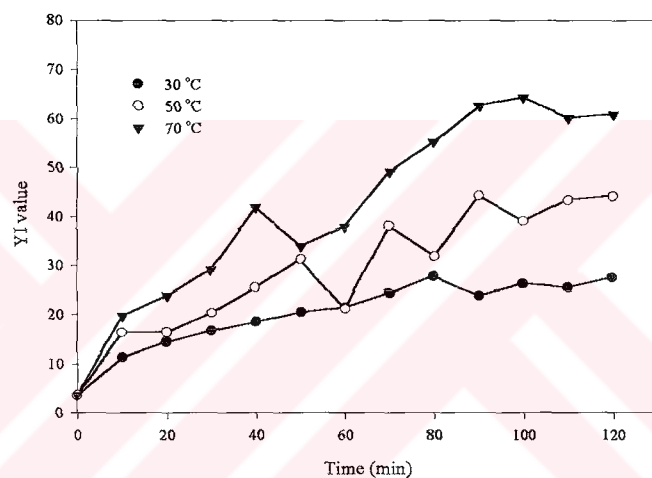


Figure 3.63 Change in YI-value of soaking water during soaking of soybean at pH 7

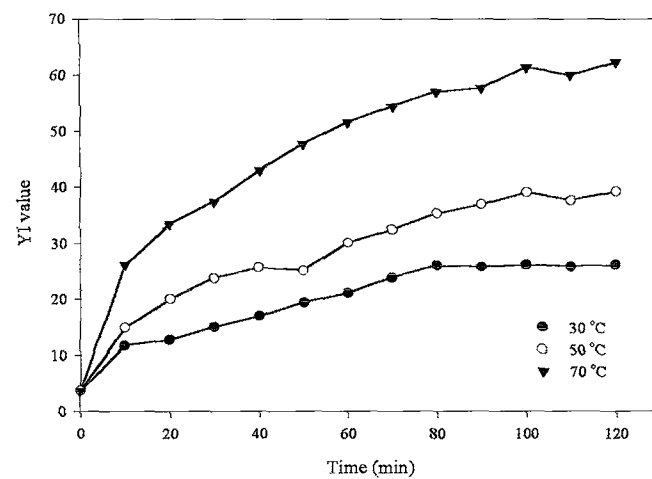


Figure 3.64. Change in YI-value of soaking water during soaking of soybean at pH 9

3.1.2. Soaking of rye

3.1.2.1. Changes in the physical attributes of rye

a. Changes in the dimensions of the rye kernel

The percent change in the length (x-value) of the rye kernel during soaking were illustrated in Figures 3.65-3.67 at 30, 50 and 70°C and at each of pH 5, 7 and 9. The x-value of the rye kernel increased ($P<0.05$) during soaking at each soaking pH and temperature. Soaking time and temperature had significant ($P<0.05$) effect on the x-value in contrast to pH.

Increase in soaking temperature increased ($P<0.05$) the change in the x-value of the rye kernel at each soaking pH. The x-value (Figures 3.65-3.67) at 30°C decreased during first 20-30 minutes at each of pH 5, 7 and 9 in contrast to soaking at 50 and 70°C. Then it increased gradually. The enlargement in the x-value (5-12%) of the rye kernel is lower than that of the soybean kernel (50-70%) due to physical (shape, size, crease etc.) and chemical (protein, starch etc.) differences. The change of the dimensions of the rye kernel was illustrated schematically in Figure 3.68.

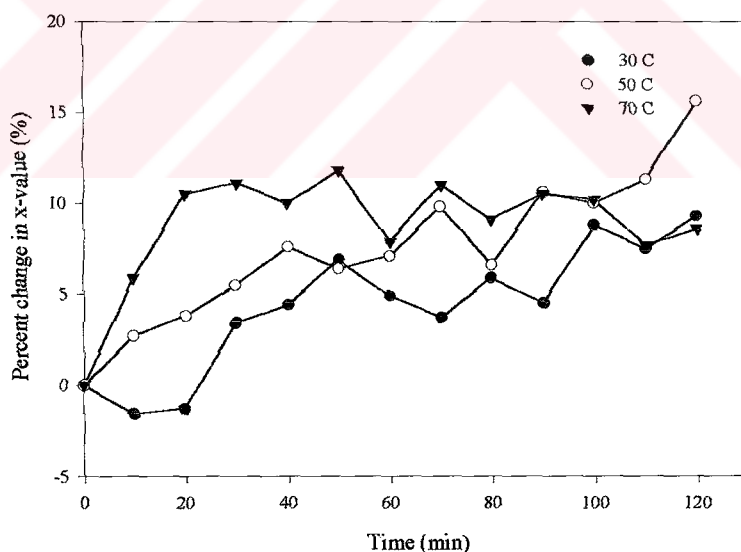


Figure 3.65 Percent change in x-value of the rye kernel during soaking at pH 5

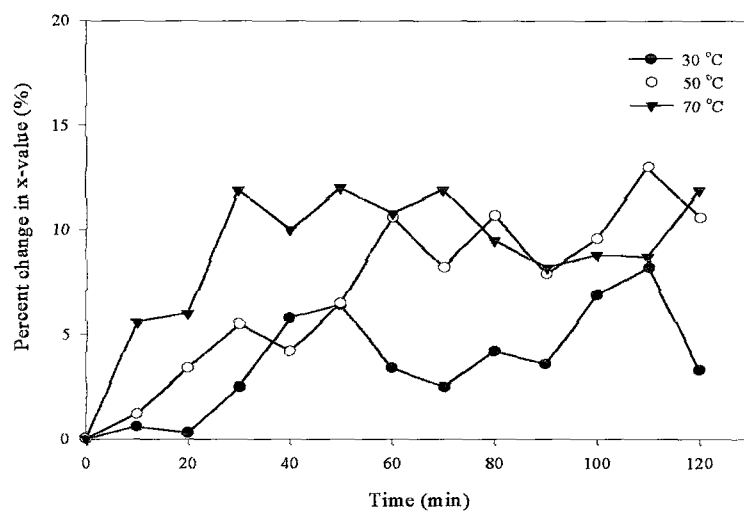


Figure 3.66 Percent change in x-value of the rye kernel during soaking at pH 7

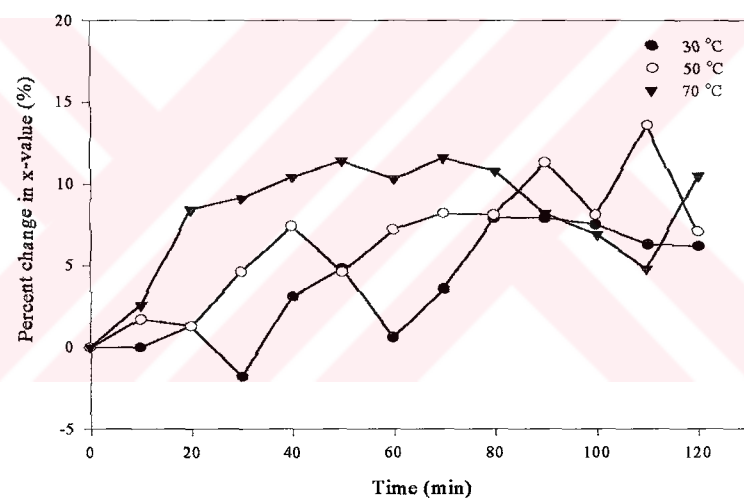


Figure 3.67 Percent change in x-value of the rye kernel during soaking at pH 9

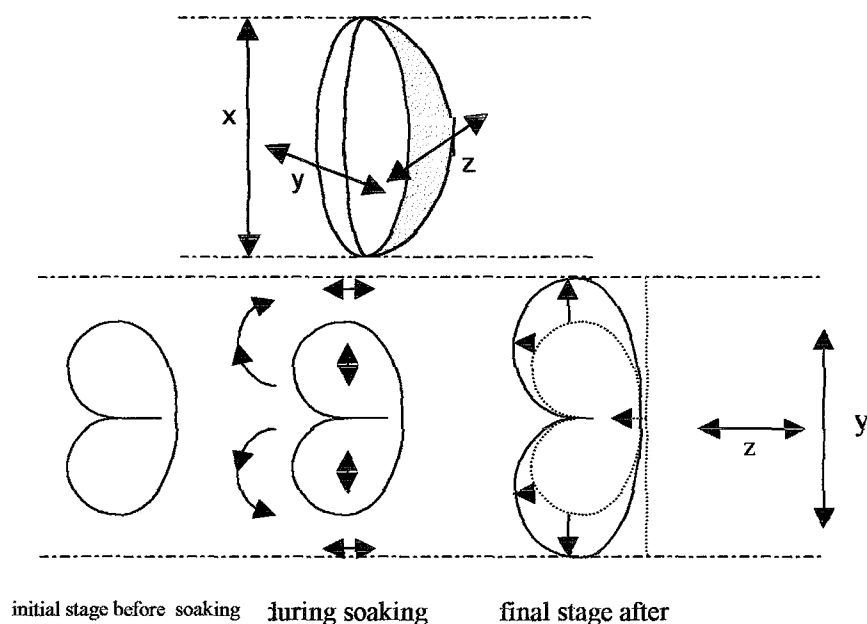


Figure 3.68 Change of dimensions of the rye kernel during soaking

The percent changes in crease side of the rye kernel (y-value) were illustrated in Figures 3.69-71. The y-value of the rye kernel affected significantly ($P < 0.05$) from soaking time and temperature due to swelling. During the soaking, increase in the y-value of the rye kernel at each soaking pH and temperature was expected. The change in y-value of the rye kernel at pH 7 was greater ($P < 0.05$) than other pH's.

The y-value is also important side due to the crease of the kernel (Figure 3.68). Swelling of the kernel during soaking might cause separation of crease of the kernel. Crease side of rye is the major dimension to control the soaking operation in order to prevent the deformation of the rye kernel. Crease is known as the guard structure for the kernel against the external force. If the crease side (y-value) is expanded largely (because crease side is the weakest dimensional side), the length of the rye might decrease also and kernel can be disrupted.

At the end of the soaking operation, percent change in y-value were in the range of 30-40, 10-20 and 5-10% at 87, 92 and 97°C, respectively. These results indicated that, the change in y-value ranges of the rye kernel was greater than that of the soybean kernel. During the soaking, the y-value of the rye kernel increased ($P < 0.05$)

steadily without significant fluctuation in contrast to the soybean kernel (Figures 3.4-3.6). It may be due to the effect of the crease in the rye kernel.

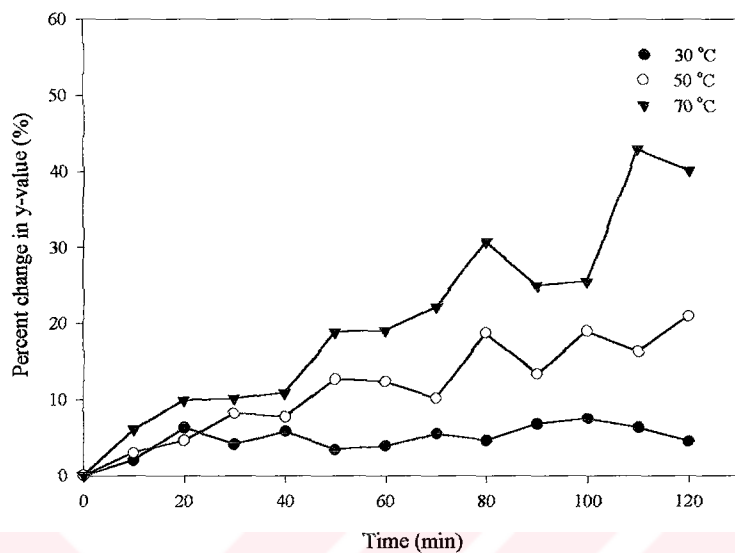


Figure 3.69 Percent change in y-value of the rye kernel during soaking at pH 5

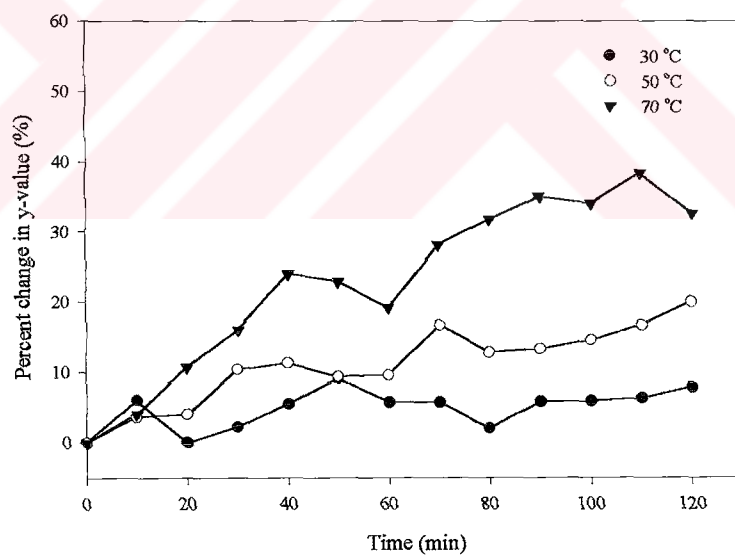


Figure 3.70 Percent change in y-value of the rye kernel during soaking at pH 7

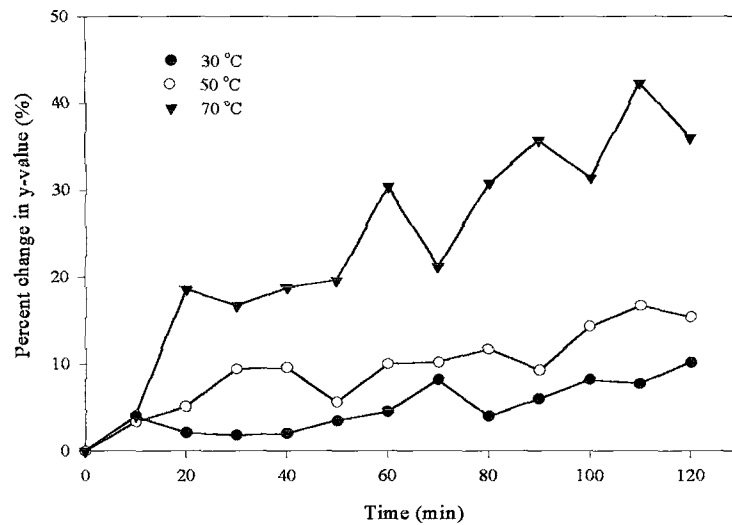


Figure 3.71 Percent change in y-value of the rye kernel during soaking at pH 9

During the soaking, secondary width i.e. cross side of crease of the rye kernel (z-value) increased significantly ($P < 0.05$) when increasing soaking temperature at each soaking pH (Figures 3.72-3.74). The pH had no significant effect ($P > 0.05$) on z-value. At the end of soaking, the z-value increased to a range of 30-40, 10-20 and 5-10% at 87, 92 and 97°C at each soaking pH, respectively. It had greater percent change value than soybean. Also, fluctuation of the z-value of the rye kernel during the soaking was very low when compared with soybean.

The final z-values of the rye kernel at the end of soaking were similar with the y-value. It was found that the percent changes of y and z-values for rye were greater than x-value in contrast to values of soybean.

As a result, adjustment of soaking water pH had no significant effect ($P > 0.05$) on the dimensions (x, y and z-values) of rye like soybean. However, dimensions of rye and soybean were significantly ($P < 0.05$) affected from soaking time and temperature. All of the dimensions of the rye kernel during soaking increased ($P < 0.05$) with increase in soaking temperature due to swelling. The level of swelling during the soaking operation is also important for subsequent operations (cooking, milling etc.) to hold the kernel together. Especially, the change in y-value is critical to prevent the separation of the kernel from crease into two parts similar with wheat (Bayram *et al.* 1998).

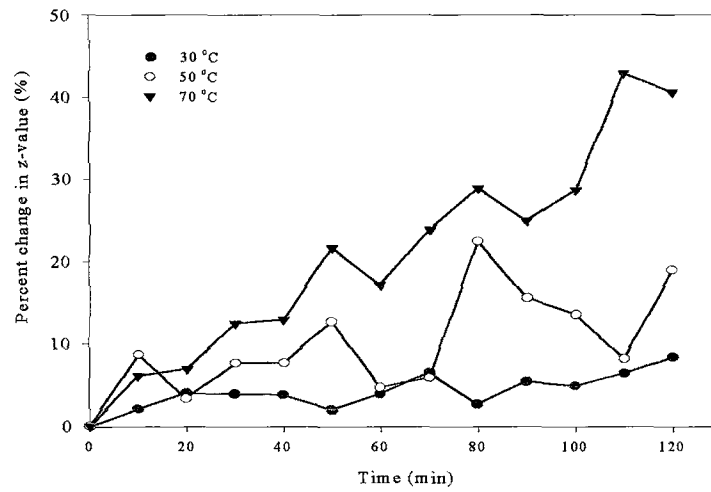


Figure 3.72 Percent change in z-value of the rye kernel during soaking at pH 5

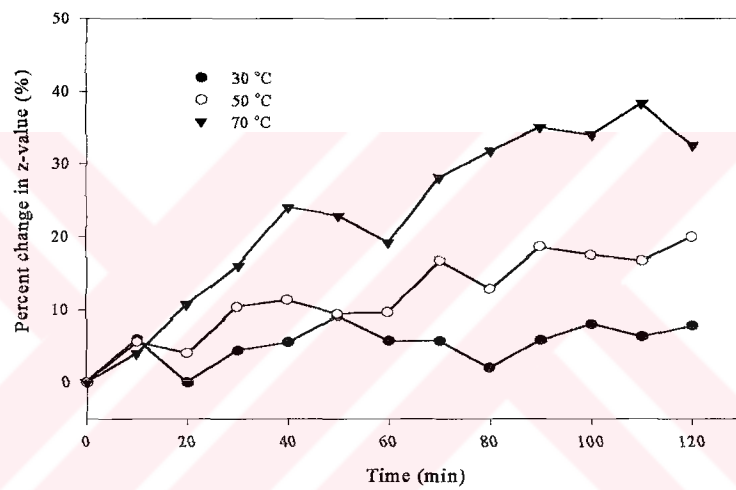


Figure 3.73 Percent change in z-value of the rye kernel during soaking at pH 7

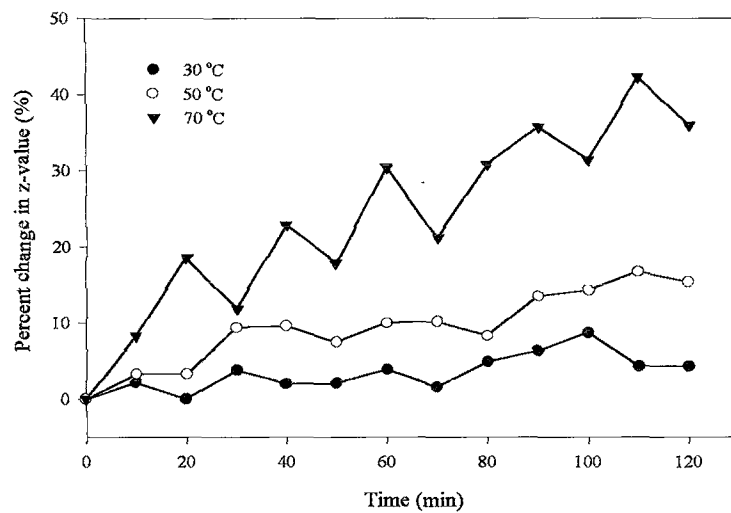


Figure 3.74 Percent change in z-value of the rye kernel during soaking at pH 9

b. Changes in weight, volume and density of the rye kernel

Change in weight of the rye kernel is related with water absorption during soaking. At each pH, during the soaking, weight of the rye kernel increased at 30, 50 and 70°C (Figures 3.75-3.77). Soaking time and temperature had significant ($P<0.05$) effect on the weight of the rye kernel in contrast to soaking pH ($P>0.05$). During the soaking, weight of the rye kernel increased with increasing soaking temperature. Greater change was observed at 70°C at each of pH 5, 7 and 9.

Volume of the rye kernel is related with the three dimensions of the kernel that simulated as an ellipsoidal. At pH 5, change in volume increased relatively at 30, 50 and 70°C and reached to 30, 60 and 120%, respectively (Figure 3.78).

The effect of the pH during soaking on the volume change was not significantly important ($P>0.05$) in contrast to soaking temperature and time ($P<0.05$). Therefore, the percent change in volume was nearly similar at each soaking pH with each other (Figure 3.78-3.80). The similar trend was observed in change of volume with the change of weight that respect to soaking time, pH and temperature.

The percent change of density during soaking depends on the changes of weight and volume. The rate of volume change was directly related with swelling and the change in dimensions of the rye kernel. The rate of change in weight is related with water absorption. Therefore, the change of density can also be used to determine the differences between their weight and volume rates.

The percent change of density slightly decreased during soaking at 70°C at each pH ($P<0.05$, Figures 3.81-3.83) and negative values were observed for the percent change of density due to significant increase in volume, however extent of decrease ($P<0.05$) were lower at 30 and 50°C. It can be due to disruption effect of the high soaking temperature i.e. 70°C on cells of rye. In turn, injured cells swelled excessively that caused the increase in volume of the rye kernel. It was found that the change of density at 30°C had positive low values, but it had both positive and negative values at 50°C. As a result, temperature could decrease the resistance of the kernel firmness, and then the rye kernel swells easily.

Negative values in the changes of soybean density were observed at each soaking temperature in contrast to rye. This difference can be explained by the differences between the textural properties of rye ($F_{\max}=26.971$ N) and soybean ($F_{\max}=18.306$ N). It can be concluded that swelling of rye was more difficult than that of soybean due to its tougher textural properties.

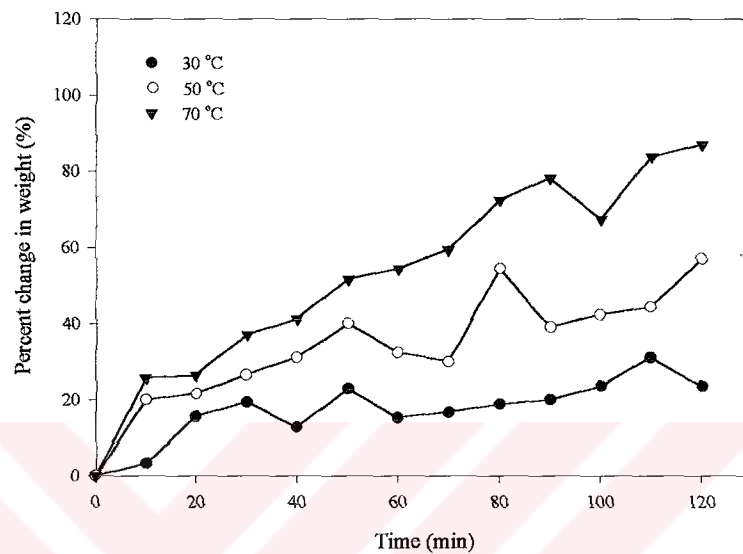


Figure 3.75 Percent change in weight of the rye kernel during soaking at pH 5

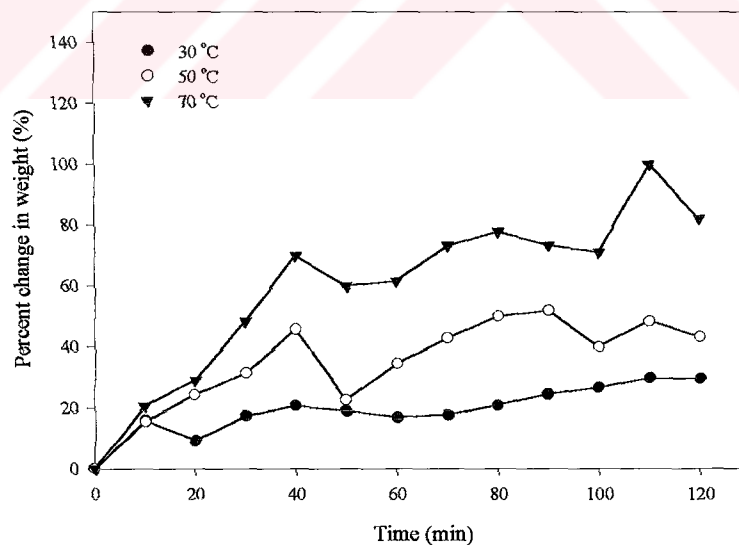


Figure 3.76 Percent change in weight of the rye kernel during soaking at pH 7

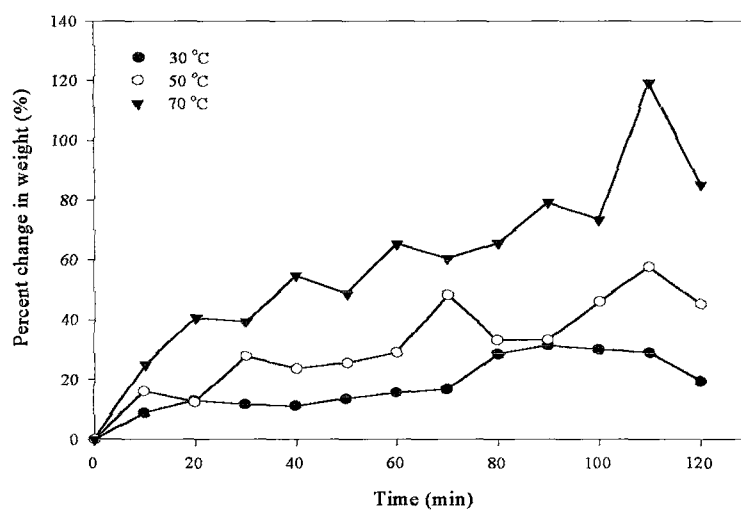


Figure 3.77 Percent change in weight of the rye kernel during soaking at pH 9

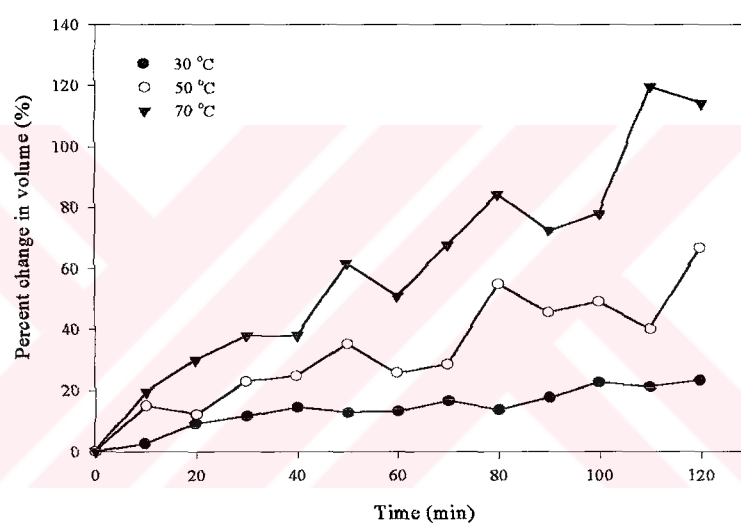


Figure 3.78 Percent change in volume of the rye kernel during soaking at pH 5

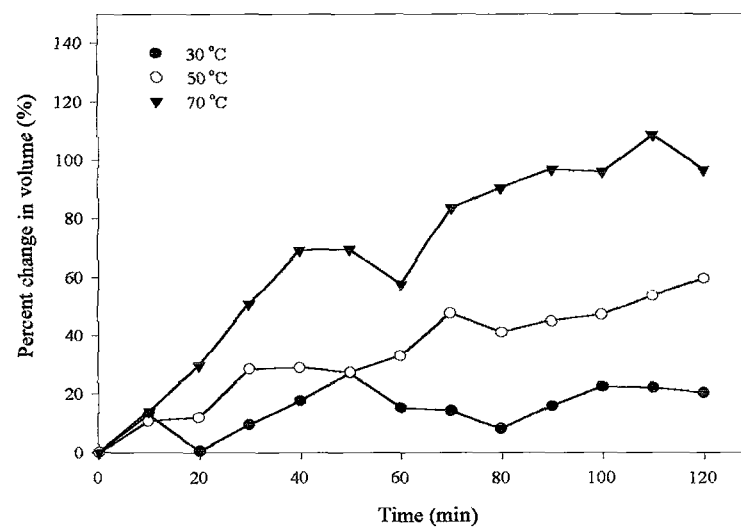


Figure 3.79 Percent change in volume of the rye kernel during soaking at pH 7

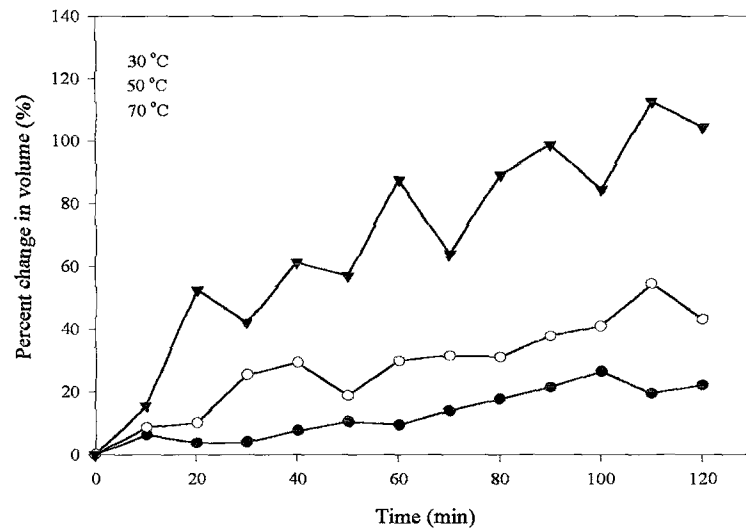


Figure 3.80 Percent change in volume of the rye kernel during soaking at pH 9

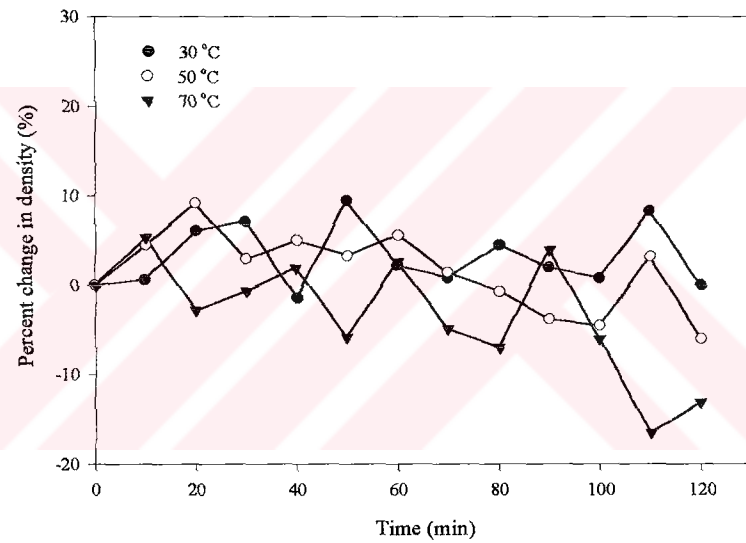


Figure 3.81 Percent change in density of the rye kernel during soaking at pH 5

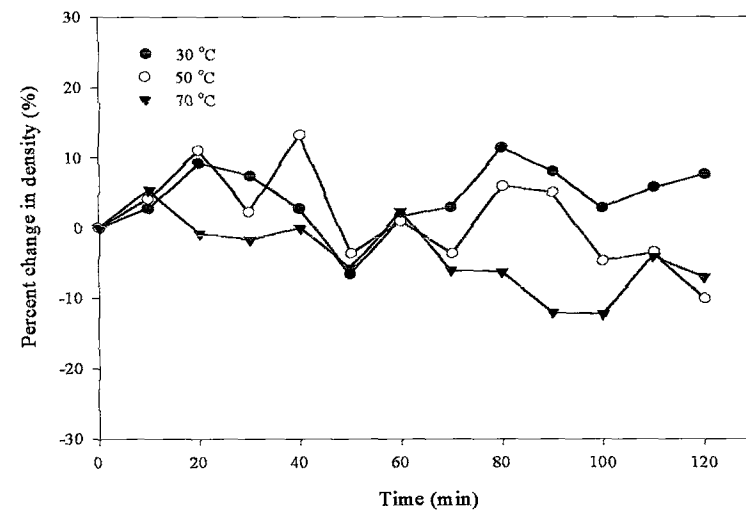


Figure 3.82 Percent change in density of the rye kernel during soaking at pH 7

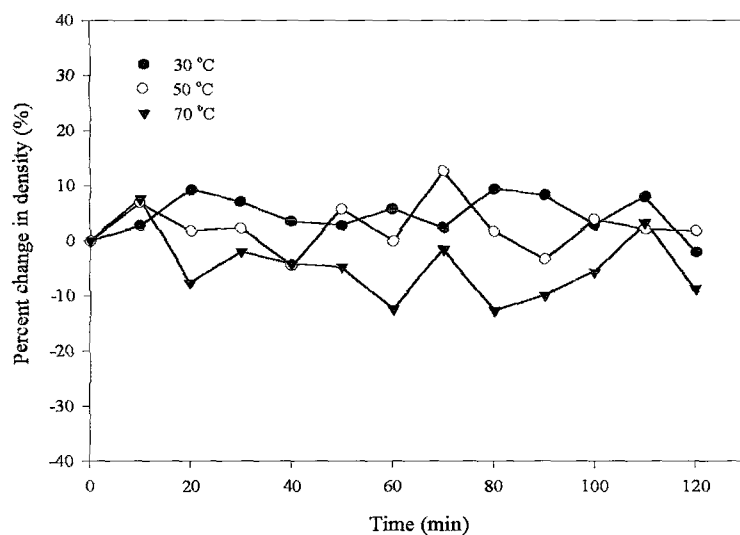


Figure 3.83 Percent change in density of the rye kernel during soaking at pH 9

c. Change in moisture content of rye during soaking

Initial moisture content of rye was measured as 9.9% (w.b.) before the soaking operation. Moisture content measurements during soaking were given in Figures 3.84-3.86. During soaking, moisture content of rye increased significantly ($P < 0.05$) at 30, 50 and 70°C at each of pH 5, 7 and 9. At each pH, moisture did not reached to 40% at the end of the soaking operation at 30°C in contrast to 50 and 70°C (Figures 3.84-3.86) due to the hardness of the rye kernel ($F_{\max} = 26.971$ N). Additional soaking should be made before pressure and microwave cooking operations to have the optimum cooking moisture i.e. 40% at 30°C to obtain parallel study with soybean.

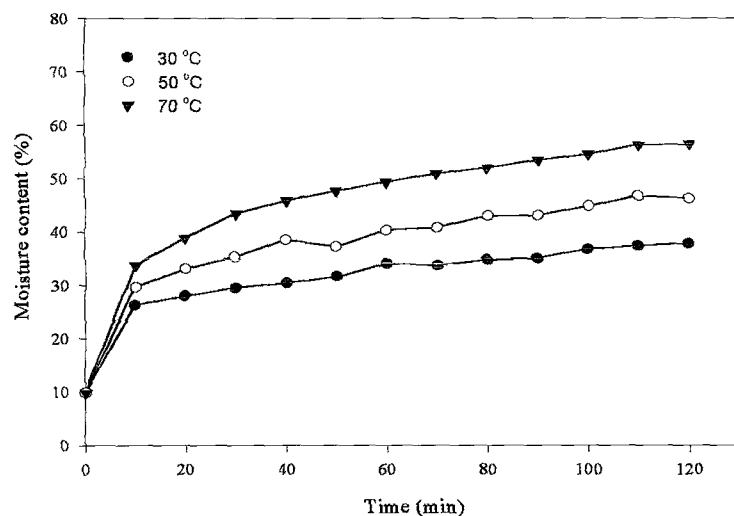


Figure 3.84 Change in moisture content of rye during soaking at pH 5

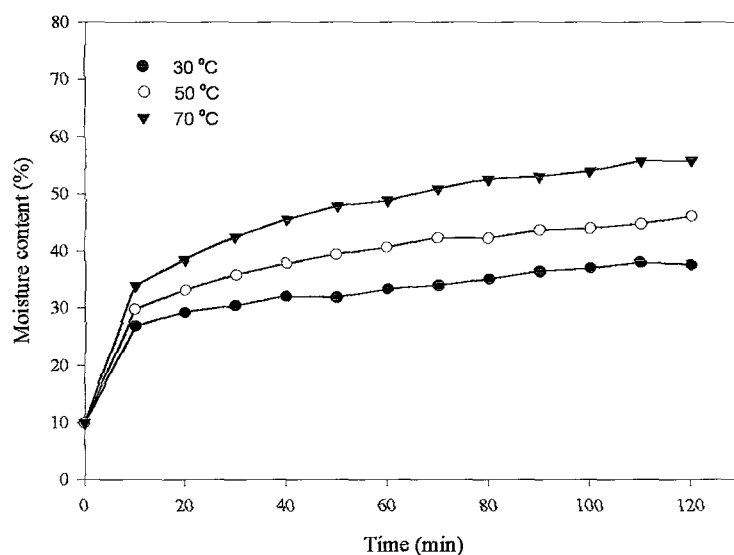


Figure 3.85 Change in moisture content of rye during soaking at pH 7

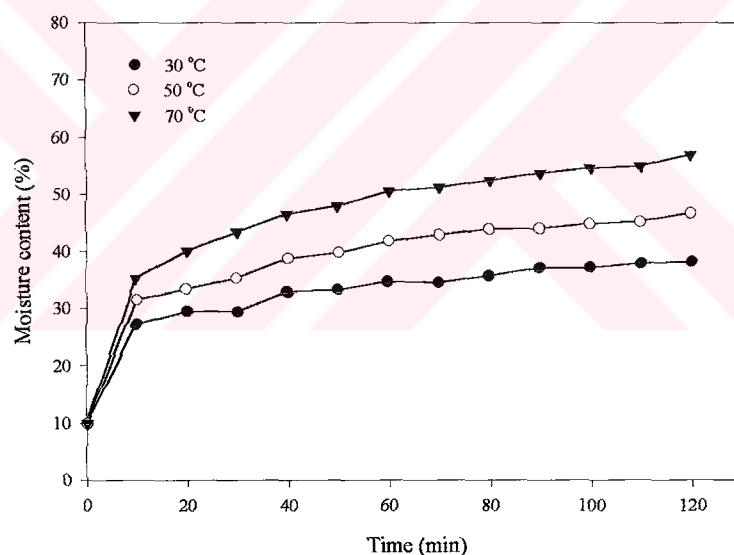


Figure 3.86 Change in moisture content of rye during soaking at pH 9

d. Change in color of rye during soaking

The initial L, a, b and YI values of unprocessed rye were measured as 45.22, 4.70, 12.94 and 59.63, respectively. The obtained L, a, b and YI values during soaking were illustrated in Figures 3.87-3.89, 3.90-3.92, 3.93-3.95 and 3.96-3.98, respectively at various pH values.

The L-value sharply decreased ($P<0.05$) during first 10 minutes at each of soaking conditions, then became nearly constant during the further soaking period due to the effect of the soaking water on color of the rye (Figures 3.87-3.89). During soaking, the L-value decreased significantly ($P<0.05$) with increasing the soaking pH. It was found that, there was no significant ($P>0.05$) effect of the soaking temperature on L-value.

Additionally, during soaking, positive a and b-values were obtained, that illustrate the existence of redness and yellowness (Figure 3.90-3.95). Both a and b-values increased ($P<0.05$) during soaking. But, sharp increase ($P<0.05$) was determined for first 10 minutes that similar with L-value. The soaking pH had no significant effect ($P>0.05$) on the a-value in contrast to b-value. But, soaking time and temperature had significant ($P<0.05$) effect on the a and b-values.

In contrast to decrease in a-value of soybean (Figure 3.25-3.27) during soaking, the a-value of rye increased (Figures 3.90-3.92). The difference between a-values of rye and soybean could be explained by difference in bran properties. The bran of soybean is tough and opaque; in contrast to rye bran which is thin and transparent. Since, measured color of rye during soaking could be affected from color of the layers that under transparent bran of rye i.e. aleurone and endosperm layers.

Similar trends were observed for YI-values of soybean and rye as their a-values (Figure 3.96-3.98). It was found that, the YI-value of rye sharply increased during first 10 minutes of soaking at each of pH 5, 7 and 9, then became nearly constant (Figure 3.96-3.98). Soaking time, temperature and pH had significant effect ($P<0.05$) on the YI-value. Increase in YI value was correlated with decrease in L-value and increase in b-values due to the loss of the clarity and changing of color of the aleurone and endosperm layers for rye.

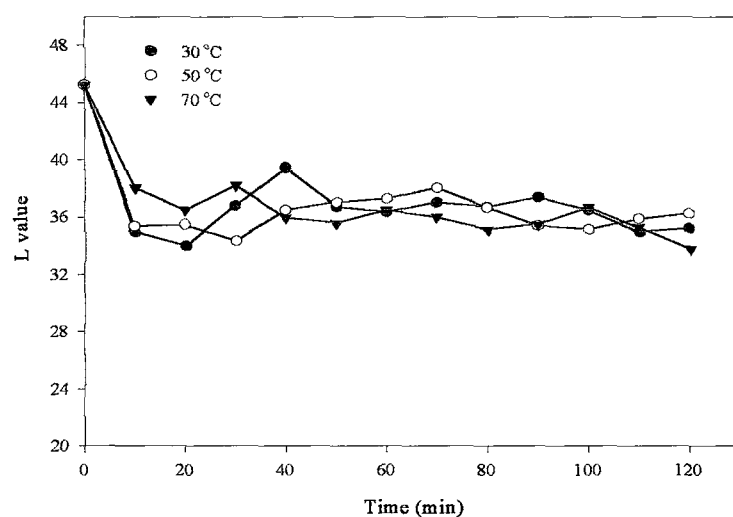


Figure 3.87 Change in L-value of rye during soaking at pH 5

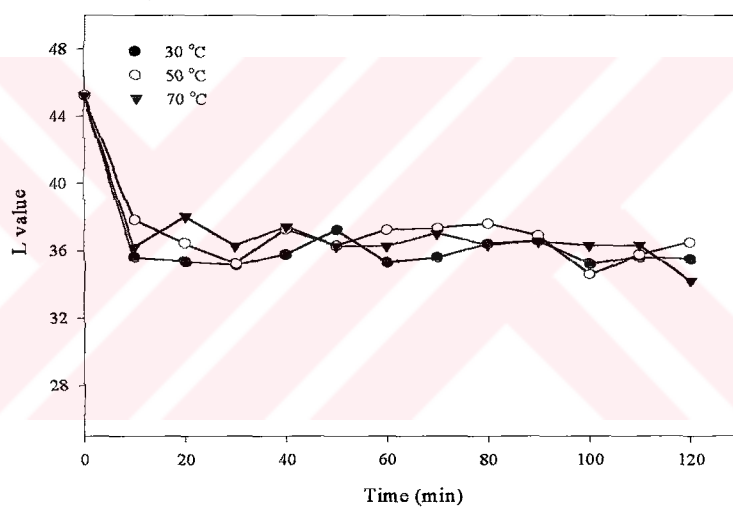


Figure 3.88 Change in L-value of rye during soaking at pH 7

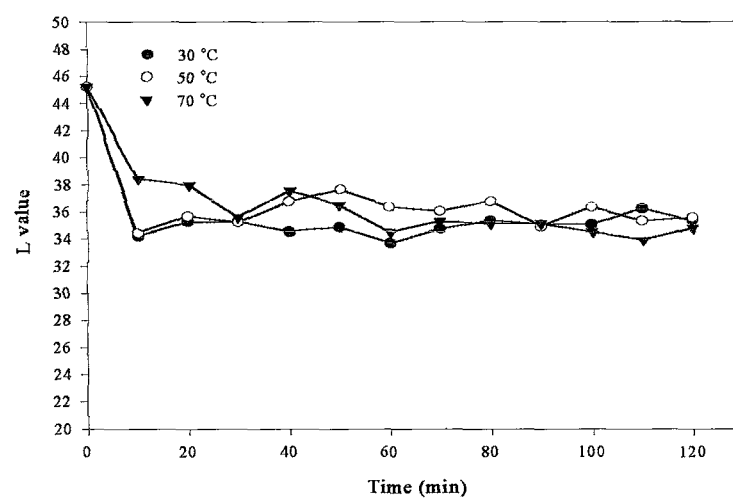


Figure 3.89 Change in L-value of rye during soaking at pH 9

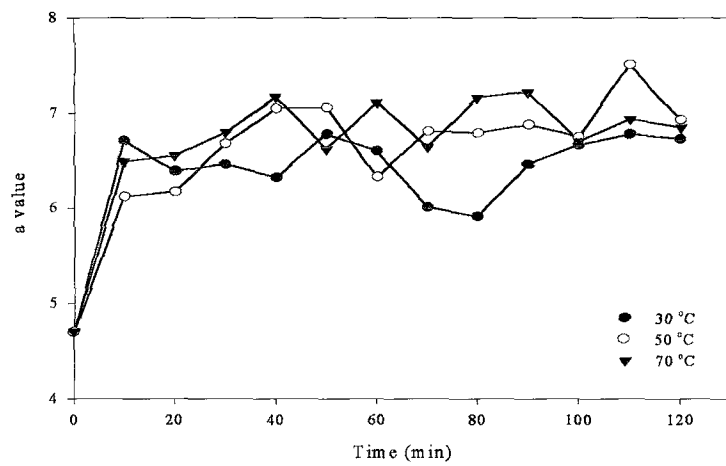


Figure 3.90 Change in a-value of rye during soaking at pH 5

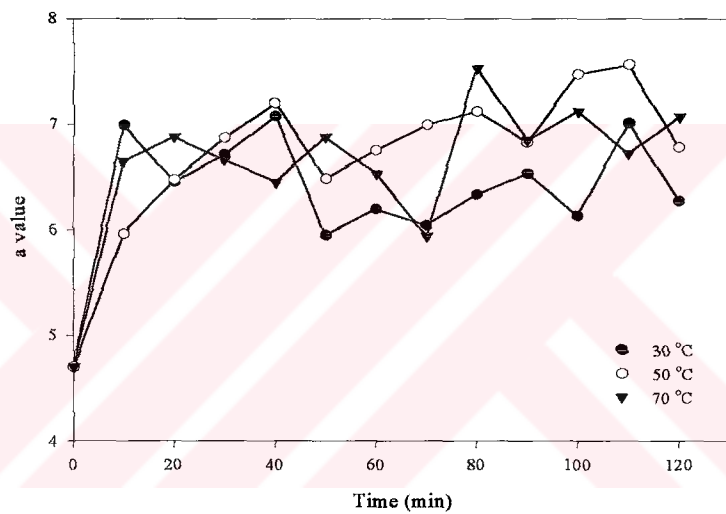


Figure 3.91 Change in a-value of rye during soaking at pH 7

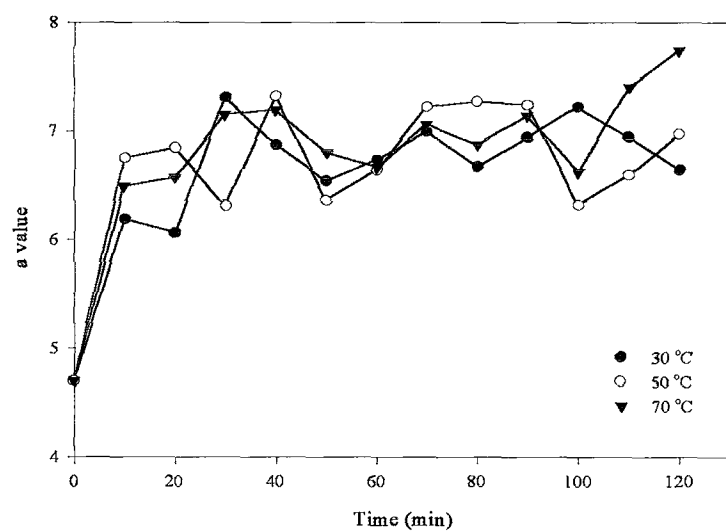


Figure 3.92 Change in a-value of rye during soaking at pH 9

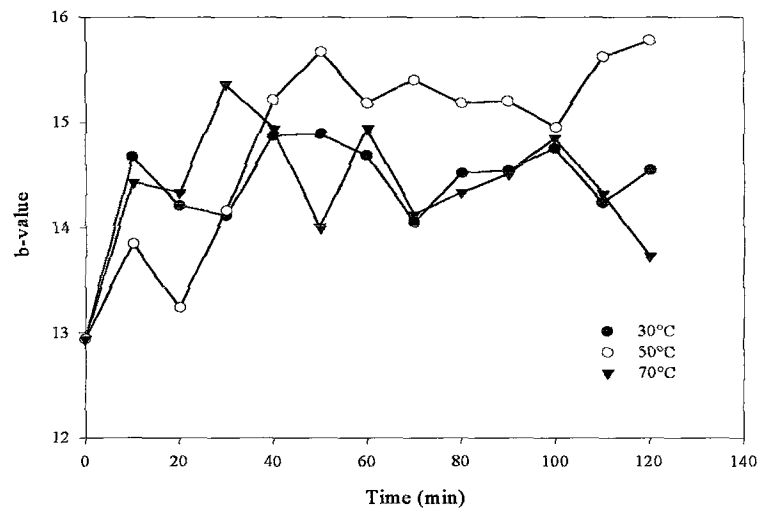


Figure 3.93 Change in b-value of rye during soaking at pH 5

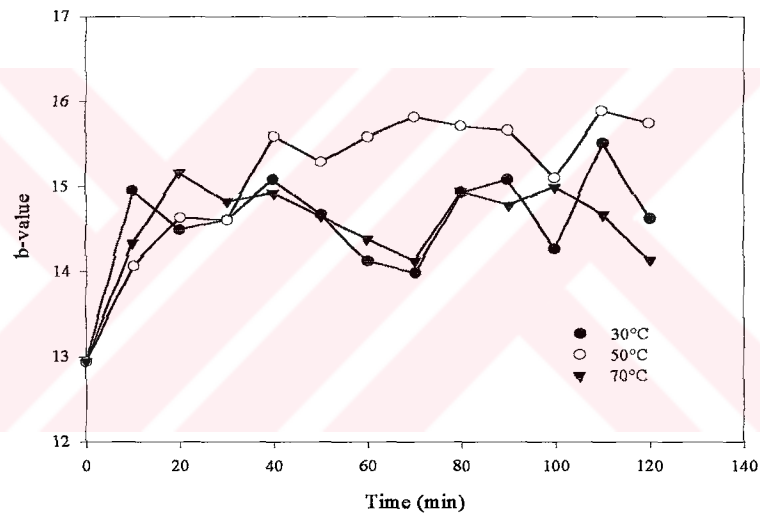


Figure 3.94 Change in b-value of rye during soaking at pH 7

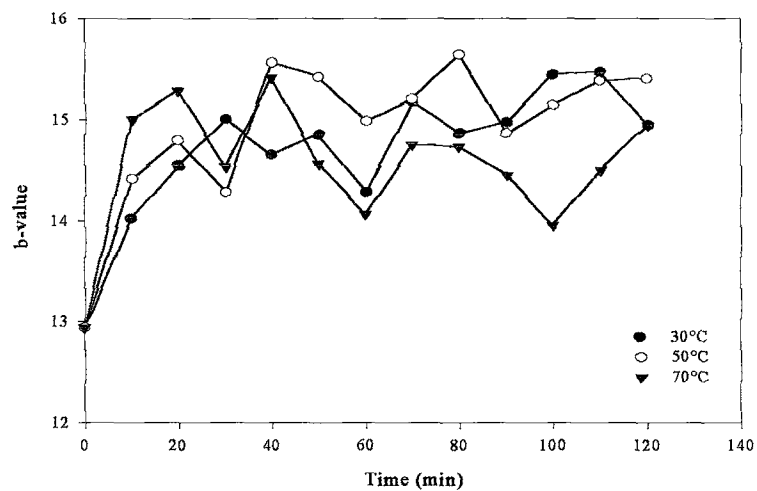


Figure 3.95 Change in b-value of rye during soaking at pH 9

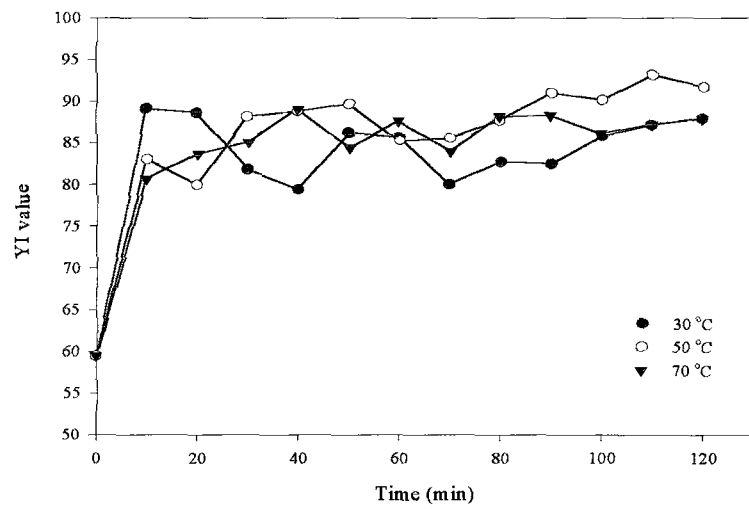


Figure 3.96 Change in YI-value of rye during soaking at pH 5

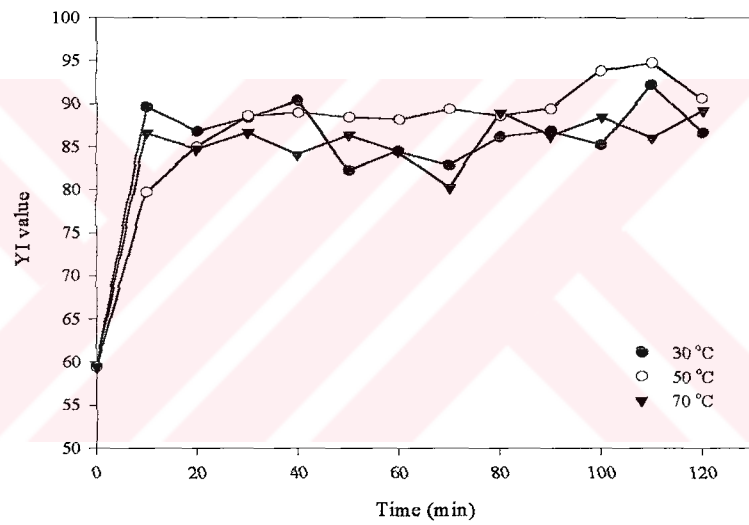


Figure 3.97 Change in YI-value of rye during soaking at pH 7

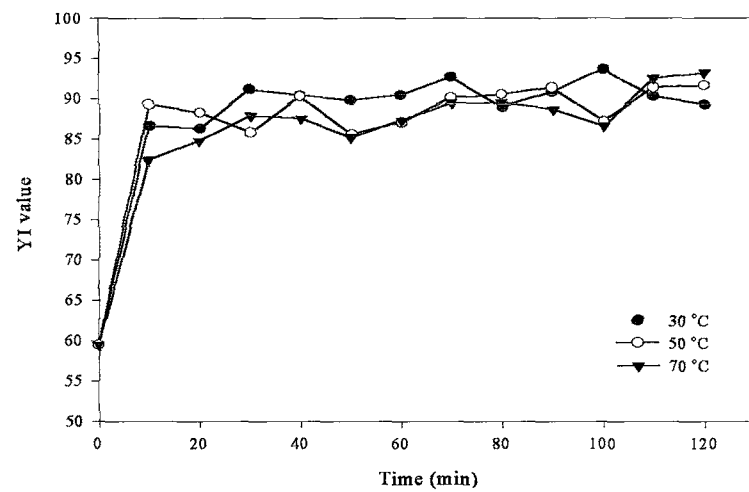


Figure 3.98 Change in YI-value of rye during soaking at pH 9

e. Change in texture of rye during soaking

Initial $F_{\max}$ and A_p values of the unprocessed rye kernel were measured as 26.971 N and 17.61 N.s, respectively. $F_{\max}$ and A_p values during soaking were given in Figures 3.99-3.101 and 3.102-3.104, respectively. Soaking time and temperature had significant ($P<0.05$) effect on the $F_{\max}$ in contrast to pH ($P>0.05$). But, they had significant ($P<0.05$) effect on the A_p . As expected, both textural values decreased with increasing temperature during soaking.

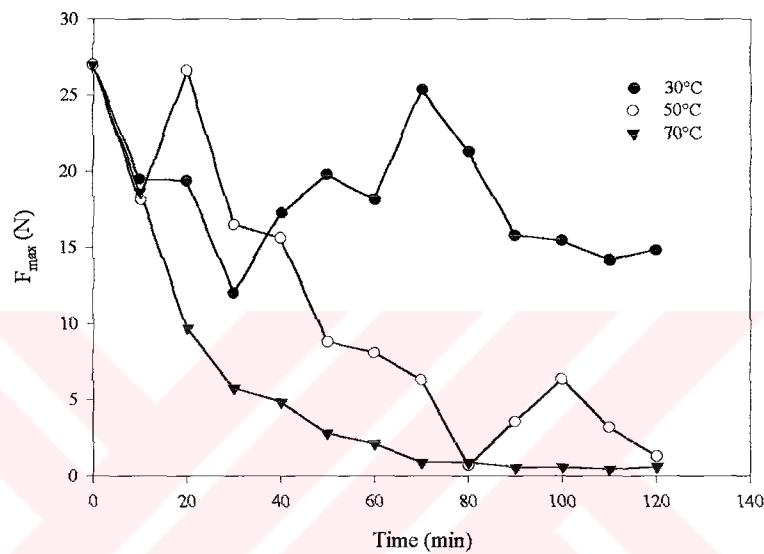


Figure 3.99 Change in $F_{\max}$ of rye during soaking at pH 5

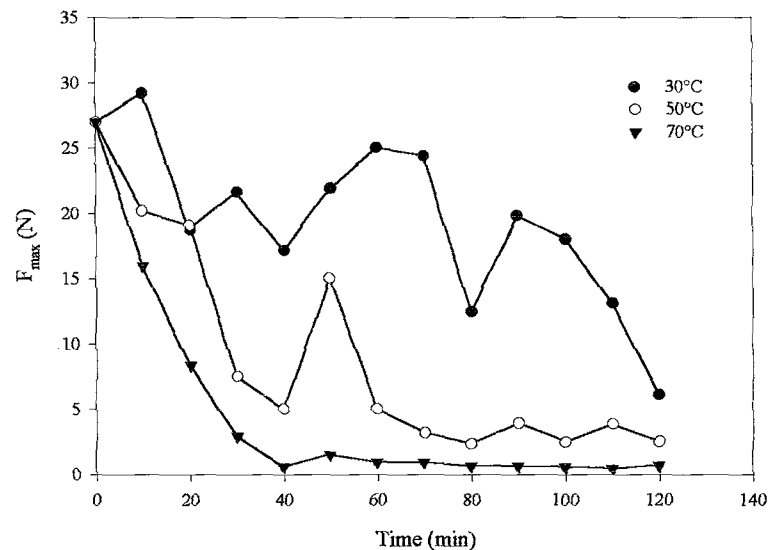


Figure 3.100 Change in $F_{\max}$ of rye during soaking at pH 7

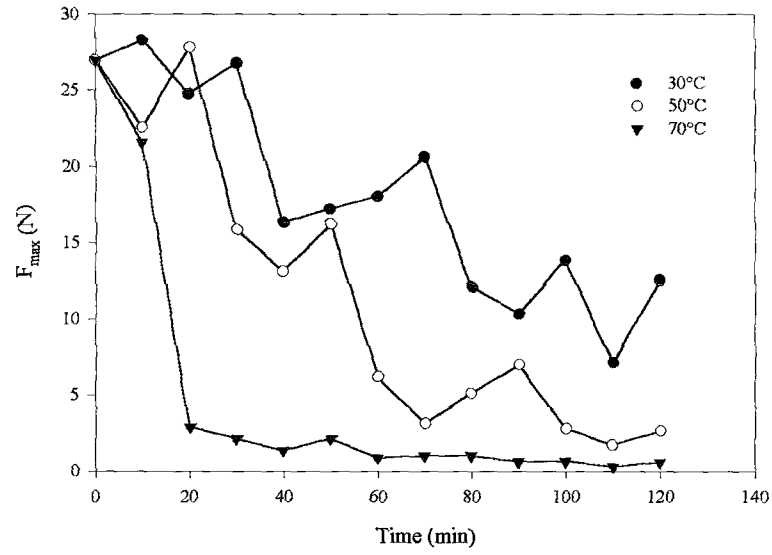


Figure 3.101 Change in $F_{\max}$ of rye during soaking at pH 9

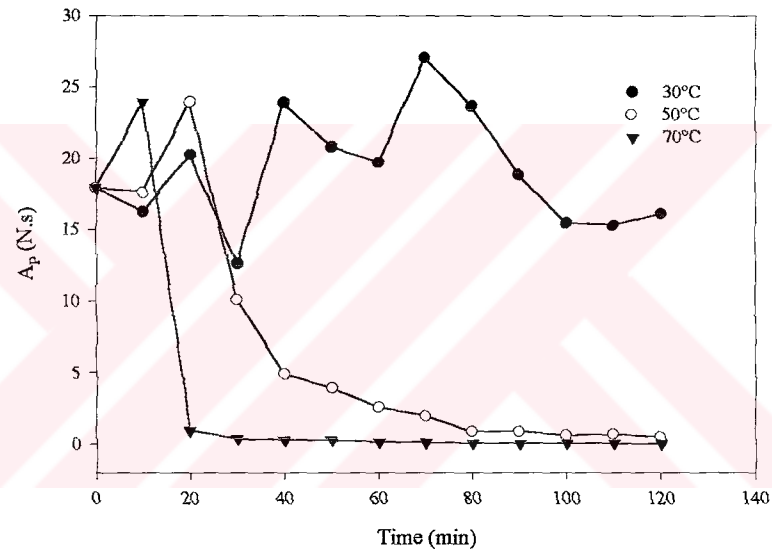


Figure 3.102 Change in A_p of rye during soaking at pH 5

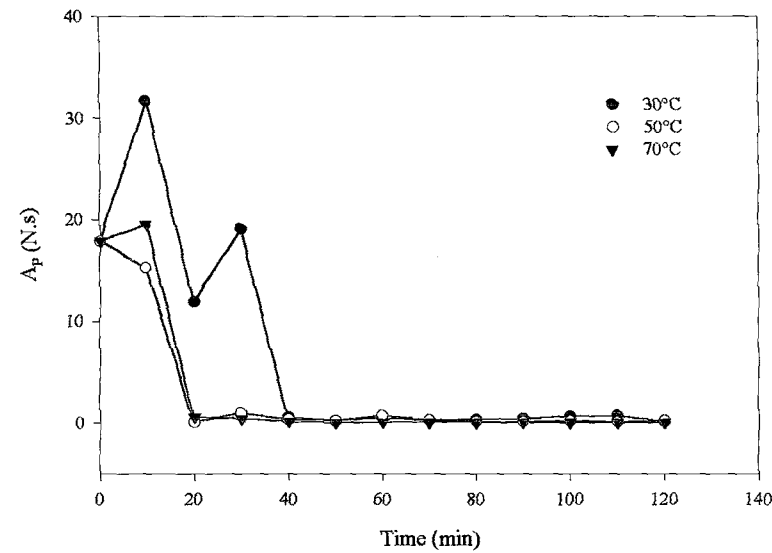


Figure 3.103 Change in A_p of rye during soaking at pH 7

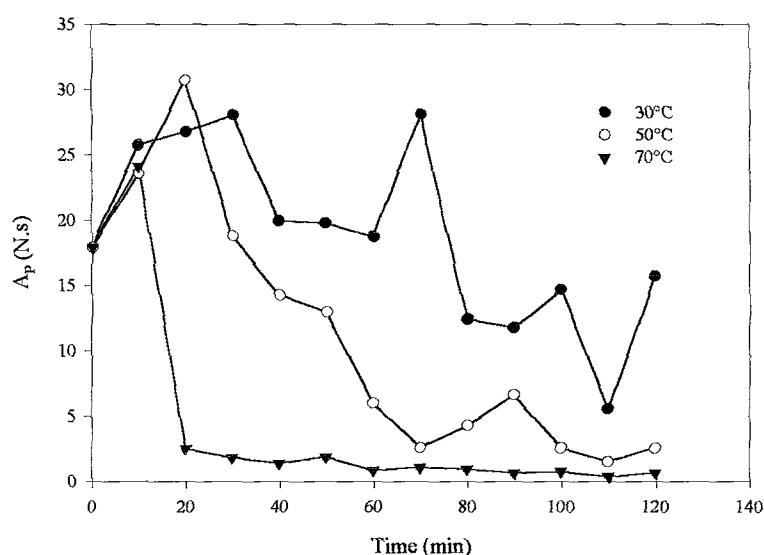


Figure 3.104 Change in A_p of rye during soaking at pH 9

3.1.2.2. Changes in soaking water

a. Change in pH value of soaking water of rye

Initial pH of the unprocessed rye was measured as 6.19. Measured pH values of soaking water during the soaking operation were given in Figures 3.105-3.107 at each of pH 5, 7 and 9. It was determined that soaking time, temperature and pH had significant effect ($P < 0.05$) on pH of the soaking water.

pH of the soaking water increased ($P < 0.05$) sharply to about 6.10 during the first 10 minutes of soaking then became nearly constant to about 5.80 (Figure 3.105). However, at pH 7 and 9, the pH of the soaking water decreased ($P < 0.05$) sharply during first 10 minutes.

Similar trends were observed for pH values of the soaking water of rye and soybean. This could be due to the leaching of the buffering compounds from rye into water can cause these changes in pH of the soaking water like soaking of soybean.

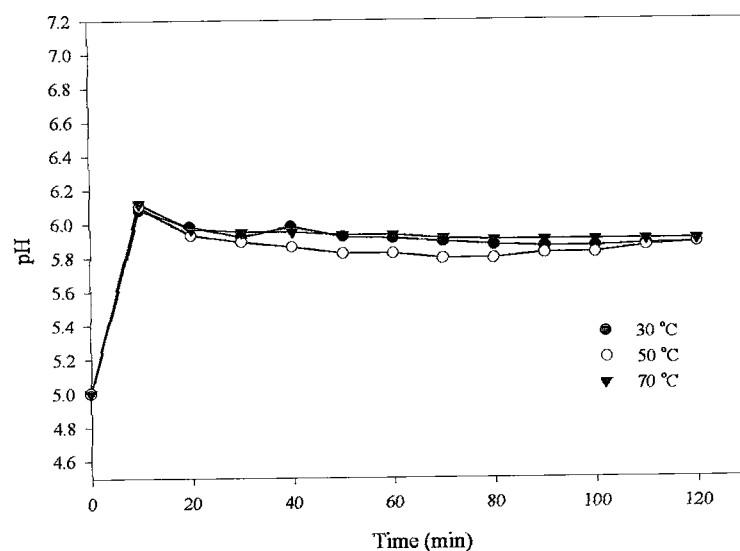


Figure 3.105 Change in pH value of soaking water during soaking of rye at pH 5

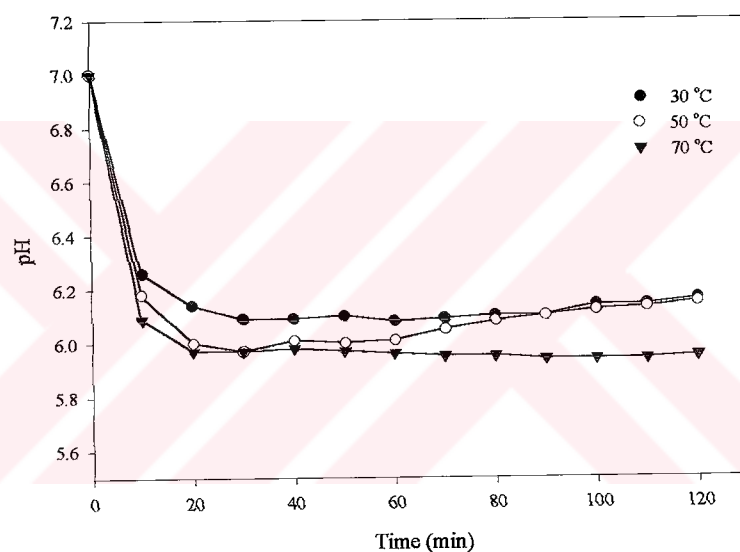


Figure 3.106 Change in pH value of soaking water during soaking of rye at pH 7

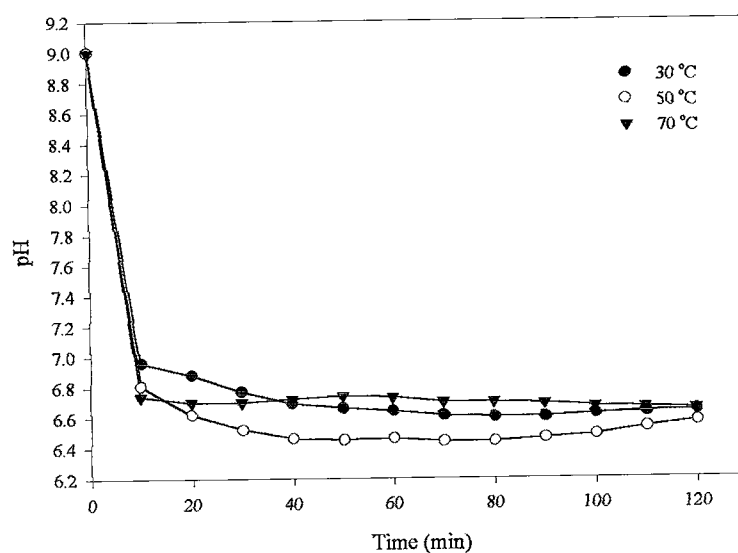


Figure 3.107 Change in pH value of soaking water during soaking of rye at pH 9

b. Change in conductivity of soaking water of rye

The initial conductivity values of soaking water were 28.1, 6.5 and 43.3 μS at pH 5, 7 and 9, respectively. During soaking, conductivity of the soaking water increased significantly ($P < 0.05$) with soaking time and temperature at each of pH 5, 7 and 9 (Figure 3.108-3.110). Maximum conductivity was obtained at pH 7 (Figure 3.109). Increase in conductivity of soaking at 70°C was greater than that at 30°C and 50°C as expected. Conductivity at 70°C increased to 680, 900 and 750 μS at pH 5, 7 and 9, respectively. These results indicated that, dissolved inorganic compounds, such as chloride, nitrate, sulphate, phosphate, sodium, magnesium etc. could be easily dissolved in soaking water during soaking of rye at 70°C . Therefore, loosening of minerals increased with increasing soaking temperature. As a result, soaking of rye should be made at low temperatures i.e. 30°C at pH 7 to prevent the loss of high amount of minerals.

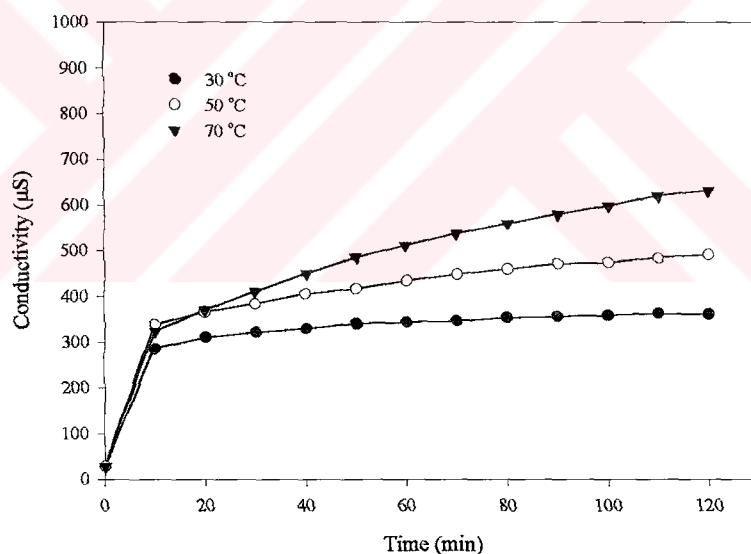


Figure 3.108 Change in conductivity of soaking water during soaking of rye at pH 5

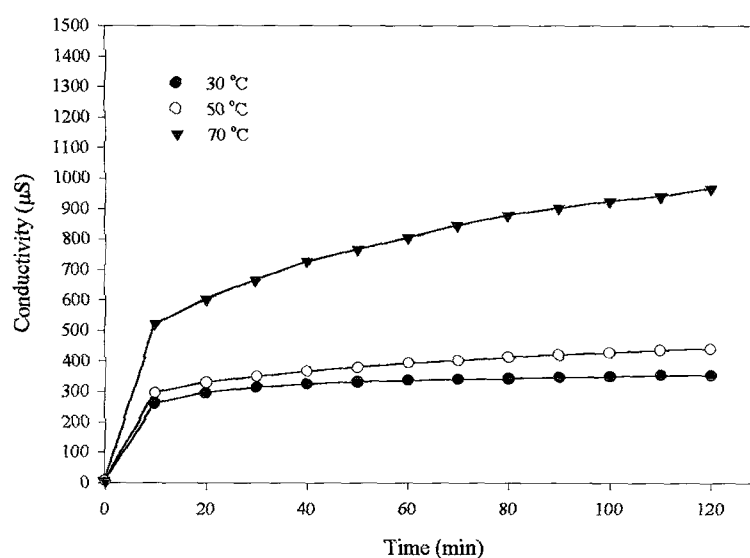


Figure 3.109 Change in conductivity of soaking water during soaking of rye at pH 7

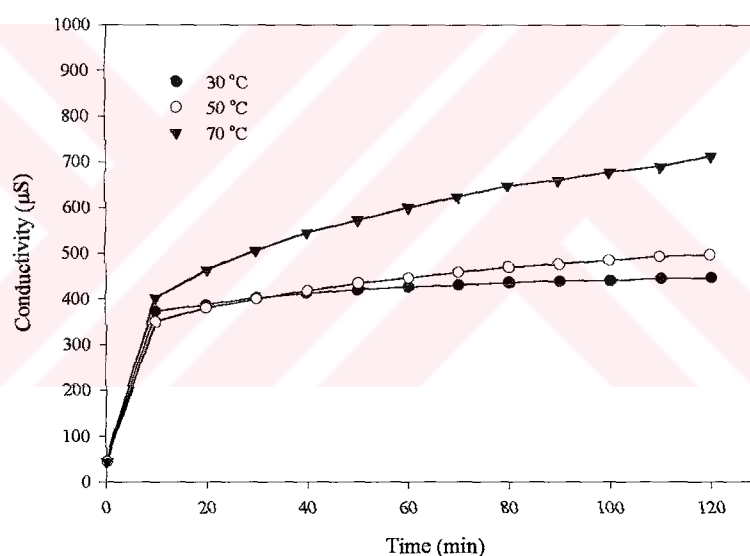


Figure 3.110 Change in conductivity of soaking water during soaking of rye at pH 9

c. Change in turbidity/absorbance of soaking water of rye

The leaching of organic compounds (i.e. turbidity/absorbance) increased gradually ($P < 0.05$) at each of pH 5, 7 and 9 (Figures 3.111-3.113). Soaking time, temperature and pH had significant ($P < 0.05$) effect on the turbidity/absorbance of the soaking water.

Change in absorbance of the soaking water at 500 nm during soaking at pH 5 was given in Figure 3.111. It shows that absorbance at 50°C is higher than that at 30 and

70°C of soaking until nearly 70 minutes. After that time, soaking at 70°C had higher value than others. It can be due to gelation of rye at 70°C in acidic condition until 70 minutes. Then, dispersion of the cells, i.e. softening of rye could be started after the completion of gelation.

It was found that soaking at pH 9 (Figure 3.113), alkaline effect became important on the leaching of organic compounds. Therefore, absorbance values of the soaking water at 70°C had higher value than that at 30 and 50°C after 40 minutes at pH 9. In addition, absorbance at 50°C had lower value than others during overall soaking operation. It can be due to the gelation effect of pH 9, since leaching of organic compounds can be regarded at this pH. Due to synergistic relation between pH and temperature, much higher gelation was observed at soaking in pH 9 water at 50°C. However, soaking at 70°C with pH 9, increased the leaching of organic compounds. This can be explained as softening effect may be higher than gelation effect at this temperature and pH.

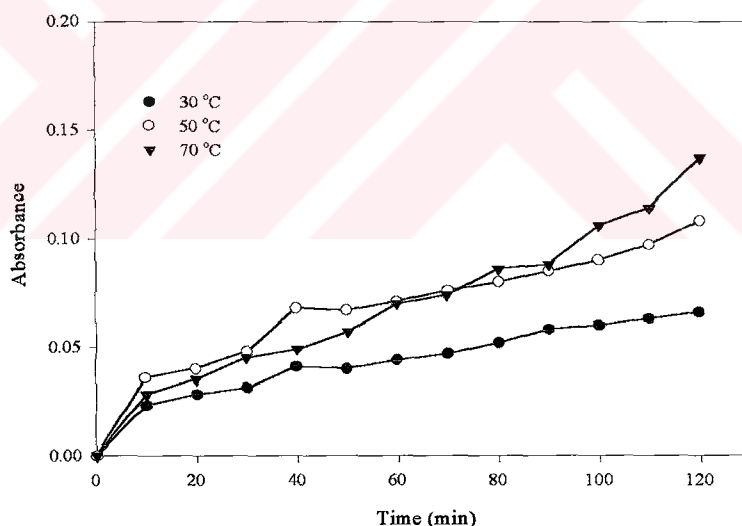


Figure 3.111 Change in absorbance of soaking water during soaking of rye at pH 5

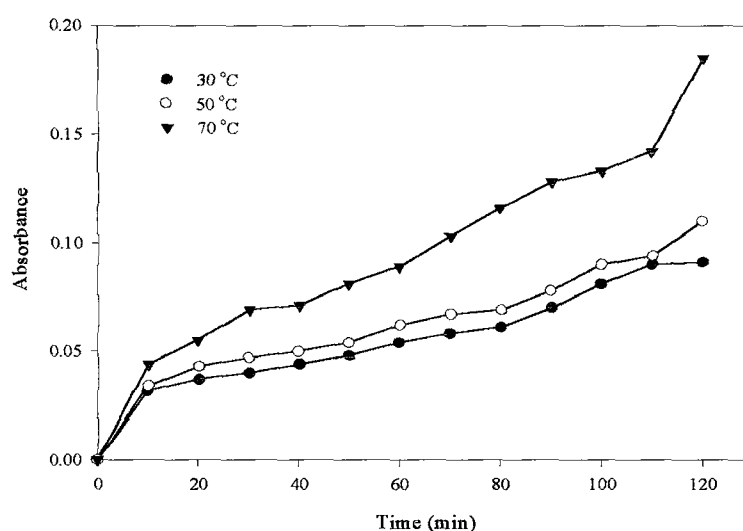


Figure 3.112 Change in absorbance of soaking water during soaking of rye at pH 7

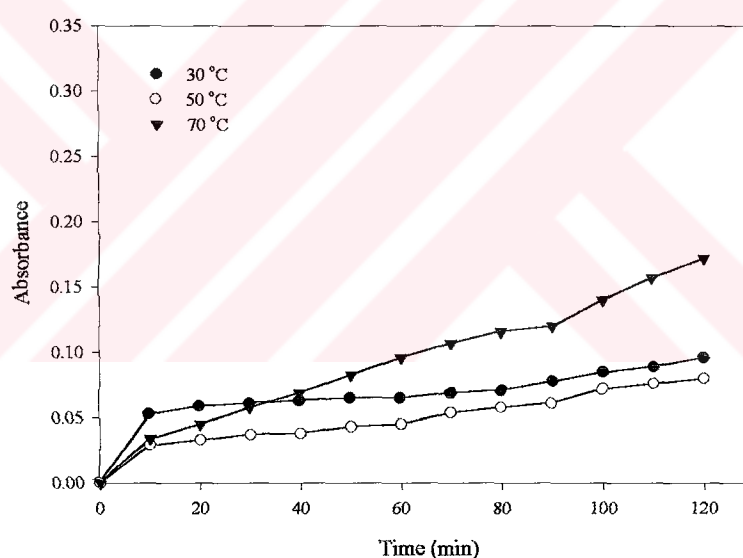


Figure 3.113 Change in absorbance of soaking water during soaking of rye at pH 9

d. Change in soluble solids content of soaking water of rye

Changes in soluble solids content during soaking were given in Figures 3.114-3.116 at 30, 50 and 70°C at each of pH 5, 7 and 9. Soaking time, temperature and pH had significant ($P < 0.05$) effect on soluble solids content. Soluble solids content sharply increased ($P < 0.05$) during first 10 minutes of soaking, then became nearly constant after this point. At pH 5, it increased to nearly 0.1, 0.2 and 0.5% at 30, 50 and 70°C after the first 10 minutes, respectively. When the initial pH of the soaking water was adjusted to 7, soluble solids content increased to 0.2, 0.3 and 0.5% at 30, 50 and

70°C, respectively. Similar results were observed for soluble solids content at pH 9 and pH 7. During the soaking of rye soluble solids content of the soaking water did not significantly ($P>0.05$) change after pH 7. Similar results were obtained for conductivity and absorbance values. Additionally, soluble solids content for soaking of soybean increased steadily during soaking in contrast to that of rye due to its textural properties i.e. $F_{\max}$ of soybean (18.306 N) was higher than rye (26.971 N).

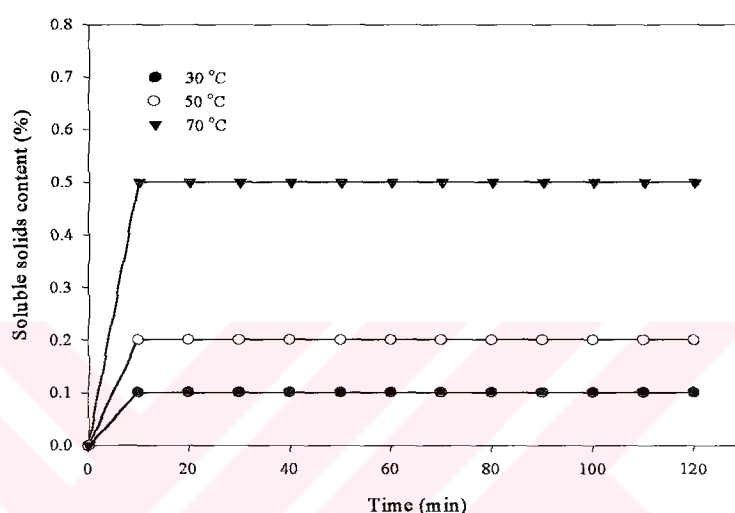


Figure 3.114 Change in soluble solids content of soaking water during soaking of rye at pH 5

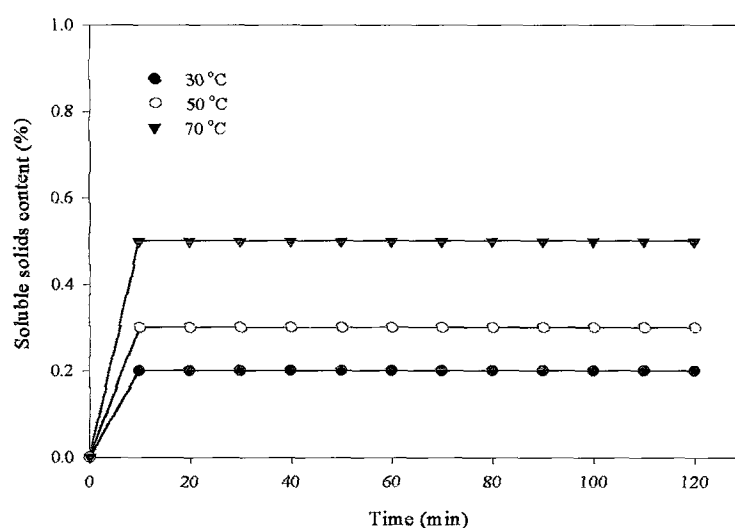


Figure 3.115 Change in soluble solids content of soaking water during soaking of rye at pH 7

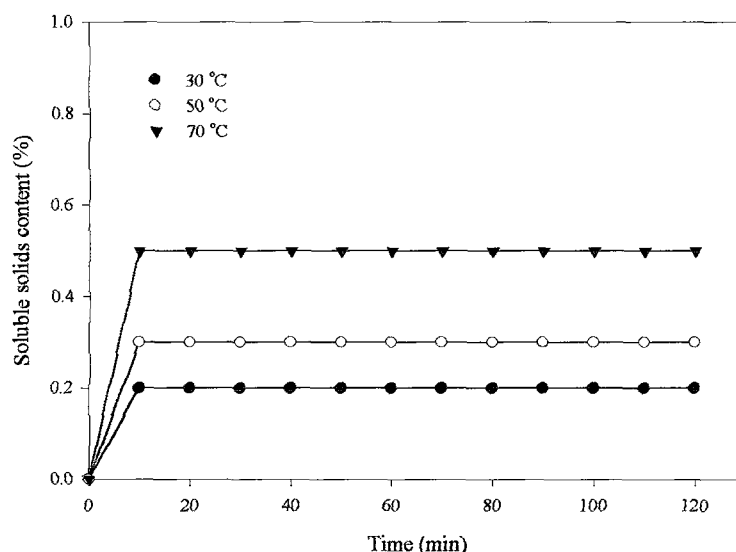


Figure 3.116 Change in soluble solids content of soaking water during soaking of rye at pH 9

e. Change in color of soaking water of rye

During soaking, measurement of color could give an idea about the overall leaching of pigments and coloring substances in water which comes from rye. Therefore, L, a, b and YI-values of the soaking water were measured during the soaking operation (Figures 3.117-3.128). Soaking time, pH and temperature had significant effect ($P < 0.05$) on all color values.

During soaking of rye, lightness of the soaking water (L-value) decreased ($P < 0.05$) at each soaking pH (Figures 3.117-3.119). Also, increasing soaking temperature decreased ($P < 0.05$) the lightness of the soaking water.

Negative a-values were found which means that greenness existed in the soaking water during soaking (Figures 3.120-3.122) in contrast to existing of redness in rye. During soaking, the degree of greenness of the soaking water increased ($P < 0.05$) initially then decreased steadily. Increase in greenness in the soaking water could be explained by the leaching of pigments, vitamins etc. Also, decrease of greenness after a certain time during soaking might be due to mixing of other coloring material and decomposition of green pigments. Greenness reached to maximum value at 50°C. At low temperature (30°C), greenness had low value due to low leaching. At

high temperature (70°C), degree of greenness decreased due to degradation effect of temperature on green pigments.

Multiple range test showed that when the initial pH of the soaking water was increased from 5 to 9, greenness in the soaking water negatively decreased ($P<0.05$). Namely, at acidic condition, greenness increased. Oppositely, yellowness (b-value) increased ($P<0.05$) with increase of pH (Figures 3.123-3.125). Increasing temperature caused increase in yellowness of the soaking water due to the leaching of yellow coloring pigments. During soaking, the degree of yellowness in the soaking water increased ($P<0.05$) with soaking time and temperature. The b-values did not change with the changing soaking pH from 5 to 7 at each temperature. But it had maximum value at 70°C when pH of the soaking water was 9. This increase in yellowness could be explained with the leaching of yellow color pigments and coloring compounds at pH 9 due to the softening effect of pH 9 on the structure of rye. Additionally, pH 9 had darkening effect on color due to its alkaline property.

Yellowness index also increased ($P<0.05$) with soaking time and temperature (Figures 3.126-3.128). YI-value of the soaking water increased ($P<0.05$) sharply when the soaking temperature increased from 30 to 50 or 70°C. Yellowness index also had the maximum value at 70°C and pH 9 due to the leaching of yellow coloring compounds because of their softening effects on the structure of rye. This increase in YI-value was opposite to decrease in L-value, as expected (Figure 3.117-3.119) due to leaching of vitamins, organic materials and pigments etc. Similar trend in lightness and YI-values of the soaking water was also obtained in rye during soaking. The L-value decreased gradually in contrast to YI-value.

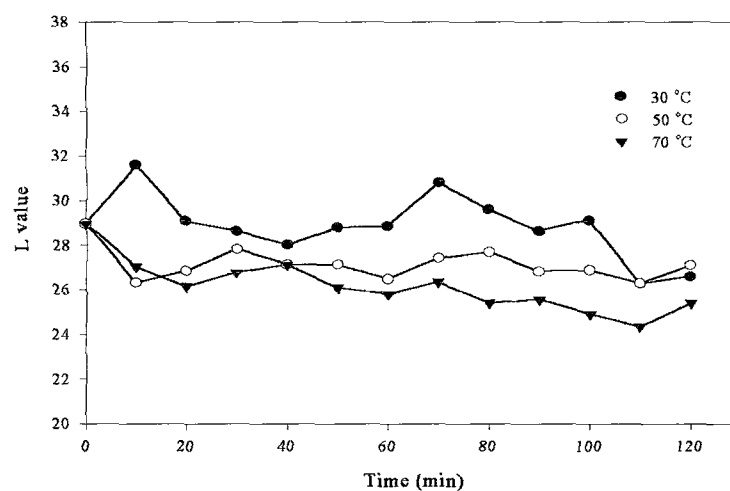


Figure 3.117 Change in L-value of soaking water during soaking of rye at pH 5

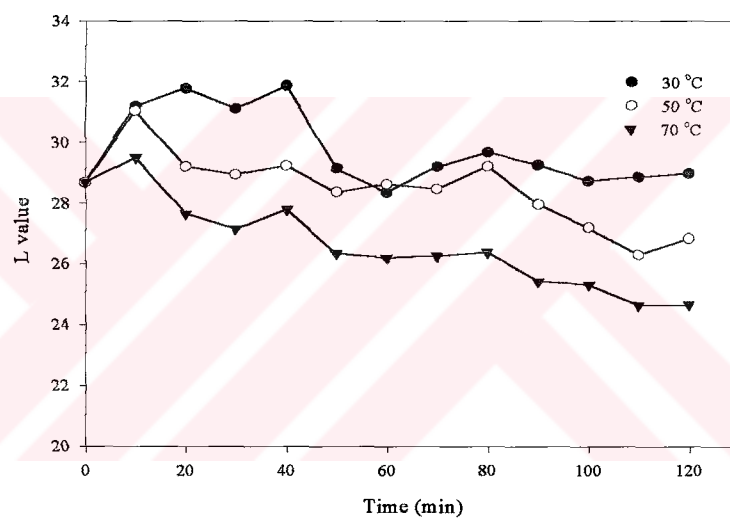


Figure 3.118 Change in L-value of soaking water during soaking of rye at pH 7

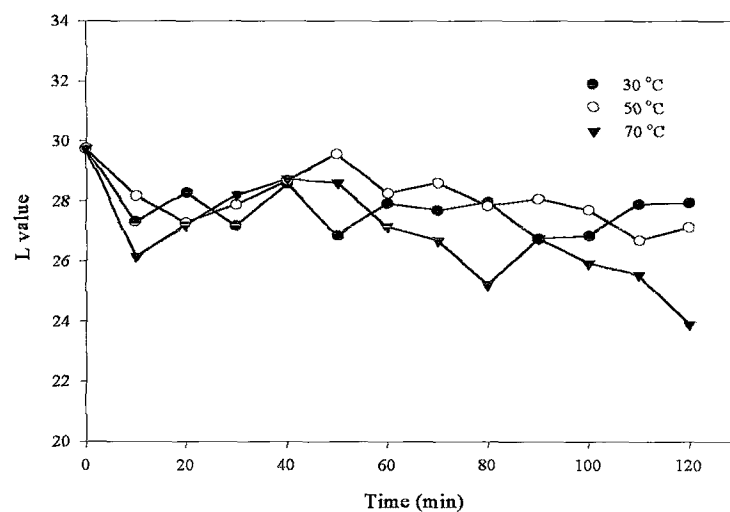


Figure 3.119 Change in L-value of soaking water during soaking of rye at pH 9

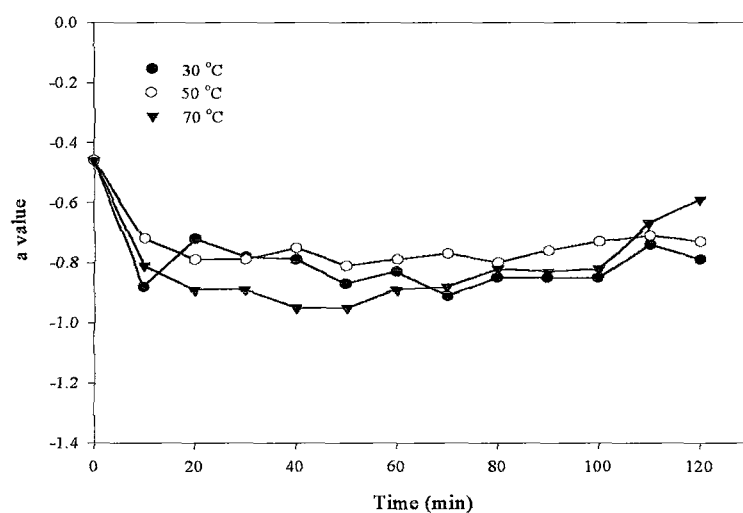


Figure 3.120 Change in a-value of soaking water during soaking of rye at pH 5

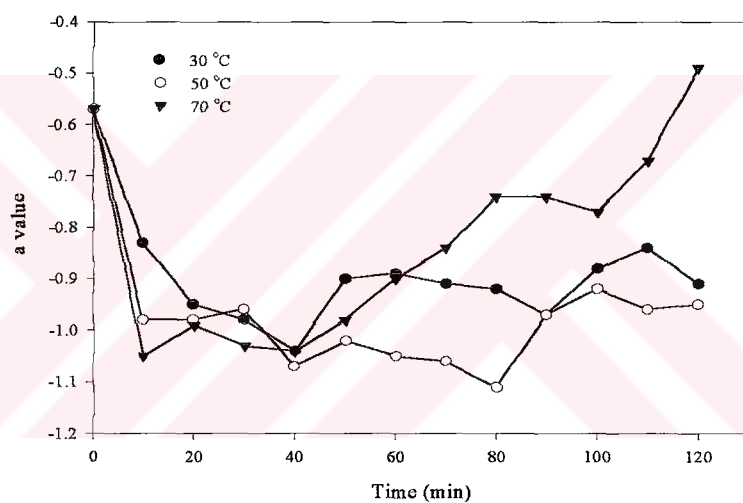


Figure 3.121 Change in a-value of soaking water during soaking of rye at pH 7

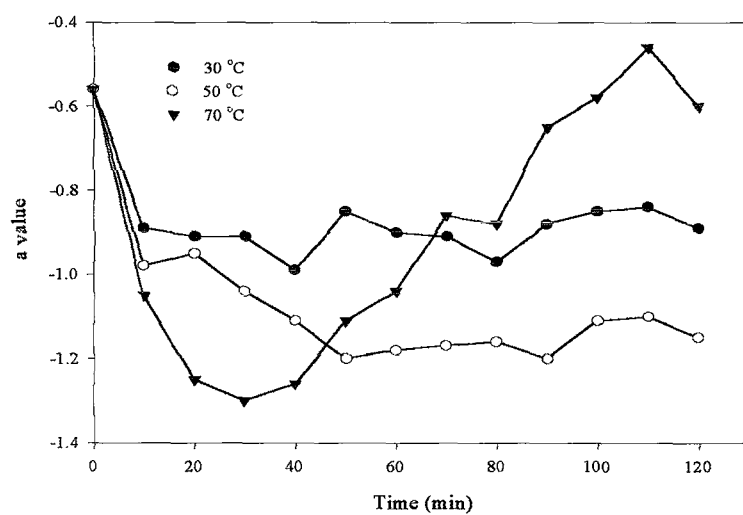


Figure 3.122 Change in a-value of soaking water during soaking of rye at pH 9

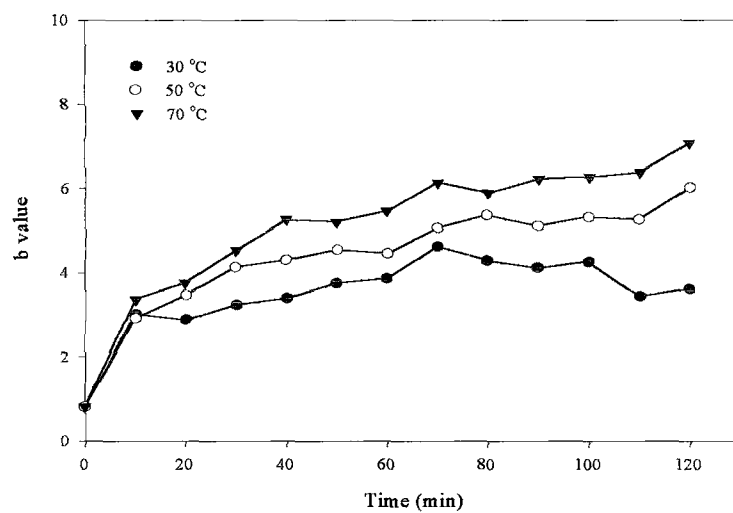


Figure 3.123 Change in b-value of soaking water during soaking of rye at pH 5

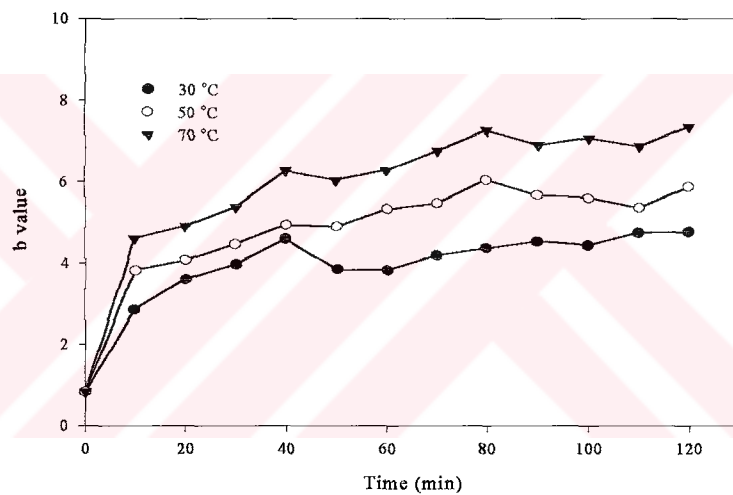


Figure 3.124 Change in b-value of soaking water during soaking of rye at pH 7

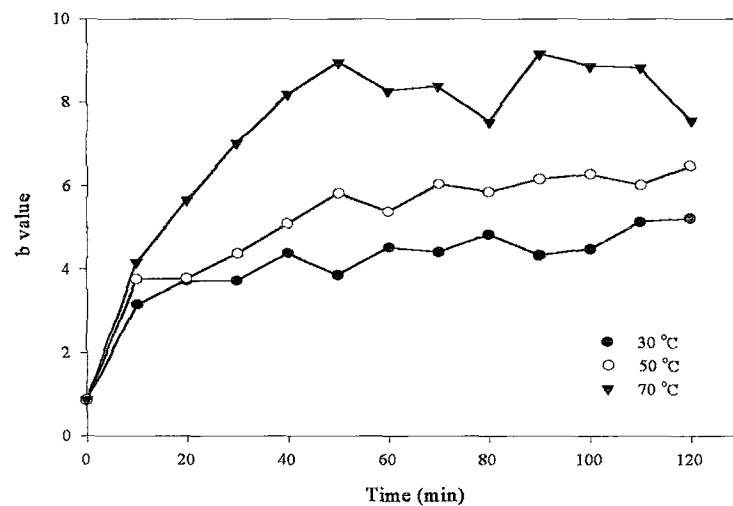


Figure 3.125 Change in b-value of soaking water during soaking of rye at pH 9

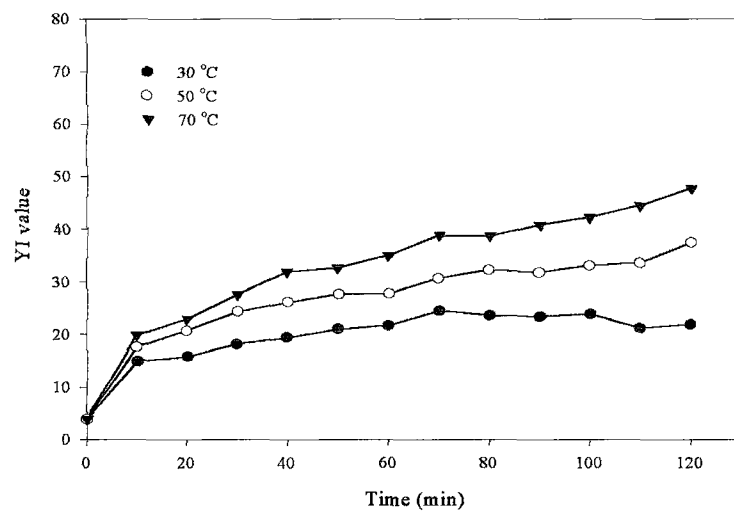


Figure 3.126 Change in YI-value of soaking water during soaking of rye at pH 5

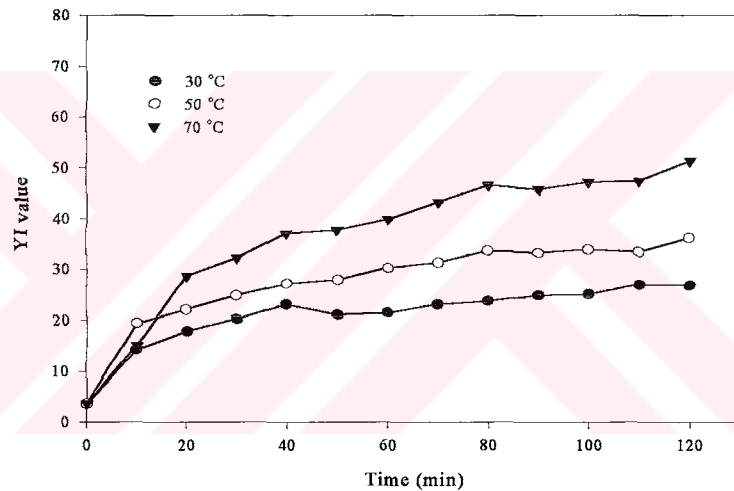


Figure 3.127 Change in YI-value of soaking water during soaking of rye at pH 7

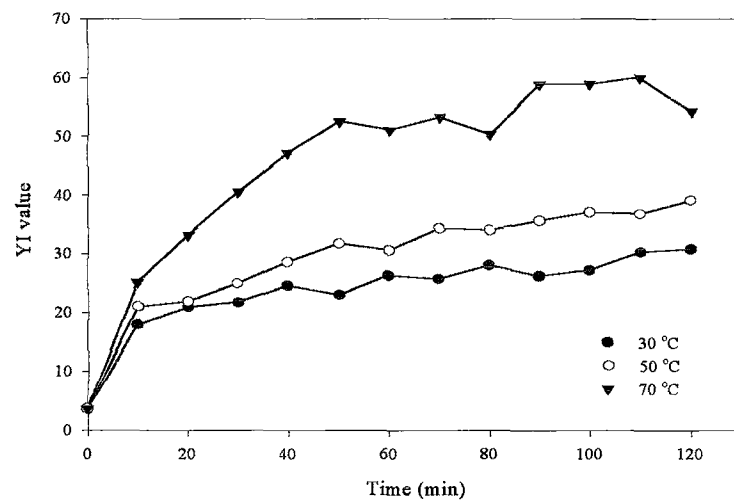


Figure 3.128 Change in YI-value of soaking water during soaking of rye at pH 9

3.2. Cooking of Soybean and Rye

Cooking and drying steps are the most critical steps for the bulgur production. Cooking time and temperature are the main parameters that affect the penetration of water into kernel. The processing variables and modeling of the cooking operation are necessary for proper design of cooker and to understand the effects of cooking on bulgur production. Kinetics deal with the changes in a system, their associated levels, the rate at which the changes occur and the mode and mechanism by which the changes are affected (Bayram *et. al.*, 2003a; b; c; d; e). Understanding behaviors of the soybean and rye kernel during cooking is of practical importance since it governs the subsequent operations and quality of the final product. Determination of the cooking mechanism and the prediction of the dimensional changes of kernel are essential for the control of the cooking operation.

Bayram (1997) and Bayram *et. al.*, (1998; 2003e) reported that the crease of the wheat kernel opens during the cooking operation, and widths of the kernel increase due to the swelling of the wheat kernel. The crease of the wheat kernel can be disrupted due to the excessive cooking operation. Thus, inner part and gelatinized starch may leach out. During the cooking operation, disruption of the wheat kernel and the leaching of the starch, cause a lot of problems (stickness, size deformation etc.) for the next operations (drying, conveying system and peeling). Therefore, the quality loss of the finished product may occur. Traditionally, the cooking of wheat i.e gelatinization of starch to produce the bulgur is controlled using the change of the size of the wheat kernel measuring by cutting of the kernel into two parts along crease side. White spot (opaque) in the kernel illustrates the incomplete gelatinization of starch.

3.2.1. Calibration curves for cooking degree of soybean and rye

In studies concerned with the development of cooking food products it became necessary to assess the extent of processing of intact cereals and legumes by one or others of the changes known to take place during cooking. Because, starch and protein constituents are the major component of cereals and legumes, gelation appeared to be an obvious choice as index of the cooking process. In bulgur production, in order to control cooking operation, knife-cutting method is used to

determine the cooking degree traditionally. But, this method may lead to make mistakes in deciding suitable cooking of cereals.

Differential scanning calorimeter (DSC) is a thermal analysis technique, which has been used for more than two decades to measure the temperature and heat flows associated with transitions in material as a function of time and temperature. Such measurements provide quantitative and qualitative information about heat capacity, physical and chemical changes that involve either endothermic or exothermic processes.

The theory supporting modulated DSC can be easily understood by comparing it to conventional DSC. In conventional DSC, the difference in heat flow between a sample and an inert reference is measured as a function of time and temperature as both the sample and reference are subjected to a controlled environment of time, temperature and pressure. The purpose of differential thermal systems is to record the difference between an enthalpy change, which occurs in a sample, and that in some inert reference material when both are heated (Boyacıoğlu and Ünal, 1993; Riva *et al.*, 2000; Biliaderis *et al.*, 1980).

In DSC the sample and reference are provided with individual heaters, which allows the determination to be conducted with no temperature difference between sample and reference. Instead of traditional method for the determination of the degree of cooking (Bayram, 1997), a new modified method was developed in present study. In present method, calibration data was prepared by mixing cooked and uncooked samples at certain fractions. ΔH values of fractions were measured using DSC and calibration curves of soybean and rye were prepared as versus to cooking degree (fraction of cooked part) (Birch and Priestly, 1973) (Figures 3.129 and 3.130).

Double peaks were obtained in DSC results of soybean in contrast to single one for rye. During calculations, first peak was used. Double peaks for soybean might be explained with the lecithin or oil content of soybean. Figures 3.129 and 3.130 were used for atmospheric, pressure and microwave cooking operations to determine the degree of cooking and optimum cooking time for soybean and rye, respectively.

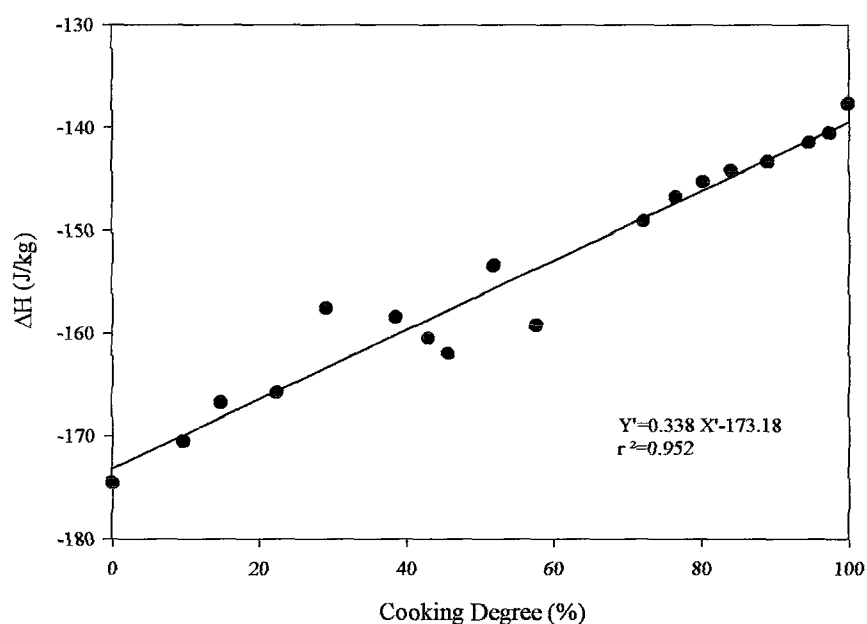


Figure 3.129 Calibration curve for soybean

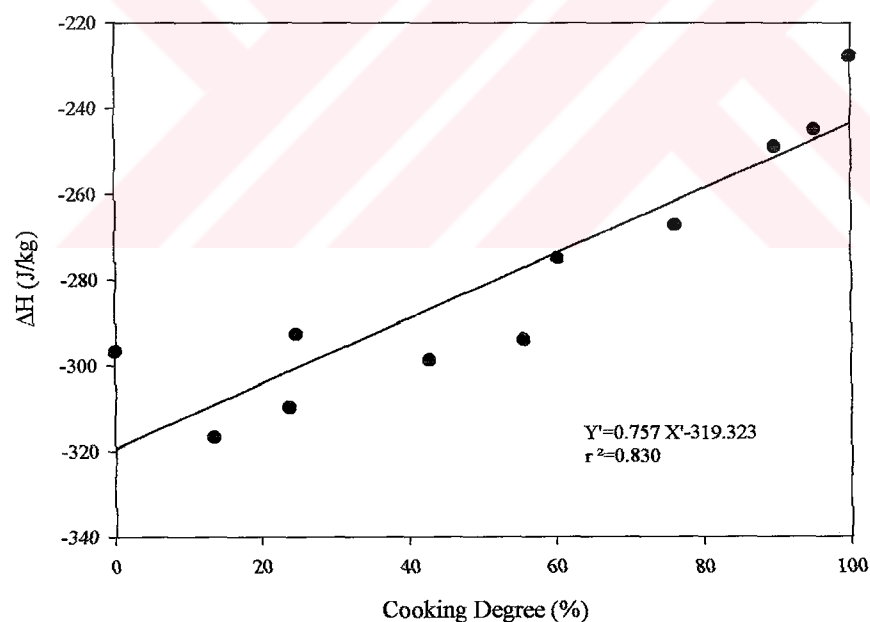


Figure 3.130 Calibration curve for rye

3.2.2. Atmospheric cooking

Soybean and rye were cooked for 120 minutes at 87, 92 and 97°C under atmospheric conditions. Due to boiling point of water 97°C was selected as maximum temperature. Also, in order to achieve the gelation of starch and protein 87°C of

cooking was selected as minimum cooking temperature (it was 10°C less than maximum cooking temperature). Cooking degree, dimensions (x, y, z), weight, volume, density, moisture content, color and textural properties were monitored during cooking. pH, conductivity, absorbance/turbidity, soluble solids content and color of cooking water were also measured. In order to evaluate the atmospheric cooking, hectoliter-weight, energy and power consumption were determined.

3.2.2.1. Atmospheric cooking of soybean

3.2.2.1.1. Determination of cooking degree of soybean

The cooking degree of soybean was determined at 87, 92 and 97°C from determination of ΔH values (Table 3.1) from calibration curve (Figure 3.129) during cooking. The cooking degrees were given in Figure 3.131.

Table 3.1 Values of ΔH of soybean at 87, 92 and 97°C for atmospheric cooking

Time (min)	ΔH (J/g)		
	87°C	92°C	97°C
0	-173.180	-173.180	-173.180
10	-170.152	-169.023	-164.865
20	-166.907	-163.091	-156.331
30	-164.517	-157.737	-146.245
40	-162.242	-154.806	-139.191
50	-157.737	-148.317	-139.001
60	-153.245	-142.865	-139.465
70	-150.210	-139.792	-139.302
80	-148.722	-138.934	-139.184
90	-144.247	-139.350	-139.505
100	-142.682	-139.498	-139.211
110	-139.083	-138.701	-138.603
120	-138.951	-139.211	-138.711

According to the cooking degree values, cooking time (i.e. 100% of cooking) for soybean was determined as 110, 80 and 40 minutes at 87, 92 and 97°C, respectively under atmospheric conditions. As expected, increasing cooking temperature decreased cooking time.

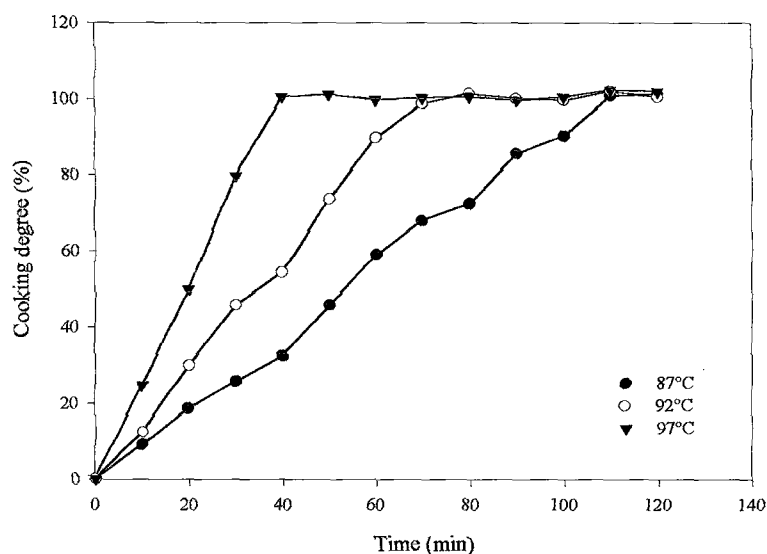


Figure 3.131 Cooking degree of soybean at 87, 92 and 97°C for atmospheric cooking

3.2.2.1.2. Changes in the physical attributes of soybean

a. Changes in the dimensions of the soybean kernel

The length of the soybean kernel increased ($P<0.05$) during the atmospheric cooking operation (Figure 3.132). Cooking time and temperature had significant effect ($P<0.05$) on the length of the soybean kernel ($P<0.05$). The percent change in the length of the soybean kernel increased during first 40 minutes, and then nearly stable (50-70%) (Figure 3.132). According to Duncan's multiple range test results, increasing cooking temperature from 87 to 97°C decreased the change of the length ($P<0.05$). It can be due to the gelation effect in the 97°C of cooking.

Joint side width of the soybean kernel (y-side) increased ($P<0.05$) during 20 minutes then decreased ($P<0.05$) until 60 minutes, and then increased ($P<0.05$) up to 70 minutes at each cooking temperature (Figure 3.133). After that, it decreased ($P<0.05$) until the end of the cooking operation, steadily. It was affected from cooking time and temperature, significantly ($P<0.05$). The change in the y-value had higher value ($P<0.05$) at 97°C than other cooking temperatures ($P<0.05$). The z-value was also affected significantly ($P<0.05$) from cooking time and temperature during the cooking operation (Figure 3.134).

It was found that the percent change in x-side (50-70%) was greater than y and z-sides (7-20% and 15-25%) similar with the soaking of soybean. The percent changes

for the x, y and z-values at optimum cooking time (i.e. 110, 80 and 40 minutes) were obtained as 65.4, 62.1 and 55.7; 10.9, 17.7 and 11.6; 19.4, 19.5 and 22.5 at 87, 92 and 97°C, respectively.

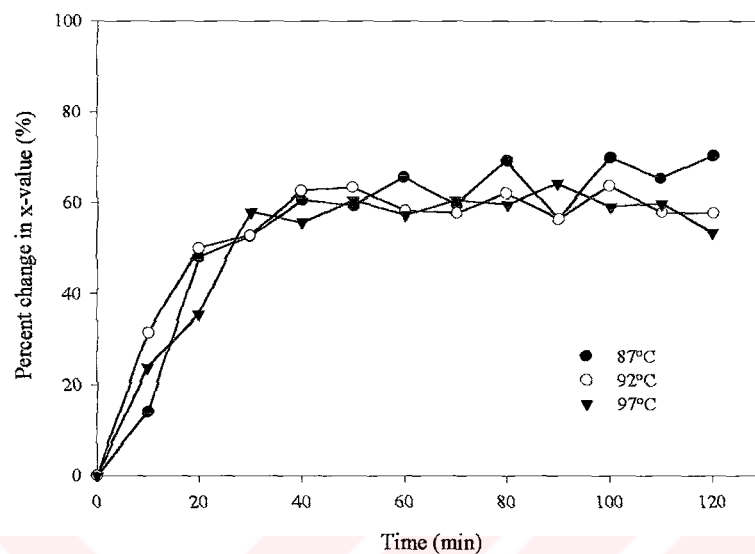


Figure 3.132 Percent change in x-value of the soybean kernel during atmospheric cooking

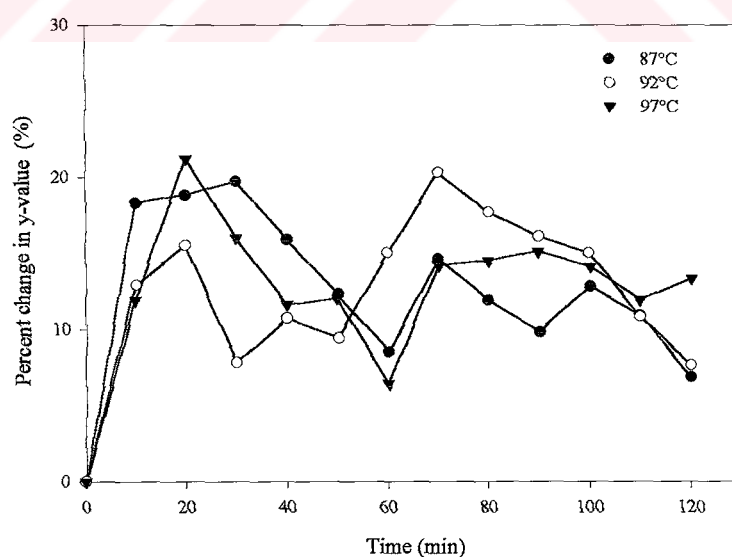


Figure 3.133 Percent change in y-value of the soybean kernel during atmospheric cooking

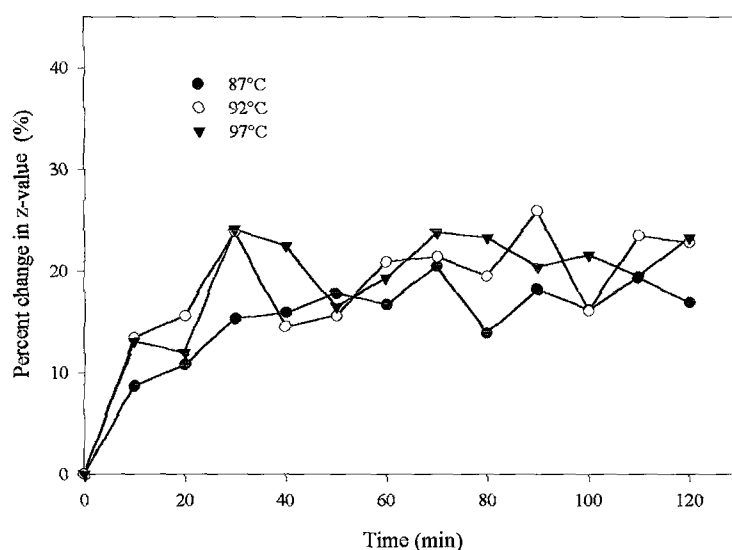


Figure 3.134 Percent change in z-value of the soybean kernel during atmospheric cooking

b. Changes in weight, volume and density of the soybean kernel

During atmospheric cooking, the percent change in weight and volume increased ($P < 0.05$) and also density had negative value due to swelling of the kernel (i.e. increase in volume than weight) (Figures 3.135-137). Cooking time and temperature significantly ($P < 0.05$) affected weight, volume and density. It was found from Duncan's multiple range test, the lowest change in weight was observed at 97 °C in contrast to volume and density at 87°C due to gelation effect. The weight and volume increased ($P < 0.05$) sharply up to 30 minutes then became nearly constant during the further cooking period at each cooking temperature. In turn, volume started to decrease at nearly 100 minutes slowly due to the completion of the swelling and gelation. According to cooking degree values and Figures 3.135 and 3.136, the major changes in weight and volume were observed during the first 30 minutes before the optimum cooking time (i.e. 30 minutes < 40, 80 and 110 minutes).

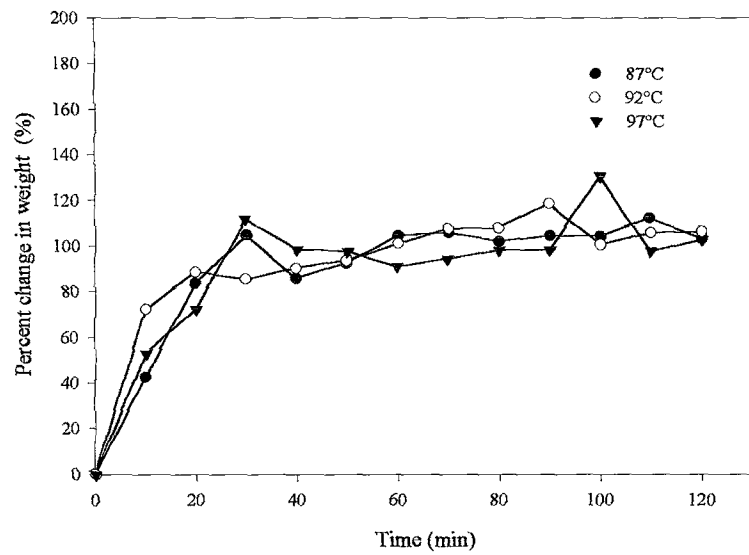


Figure 3.135 Percent change in weight of the soybean kernel during atmospheric cooking

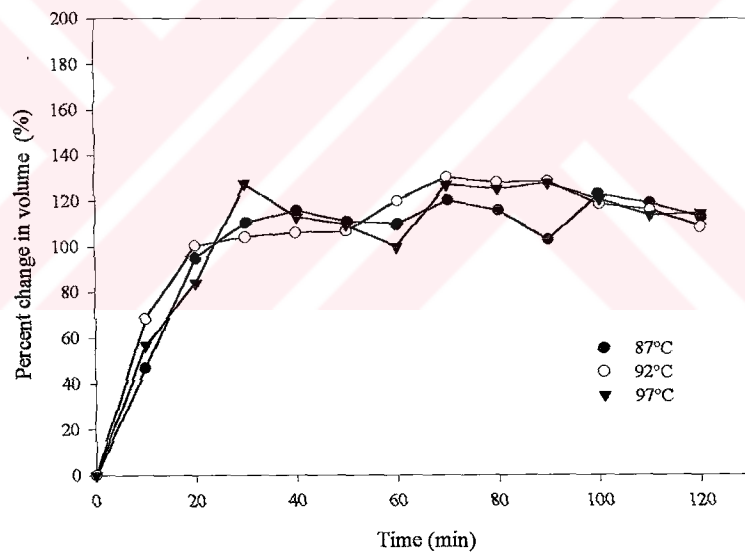


Figure 3.136 Percent change in volume of the soybean kernel during atmospheric cooking

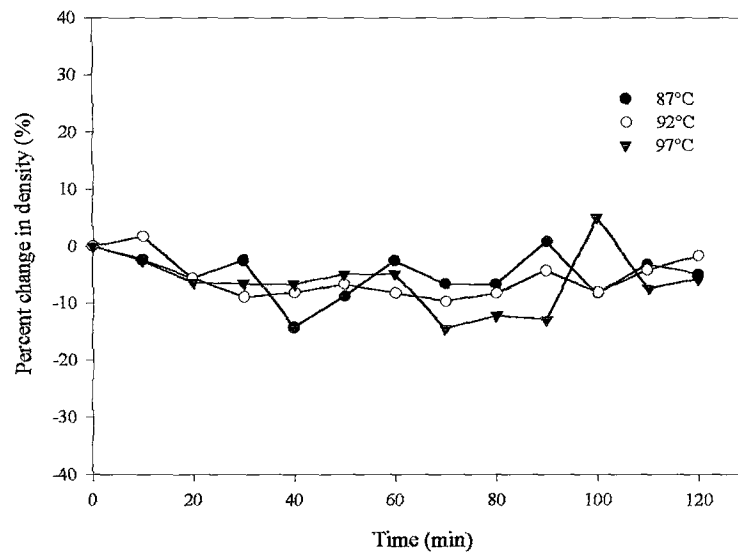


Figure 3.137 Percent change in density of the soybean kernel during atmospheric cooking

c. Moisture content of soybean during atmospheric cooking

The moisture content of soybean during atmospheric cooking was given in Figure 3.138 at 87, 92 and 97°C. Cooking time and temperature had significant effect ($P < 0.05$) on moisture content of soybean. It reached to about 60% after 40 minutes at each cooking temperature (Figure 3.138). Moisture content at optimum cooking time had higher values (nearly 60%) at 87, 92 and 97°C. It is a disadvantage for further operations (e.g. drying operation). Forty percent of moisture in product is suitable for cooking during bulgur production. Therefore, twenty percent excess water were present in soybean at optimum cooking time during atmospheric cooking. It would increase the duty and energy consumption of the dryer.

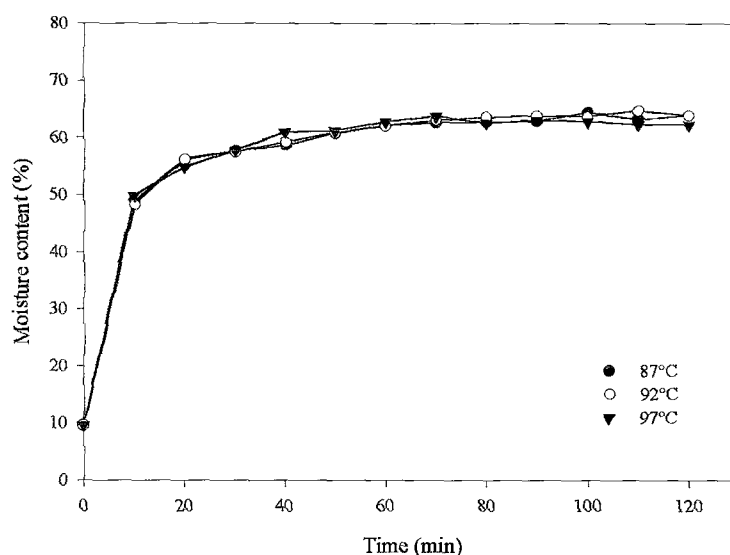


Figure 3.138 Moisture content of soybean during atmospheric cooking

d. Color of soybean during atmospheric cooking

The changes of color values of soybean were given in Figures 3.139, 3.140, 3.141 and 3.142 for L, a, b and YI-values, respectively. Cooking time and temperature had significant effect ($P < 0.05$) on the L, a, b and YI-values.

The L-values of soybean during cooking decreased during the first 10 minutes at 87 and 97°C, but up to 30 minutes reduction was observed at 97°C. Then, L-values increased steadily until 50-60 minutes and then reduction was also observed. Increase in lightness (L-value) between about 20 and 50 minutes can be due to change in the color of soybean by cooking effect (i.e. high temperature). Additionally, decrease in lightness during remaining period of the cooking operation can be explained by the browning reactions and degradation of the coloring compounds.

In addition, the a-value decreased ($P < 0.05$) during first 50, 20 and 10 minutes at 87, 92 and 97°C respectively and then increased. As expected, redness of soybean (i.e. a-value) increased during atmospheric cooking (Figure 3.140). According to the results, cooking should be made at 97°C to obtain the low a-value for acceptable soy-bulgur color.

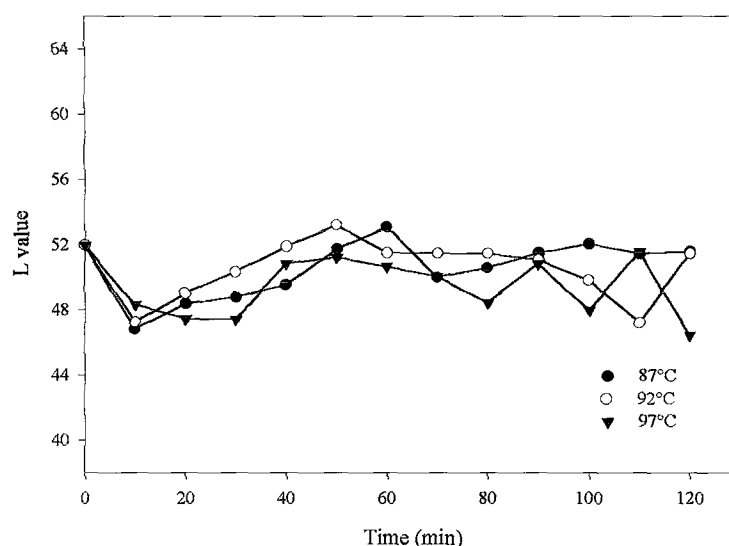


Figure 3.139 Change in L-value of soybean during atmospheric cooking

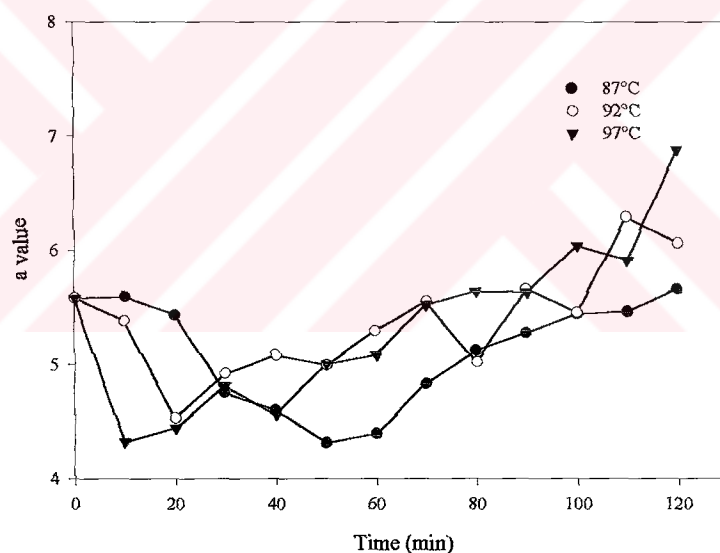


Figure 3.140 Change in a-value of soybean during atmospheric cooking

The b and YI-values increased during the atmospheric cooking operation (Figures 3.141-3.142). However, b-value reduced after 90, 40 and 60 minutes at 87, 92 and 97°C due to browning reactions and color degradation. This increase in b-value during cooking was correlated with the increase in the a-value due to darkening of soybean during cooking.

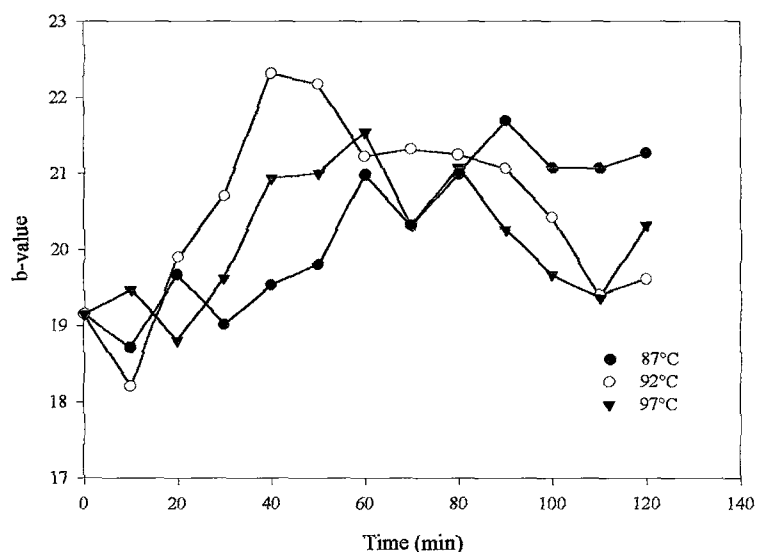


Figure 3.141 Change in b-value of soybean during atmospheric cooking

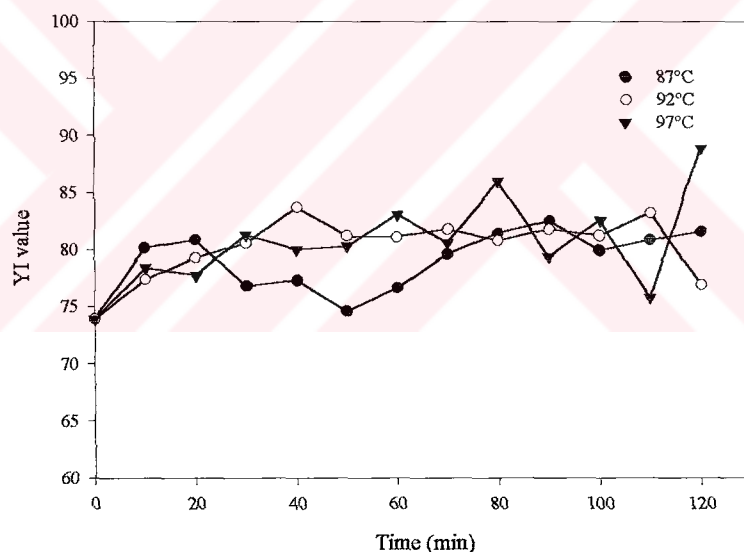


Figure 3.142 Change in YI-value of soybean during atmospheric cooking

e. Change in texture of soybean during atmospheric cooking

The results obtained for the $F_{\max}$ and A_p -values of soybean were given in Figures 3.143 and 3.144, respectively. $F_{\max}$ and A_p decreased ($P < 0.05$) sharply during first 10 minutes at each cooking temperature then became nearly constant during the further cooking period. It was found that the hardness of soybean decreased significantly ($P < 0.05$) in the first 20 minutes during atmospheric cooking. It was found that

increase in cooking temperature decreased ($P<0.05$) the hardness of soybean i.e. $F_{\max}$ and A_p .

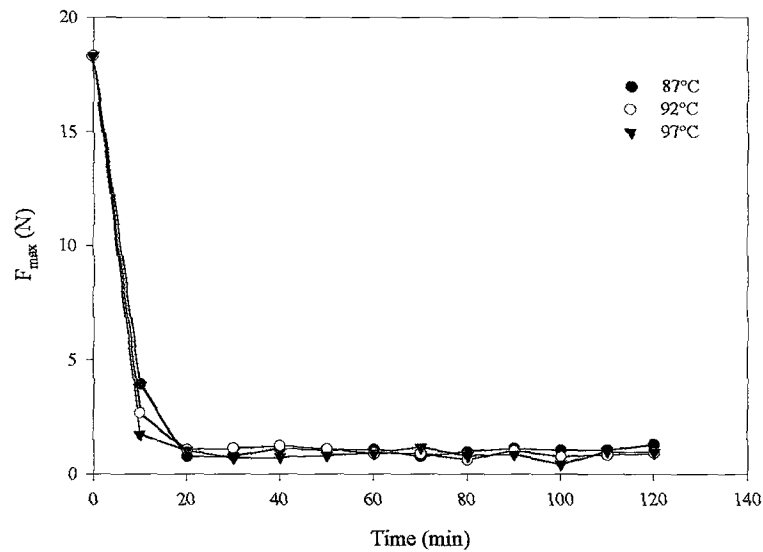


Figure 3.143 Change in $F_{\max}$ of soybean during atmospheric cooking

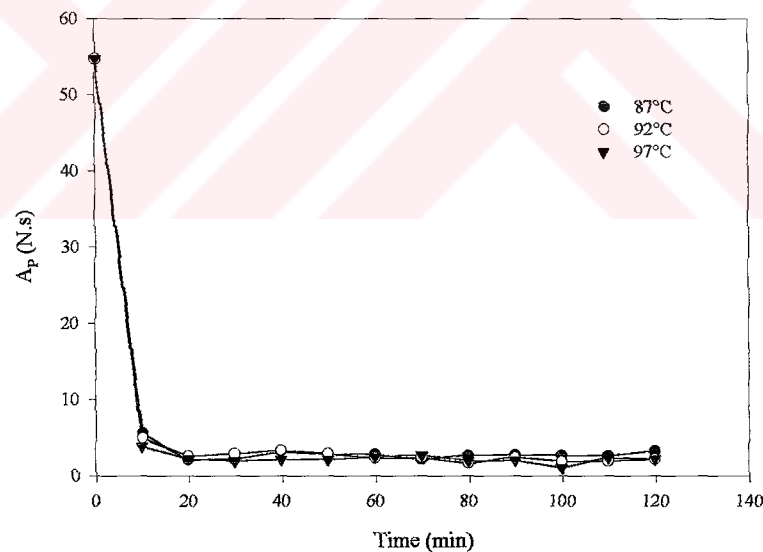


Figure 3.144 Change in A_p of soybean during atmospheric cooking

3.2.2.1.3. Changes in cooking water

a. Change in pH value of cooking water of soybean

The change in the pH values of the cooking water was given in Figure 3.145. The initial pH of water was adjusted to 7.00. During first 10 minutes of cooking, pH values decreased sharply ($P<0.05$) to 6.11, 6.16 and 6.17 at 87, 92 and 97°C

respectively. pH value of cooking water at 97°C was higher ($P<0.05$) than at 87 and 92°C during this period. It can be due to the rapid gelation of starch and protein at this high temperature, since leaching of compounds into cooking water might be slow during the first 10 minutes of cooking. At the end of the cooking operation, the pH values decreased to 5.89, 5.83 and 5.79 at 87, 92 and 97°C, respectively. pH values of the cooking water were lower than that of the soaking water. In other words, increase in temperature affected the acidity of the water.

The pH of the cooking water at the optimum cooking time (110, 80 and 40 minutes) was decreased from 7.00 to 5.90, 5.87 and 5.87 at 87, 92 and 97°C respectively. It shows that cooking water had nearly similar pH value at all cooking temperature at the end of the optimum cooking times.

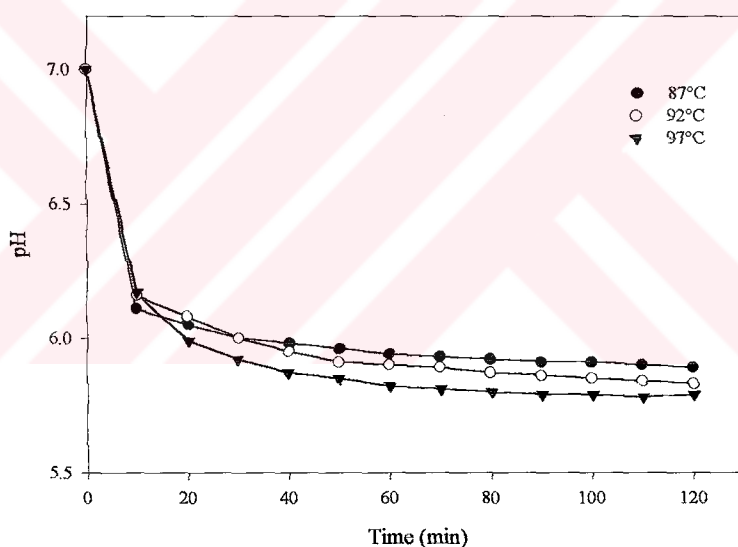


Figure 3.145 Change in pH value of cooking water during atmospheric cooking of soybean

b. Change in conductivity of cooking water of soybean

The results of conductivity of the cooking water were given in Figure 3.146. It was measured in mS (millisiemens). It was found that the conductivity of water during the cooking operation had higher value than the soaking operation (i.e. μS). Increase in temperature also significantly increased the conductivity of the cooking water. But, it increased sharply ($P<0.05$) at 97°C after 50 minutes during cooking due to leaching of the electrolytes..

According to optimum cooking time, conductivity of cooking water was determined as 3.92, 3.99 and 3.45 mS at 87, 92 and 97°C, respectively. The results indicated that increasing the cooking temperature decreased ($P<0.05$) the loss of inorganic compounds from soybean. Therefore, cooking operation should be carried out at 97°C for optimum cooking.

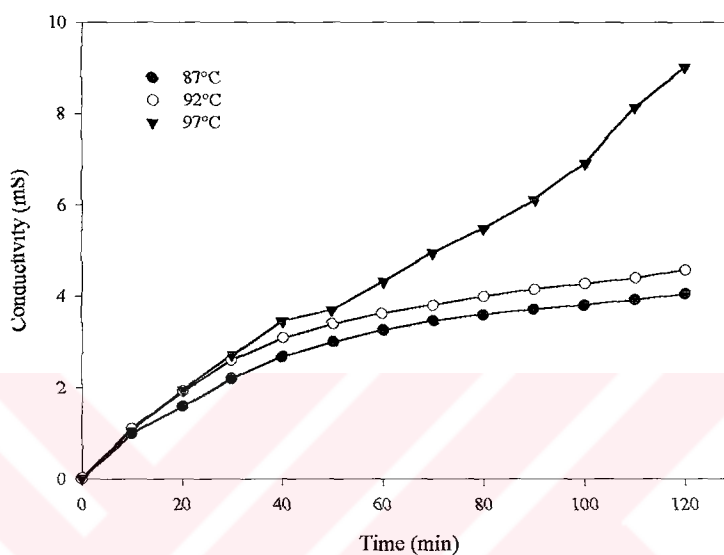


Figure 3.146 Change in conductivity of cooking water during atmospheric cooking of soybean

c. Change in turbidity/absorbance of cooking water of soybean

Changes in turbidity/absorbance were given in Figure 3.147. Cooking time and temperature were significantly effective ($P<0.05$) on the turbidity of the cooking water. Turbidity of the cooking water increased ($P<0.05$) at each cooking temperature. It was found that absorbance at 92°C was lower than that at 87 and 97°C. Leaching of organic compound at 97°C increased sharply ($P<0.05$) after the optimum cooking time (40 minutes). Therefore the optimum cooking time is very critical to prevent the loss of the organic compounds from soybean.

Absorbance at 87°C was greater than at 92 and 97°C until 50 minutes of cooking, after this point absorbance value at 97°C increased sharply (Figure 3.147). The increase in absorbance at 97°C might be due to boiling of the cooking water (water was boiling at 97°C at altitude where experiments were made) which creates turbulence and in turn increases the leaching of organic compounds from soybean

into water after the optimum cooking level i.e. overcooking (sharp increase in absorbance at 97°C started at 50 minutes, namely 50 minutes of cooking was higher than the optimum cooking time). In addition, soybean is suitable for disruption during excess cooking period. Also, before 50 minutes, absorbance at 97°C was lower than 87°C and higher than 92°C. It can be explained that 92°C of cooking could be suitable temperature for gentle gelation operation with preventing disruption of the soybean kernel from boiling effect, and the leaching of the organic compounds was limited. In addition, the reason of the higher values of absorbance at 87°C during first 50 minutes than that of 97°C could be explained with the higher rate of the leaching of organic compounds that compared with the rate of the gelation at this temperature.

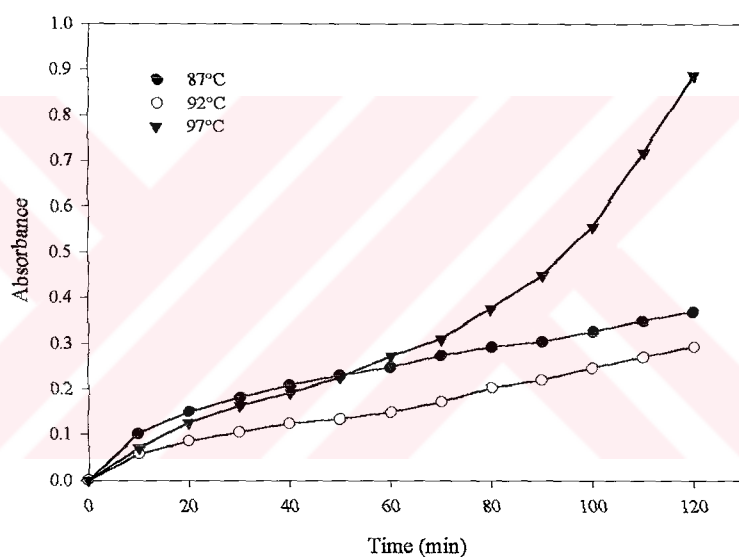


Figure 3.147 Change in absorbance of cooking water during atmospheric cooking of soybean

d. Change in soluble solids content of cooking water of soybean

Soluble solids content (Figure 3.148) of the cooking water of soybean increased ($P < 0.05$) during cooking with increase in cooking temperature. Significant increase in soluble solids content was decreased at 97°C of cooking, which may be due to the increased leaching of compounds with boiling.

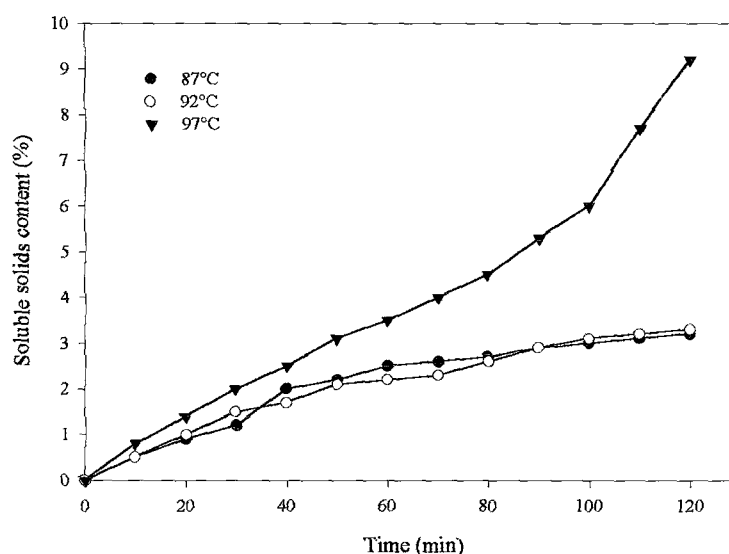


Figure 3.148 Change in soluble solids content of cooking water during atmospheric cooking of soybean

e. Change in color of cooking water of soybean

Color values of the cooking water were given in Figures 3.149-3.152. Lightness (L-value) of the cooking water during cooking decreased ($P < 0.05$). It was correlated with increase in the a and b-values ($P < 0.05$, Figures 3.149-3.151). Also, increase in cooking temperature decreased ($P < 0.05$) the L-value in contrast to the a-value and YI-value (Figure 3.149, 3.150, 3.151 and 3.152). These increases in the a and YI-values were expected due to the leaching of compounds and browning reactions.

The b-value at 97°C increased to 11.37 during 50 minutes then decreased to 6.56 at the end of the cooking (Figures 3.151). In turn, it increased to 9.05 at 30 minutes at 87°C, and then became almost constant during the further cooking period. Same trend was observed at 92°C that it reached to 10.9 at 50 minutes, and then nearly stayed constant after this point. Decrease in the b-value at 97°C was observed after 50 minutes. This could be explained by gelation of starch and protein, degradation of the coloring compounds, and formation of brown pigments (But, the decreasing of the b-value at 97°C was observed after the optimum cooking time i.e. 40 minutes at 97°C, therefore, it was not important for the atmospheric cooking of soybean up to optimum cooking time).

The YI-value was given in Figure 3.152. It increased ($P<0.05$) at each cooking temperature during cooking operation. It was found that, YI-value was parallel with b-value, but there was no decrease in YI-value at 97°C after 50 minutes. This difference could be explained by the loss of the clarity of water due to the leaching of the other soluble compounds (electrolyte, starch, coloring compounds etc.) and browning reactions.

At optimum cooking time (i.e. 110, 80 and 40 minutes at 87, 92 and 97°C, respectively), color responses were measured as 19.86, 21.13 and 23.52 for L-value, 1.56, 1.56 and -0.30 for a-value, 9.39, 10.52 and 10.78 for b-value, and 87.16, 93.11 and 79.83 for YI-value at 87, 92 and 97°C, respectively. The results at the optimum cooking time indicated that, cooking should be carried out at 97°C due to high L, low a and YI-values to prevent the loss of nutrients with discharge of cooking water.

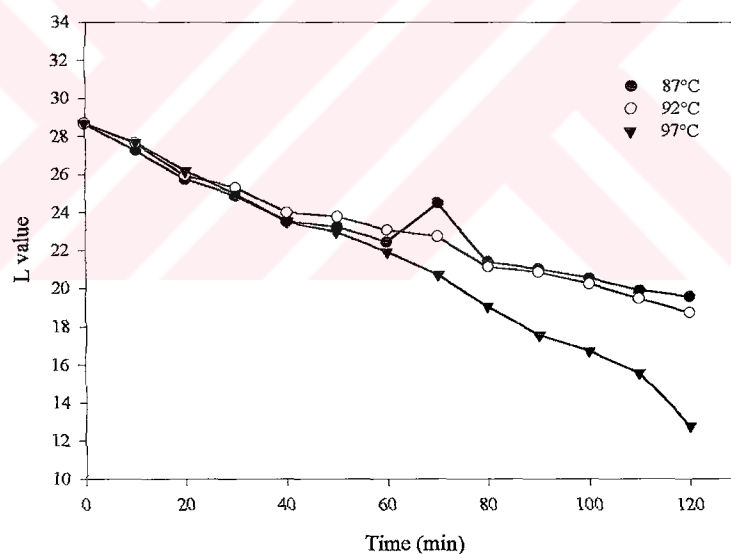


Figure 3.149 Change in L-value of cooking water during atmospheric cooking of soybean

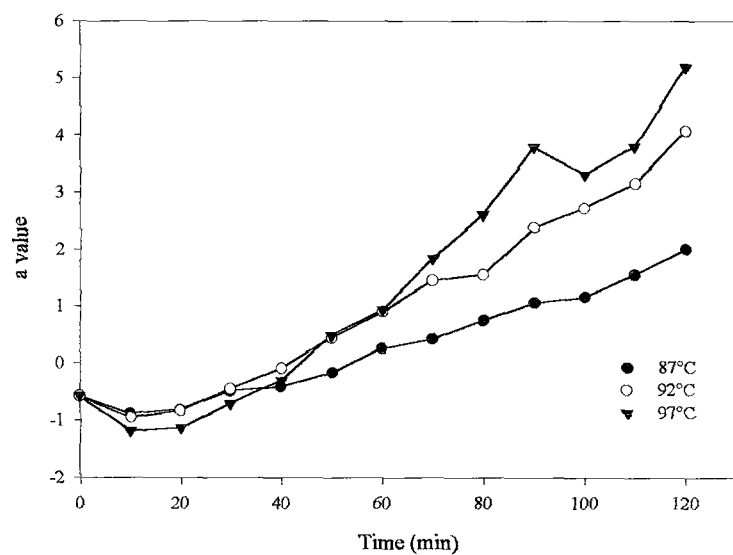


Figure 3.150 Change in a-value of cooking water during atmospheric cooking of soybean

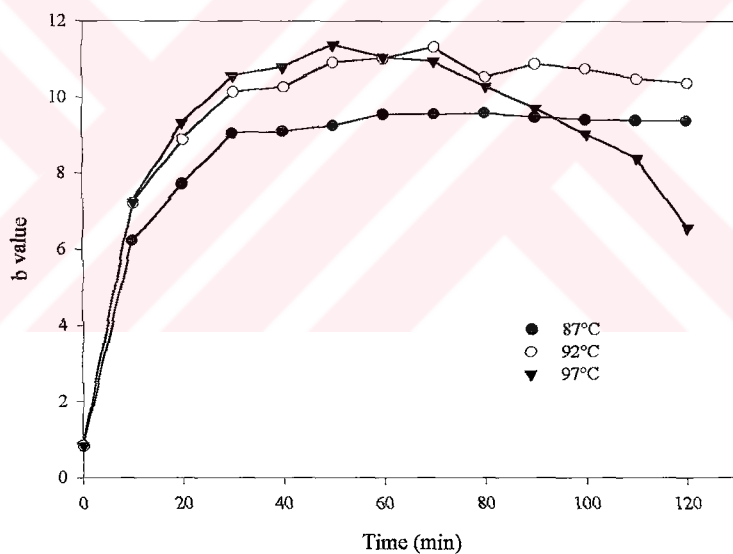


Figure 3.151 Change in b-value of cooking water during atmospheric cooking of soybean

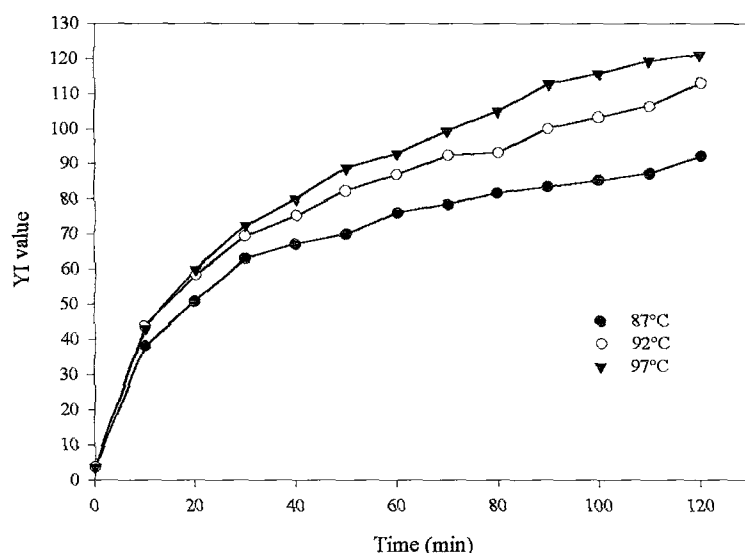


Figure 3.152 Change in YI-value of cooking water during atmospheric cooking of soybean

3.2.2.2. Atmospheric cooking of rye

3.2.2.2.1. Determination of cooking degree of rye

The cooking degree of rye was determined during cooking at 87, 92 and 97°C using measured ΔH values (Table 3.2) and calibration curve (Figure 3.130). The change in cooking degree of rye was given in Figure 3.153.

Table 3.2 Values of ΔH of rye at 87, 92 and 97°C for atmospheric cooking

Time (min)	ΔH (J/g)		
	87°C	92°C	97°C
0	-319.323	-319.323	-319.323
10	-313.502	-310.754	-300.716
20	-308.301	-299.921	-289.141
30	-299.263	-294.592	-272.480
40	-294.645	-284.796	-259.005
50	-289.611	-275.326	-242.677
60	-285.591	-270.254	-243.971
70	-280.542	-263.093	-243.434
80	-272.873	-249.997	-241.731
90	-270.353	-241.829	-242.457
100	-259.687	-242.389	-242.980
110	-256.976	-243.214	-243.350
120	-247.658	-242.018	-242.563

According to the cooking degree values (Figure 3.153), optimum cooking time (i.e. 100% cooking) for rye was determined as 90 and 70 minutes at 92 and 97°C, respectively under atmospheric conditions. But, 100% of cooking degree of rye was not obtained at 87°C. The cooking degree was reached to 94.67% at 87°C at the end of 120 minutes of cooking. Therefore, cooking should be made at the temperatures higher than 87°C to achieve cooking of rye.

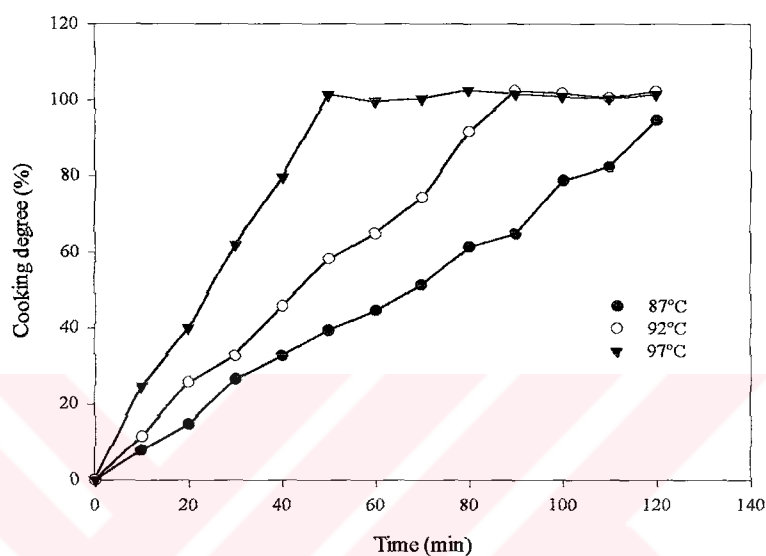


Figure 3.153 Cooking degree of rye at 87, 92 and 97°C for atmospheric cooking

3.2.2.2.2 Changes in the physical attributes of rye

The most important problem during the cooking operation is the deformation of the kernel. In general, the deformation of the kernel occurs at the crease side and causes the leaching of constituents of the kernel. In turn, adhesiveness problems for subsequent operations could occur. The deformed kernels can not be used for bulgur production. Results revealed the fact that controlling the changes in dimensions of the kernel is very important for cooking of rye.

During atmospheric cooking, samples were put into temperature-adjusted water, i.e. 87, 92 and 97°C. Samples were directly contacted with the cooking water in contrast to pressure and microwave cooking operations. Due to that destruction effect of water on the kernel occurred. Therefore, the kernels deformed after certain time during the cooking operation.

During atmospheric cooking of soybean that previously explained, at 87, 92 and 97°C, deformation of the kernel was not observed in contrast to the rye kernel. It can be due to differences between bran layers of the soybean and rye kernel. Bran layer of the rye kernel may not resist properly against the inertial destruction effect of the cooking water. Then, deformation was observed after certain time. Deformation on the rye kernel started at about 80, 70 and 50 minutes at 87, 92 and 97°C, respectively. It is important to note that deformation started before the completion of cooking of rye.

It was interesting that this type deformation also occurred during production of bulgur from soft wheat in contrast to bulgur from hard wheat due to low protein content. Therefore, low protein grains may not be suitable for bulgur production to obtain properly cooked products. Industrially, *Triticum durum* is preferred to prevent the deformation of the kernel, in turn to obtain high quality final product i.e. not-adhesive, good and yellow colored bulgur.

a. Changes in the dimensions of the rye kernel

The percent change in the x-value of the rye kernel during cooking at 87, 92 and 97°C was given in Figure 3.154. The x-value of the rye kernel increased during first 10-20 minutes then steadily decreased ($P < 0.05$). Cooking time and temperature had a significant ($P < 0.05$) effect on the x-value. Increasing cooking temperature decreased ($P < 0.05$) the percent change in the x-value. This may be due to the swelling of the kernel that can be correlated with the reported data for cooking of the wheat kernel by Bayram *et. al.* (1998).

Changes in the widths (y and z-values) of the rye kernel were given in Figures 3.155 and 3.156. Although, both of them increased ($P < 0.05$) during cooking, increase in cooking temperature did not significantly ($P > 0.05$) affect their changes. Due to deformation of the kernel, important fluctuations in y and z-values were observed after 70-80 minutes of cooking (Figures 3.155-3.156).

The y-value of the rye kernel increased steadily during cooking, however it decreased after certain period for the soybean kernel. It may be due to thin and weak bran structure of the rye kernel in contrast to the soybean kernel.

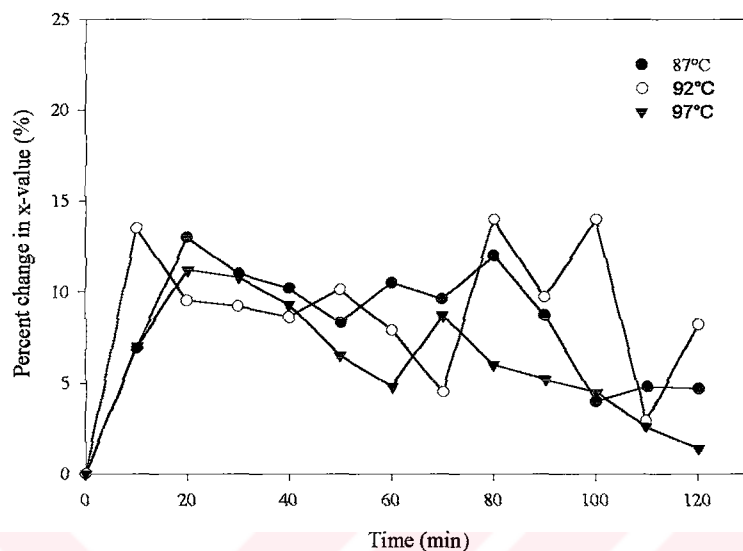


Figure 3.154 Percent change in x-value of the rye kernel during atmospheric cooking

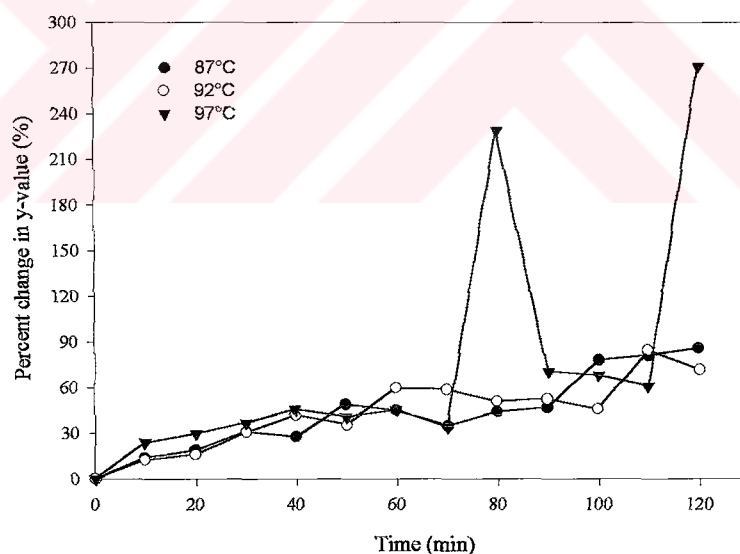


Figure 3.155 Percent change in y-value of the rye kernel during atmospheric cooking

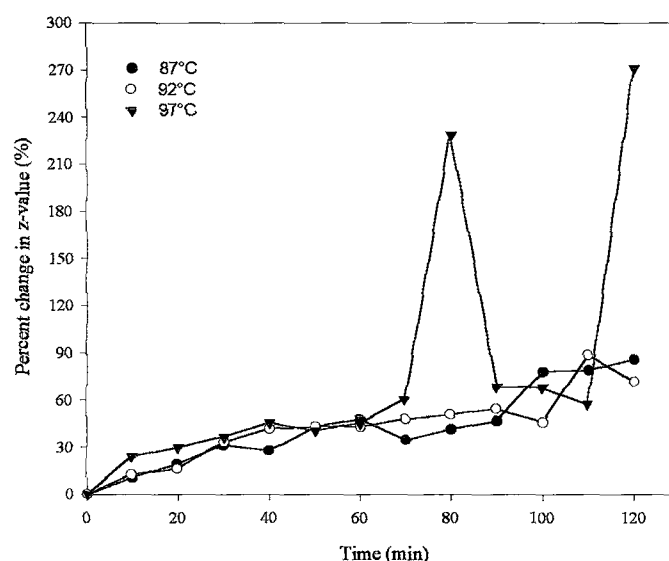


Figure 3.156 Percent change in z-value of the rye kernel during atmospheric cooking

b. Changes in weight, volume and density of the rye kernel

The changes in weight, volume and density of the rye kernel were given in Figures 3.157, 3.158 and 3.159, respectively. Cooking time and temperature had significant ($P < 0.05$) effect on weight in contrast to volume and density. Increase in temperature increased ($P < 0.05$) the percent change in the weight. As observed in the soybean kernel, density change was observed as negative due to significant swelling of the kernel and high volume change in the kernel.

Fluctuation in weight, volume and density were observed after deformation started. Fluctuation in volume is important because it is strong function of three dimensions of the kernel i.e. x, y and z values. Similar fluctuation shape (Figure 3.158) for the change of volume was obtained with y and z-values (Figures 3.155 and 3.156). It was found that deformation in the kernel caused 100-1300% of change in volume at about 80 and 120 minutes and these values are not acceptable for the bulgur processing due to product loss (size problem and increase in amount of flour size product etc.).

Change in density of the rye kernel increased during cooking (negatively) due to excessive volume change. It showed that for cooking of rye (and soybean) additional headspace is required in cooker to accommodate their volume increase.

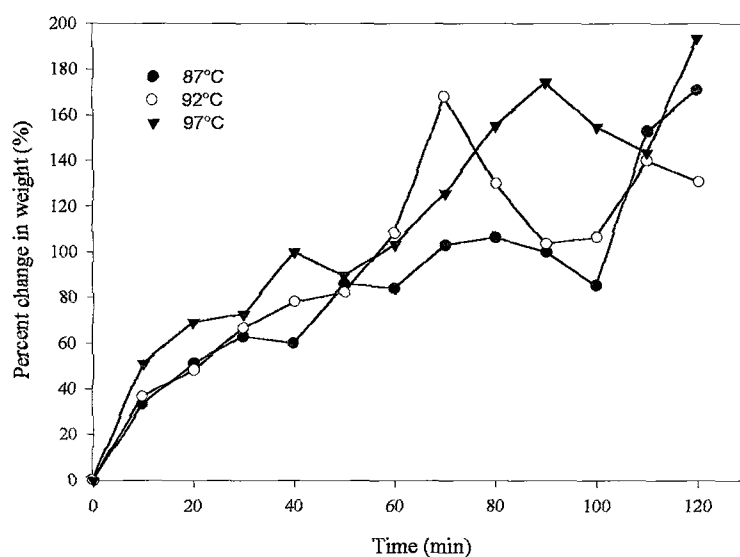


Figure 3.157 Percent change in weight of the rye kernel during atmospheric cooking

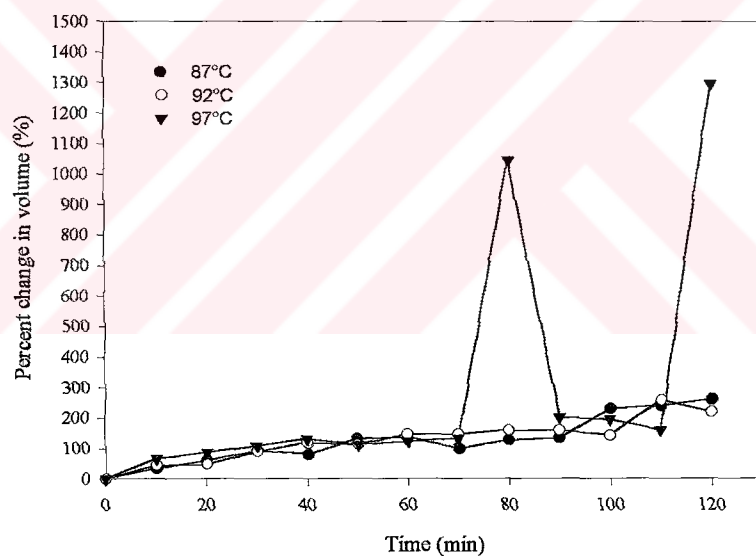


Figure 3.158 Percent change in volume of the rye kernel during atmospheric cooking

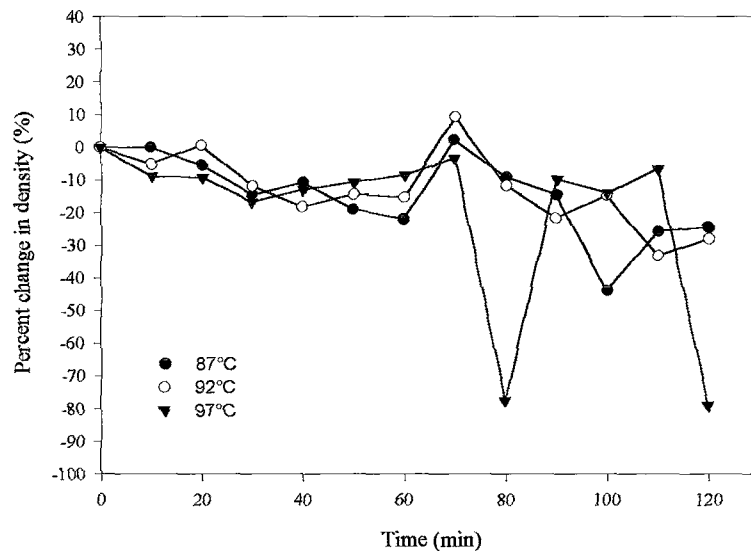


Figure 3.159 Percent change in density of the rye kernel during atmospheric cooking

c. Moisture content of rye during atmospheric cooking

The change in moisture content of rye was given in Figure 3.160. Increase in temperature increased ($P < 0.05$) moisture content of rye. Moisture content of rye reached to about 60% at all cooking temperatures at the end of the cooking operation. (at optimum cooking time, moisture content was about 60% at 92 and 97°C). The 60% of moisture level was not suitable for the drying operation (i.e. $> 40\%$) due to excess 20% moisture. It increases the duty and energy consumption of dryer with decreasing capacity.

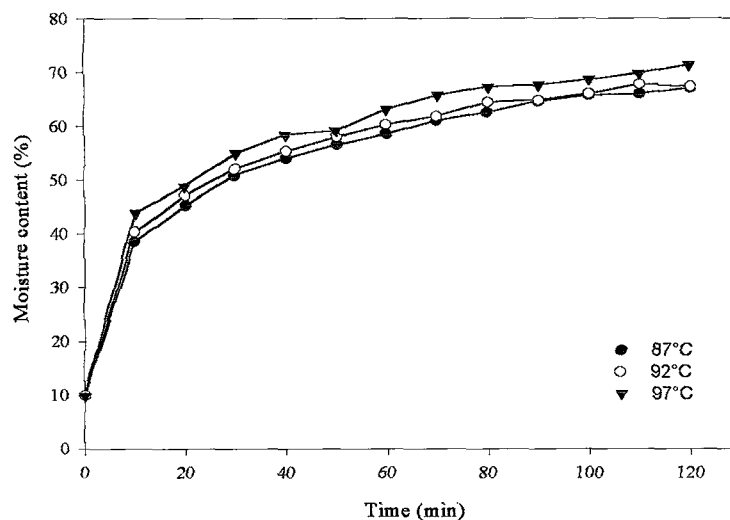


Figure 3.160 Moisture content of rye during atmospheric cooking

d. Color of rye during atmospheric cooking operation

The change in L, a, b and YI-values of rye were given in Figure 3.161, 3.162, 3.163 and 3.164, respectively. There was no significant ($P>0.05$) effect of the cooking temperature in contrast to cooking time on the color values.

The L-value decreased ($P<0.05$) during 30 minutes then became nearly constant up to end of cooking. Additionally, the a-value sharply increased ($P<0.05$) during 10 minutes, then changed steadily. The a-value was positive, which indicates redness of the product probably due to red pigments. Redness of rye decreased slowly after first 10 minutes of cooking.

There was no sharp increase or decrease in the b-value in contrast to the L and a-values (Figures 3.61-3.163). The b-value decreased ($P<0.05$) slightly, which indicates the decrease in yellowness of rye. It could also be due to the degradation of coloring compounds during cooking.

The changing trend of YI-value was similar with the a-value, increased ($P<0.05$) sharply during first 10 minutes, and then changed slightly (Figure 3.164). Increase in the a-value may also be caused by the loss of clarity of rye, i.e. increase in YI-value.

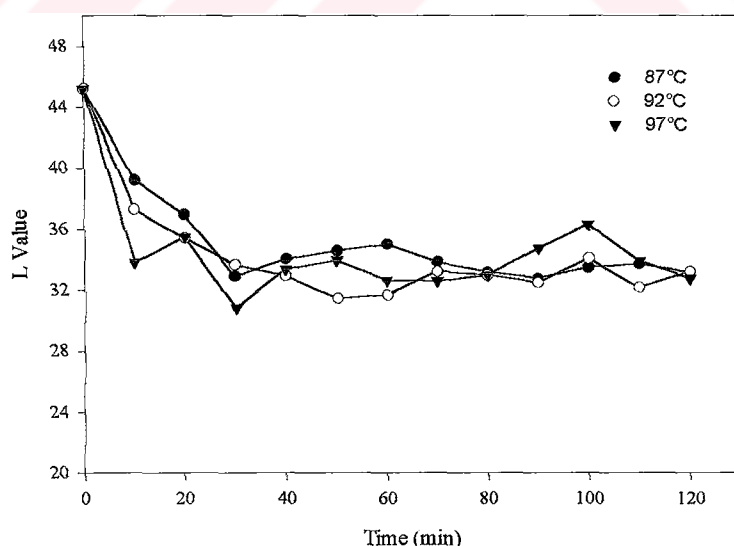


Figure 3.161 Change in L-value of rye during atmospheric cooking

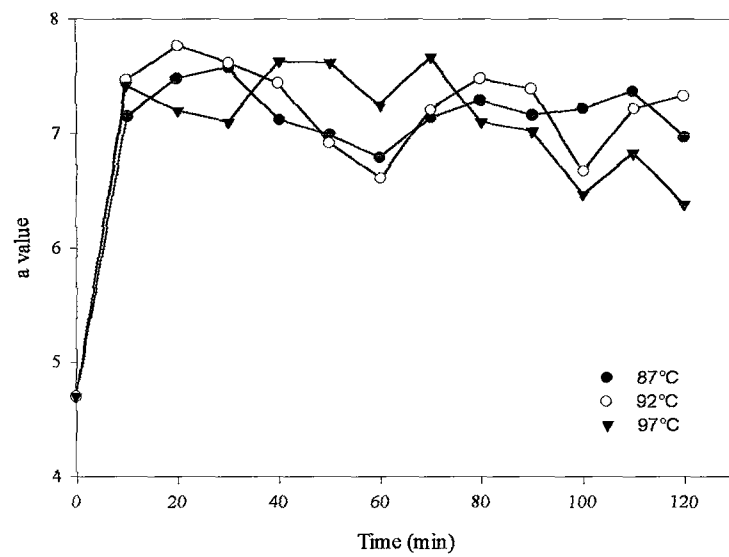


Figure 3.162 Change in a-value of rye during atmospheric cooking

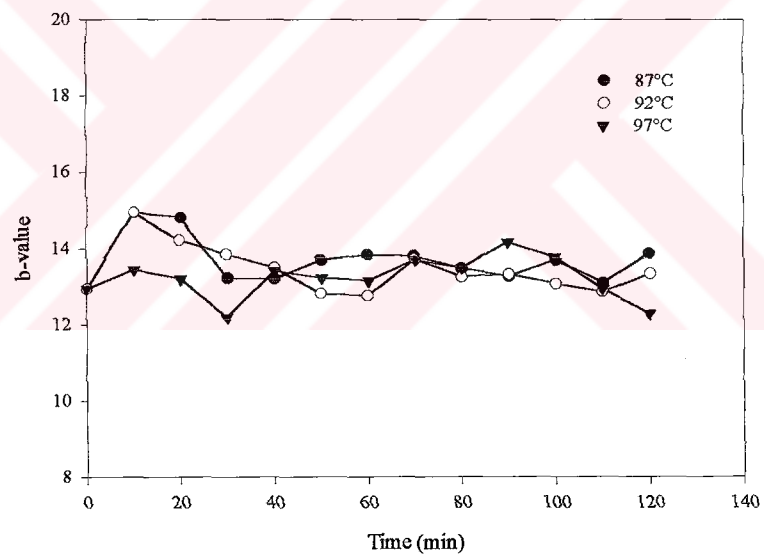


Figure 3.163 Change in b-value of rye during atmospheric cooking

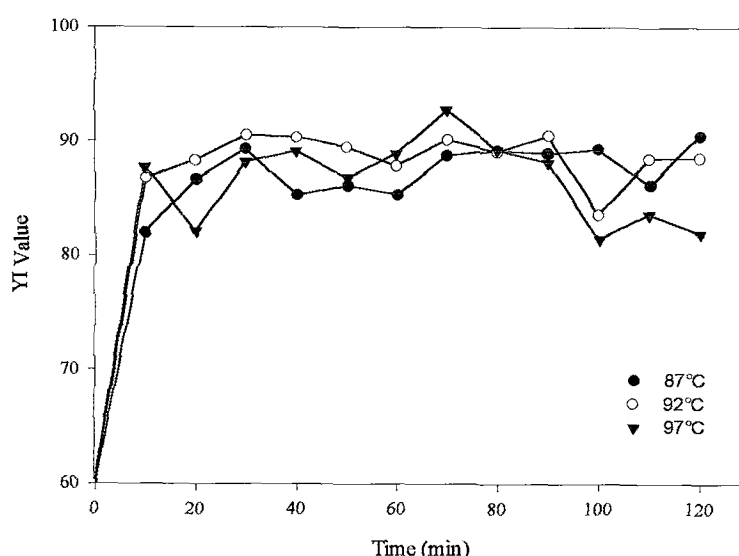


Figure 3.164 Change in YI-value of rye during atmospheric cooking

e. Change in texture of rye during atmospheric cooking

The measured values of the $F_{\max}$ and A_p were given in Figures 3.165 and 3.166, respectively. Both of the textural properties decreased ($P < 0.05$) sharply during the first 20 minutes at all cooking temperatures. However, cooking temperatures had no significant ($P > 0.05$) effect on the both properties. Figures 3.165 and 3.166 illustrated that, softening of rye increased ($P < 0.05$) during cooking, this was expected result for atmospheric cooking operation due to direct contact of the cooking water in cooker.

Textural results affected from deformation of the kernel as observed (i.e. 80, 70 and 50 minutes at 87, 92 and 97°C, respectively) then fluctuations were observed. In general deformed kernels were softer than undeformed one due to popping of the kernel and the leaching out of the inner constituents (additionally bran of rye losses its protecting property against the external forces).

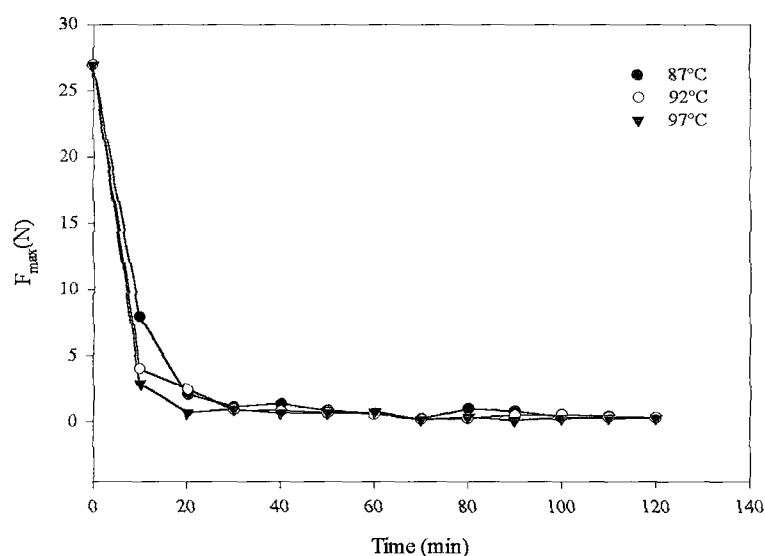


Figure 3.165 Change in F_{max} of rye during atmospheric cooking

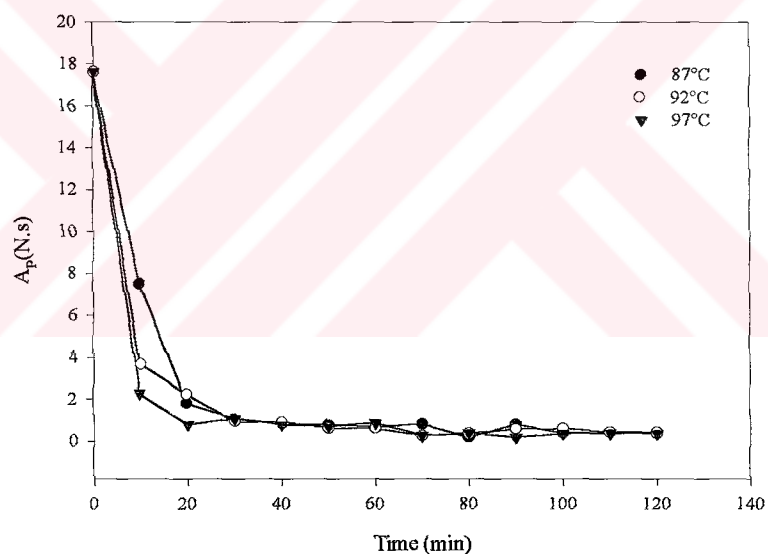


Figure 3.166 Change in A_p of rye during atmospheric cooking

3.2.2.2.3 Changes in soaking water

a. Change in pH value of cooking water of rye

The change in pH of cooking water was illustrated in Figure 3.167 during cooking. The pH of the cooking water decreased ($P < 0.05$) sharply during first 10 minutes then became constant between about 5.60-6.00. It was found that increase in cooking temperature after 70 minutes significantly ($P < 0.05$) decreased the pH of the cooking water. In addition, at the end of the cooking operation, acidic pH was obtained and it

did not change significantly ($P>0.05$) due to the leaching of the acidic and/or buffering compounds from rye into cooking water during cooking.

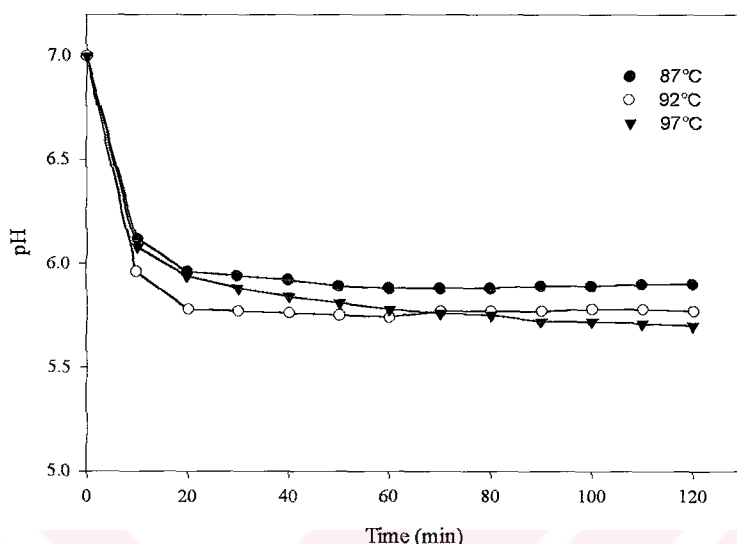


Figure 3.167 Change in pH value of cooking water during atmospheric cooking of rye

b. Change in conductivity of cooking water of rye

The change in conductivity of cooking water of rye was given in Figure 3.168. Initial conductivity of cooking water was $6.5 \mu\text{S}$ at pH 7. Cooking time and temperature had significant ($P<0.05$) effect on conductivity of the cooking water during atmospheric cooking of rye. During cooking operation, conductivity of the cooking water increased ($P<0.05$) with increasing cooking temperature. Conductivity value of the cooking water of rye was higher than soaking water of rye due to the effect of temperature on the leaching of minerals from rye and occurring of soft structure of rye during atmospheric cooking. It was interesting to note that conductivity value of the cooking water of rye (Figure 3.168) was lower than the cooking water of soybean (Figure 3.146) which may be due to higher ash content of soybean (4.84%) than rye (1.53%).

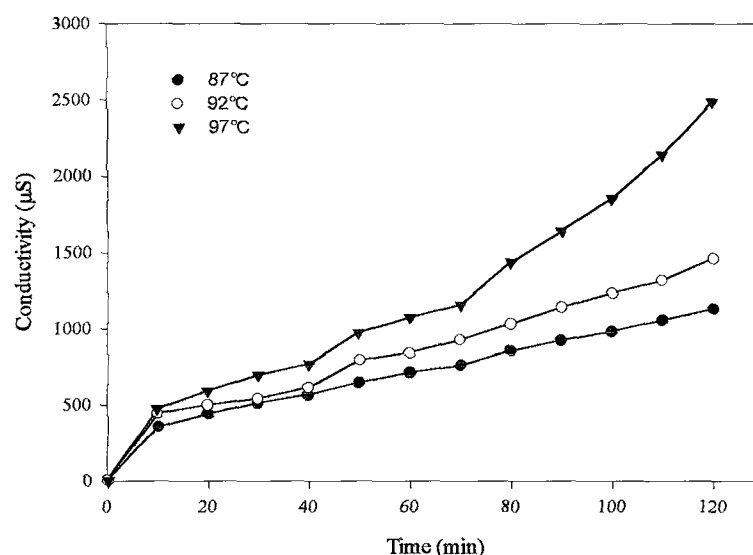


Figure 3.168 Change in conductivity of cooking water during atmospheric cooking of rye

c. Change in turbidity/absorbance of cooking water of rye

The change in turbidity/absorbance of the cooking water of rye was given in Figure 3.169. It was found that cooking time and temperature had significant ($P < 0.05$) effect on the turbidity of the cooking water. Increase in cooking temperature increased ($P < 0.05$) turbidity of water. The highest turbidity was observed at 97°C. It can be due to the deformation effect of high temperature (97°C) on the structure of the kernel. Turbidity value of the cooking water of rye (Figure 3.169) was higher than that of soybean (Figure 3.147) at all cooking temperatures. The reason of this could be higher starch content of rye (60.6%) than soybean (0.47%). Starch can easily leach out and dissolve in water and cause turbidity. Results reveal the fact that dissolved starch molecules are governing turbidity rather than protein, because soybean has higher protein (37.7%) than rye (10.4%).

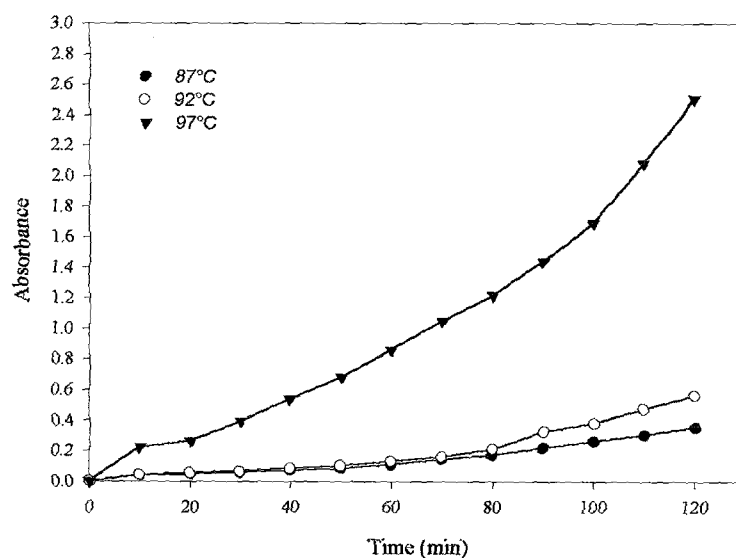


Figure 3.169 Change in absorbance of cooking water during atmospheric cooking of rye

d. Change in soluble solids content of cooking water of rye

Change in soluble solids content of the cooking water of rye was given in Figure 3.170. It was found that cooking time and temperature had significant ($P < 0.05$) effect on soluble solids content. During the first 40 minutes, increase in cooking temperature decreased ($P < 0.05$) soluble solids content. Soluble solids content at 97°C after 50 minutes of cooking increased sharply ($P < 0.05$) due to deformation of rye i.e. leaching of soluble compounds into the cooking water.

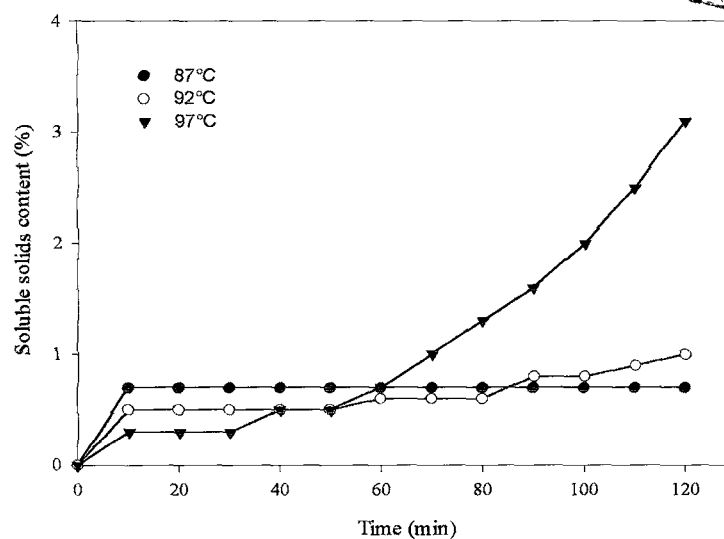


Figure 3.170 Change in soluble solids content of cooking water during atmospheric cooking of rye

e. Change in color of cooking water of rye

Changes in the color values, L, a, b and YI-values, of the cooking water were given in Figures 3.171, 3.172, 3.173 and 3.174, respectively. There were no significant ($P>0.05$) effect of cooking time and temperature on the L-value. During cooking at 97°C, after deformation of rye i.e. 50 minutes, the L-value increased ($P<0.05$). The L-value at 87 and 92°C decreased steadily during cooking (Figure 3.171).

The a-value of the cooking water significantly ($P<0.05$) affected from cooking time and temperature. The a-value at 87 and 92°C decreased during first 10 minutes then increased gradually in contrast to that at 97°C, however it increased ($P<0.05$) up to 40 minutes at 97°C then decreased up to 100 minutes due to starting of the deformation of rye. Finally, the a-value increased ($P<0.05$) until the end of the cooking period at 97°C. The decrease in the a-value between 40 and 100 minutes can be due to the excessive leaching of starch (i.e. deformation of rye). Also, final increasing stage for the a-value can be explained as the formation of browning pigments.

The b and YI-values were significantly ($P<0.05$) affected from cooking time, but not ($P>0.05$) temperature. Both color values at 87 and 92°C increased steadily during cooking. Increase in the b and YI values are expected results due to browning and

leaching. But, change in both values at 97°C (Figures 3.173 and 3.174) can be explained by deformation of rye and leaching of coloring compounds. Because, YI-value at 97°C increased ($P<0.05$) during first 40 minutes then decreased ($P<0.05$) until 80 minutes, and then started to increase until the end of the cooking operation.

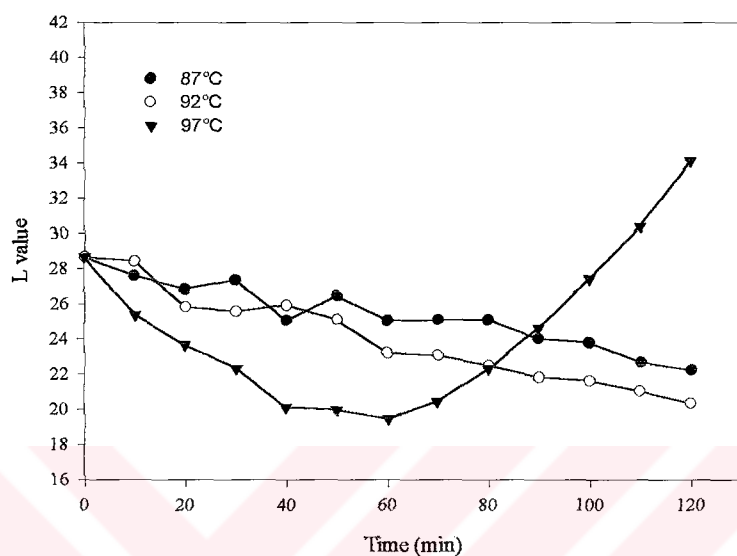


Figure 3.171 Change in L-value of cooking water during atmospheric cooking of rye

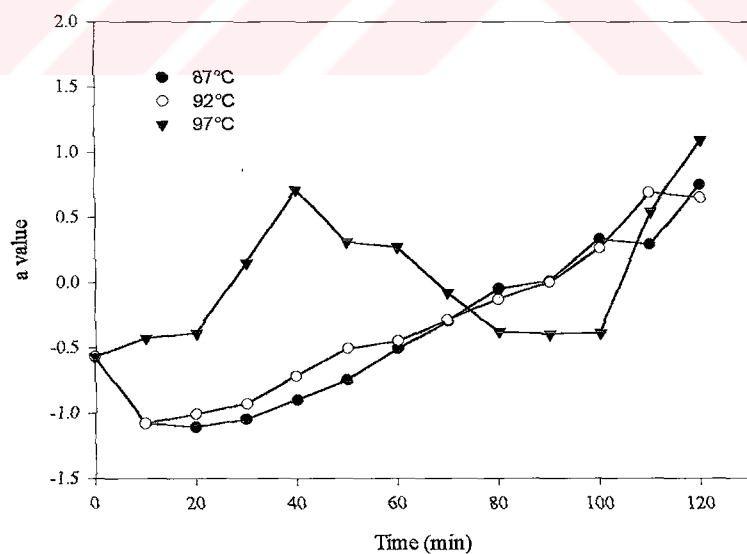


Figure 3.172 Change in a-value of cooking water during atmospheric cooking of rye

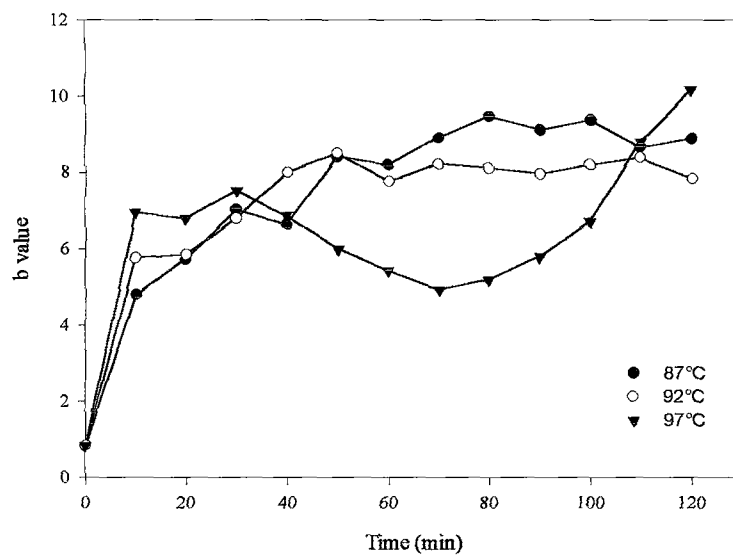


Figure 3.173 Change in b-value of cooking water during atmospheric cooking of rye

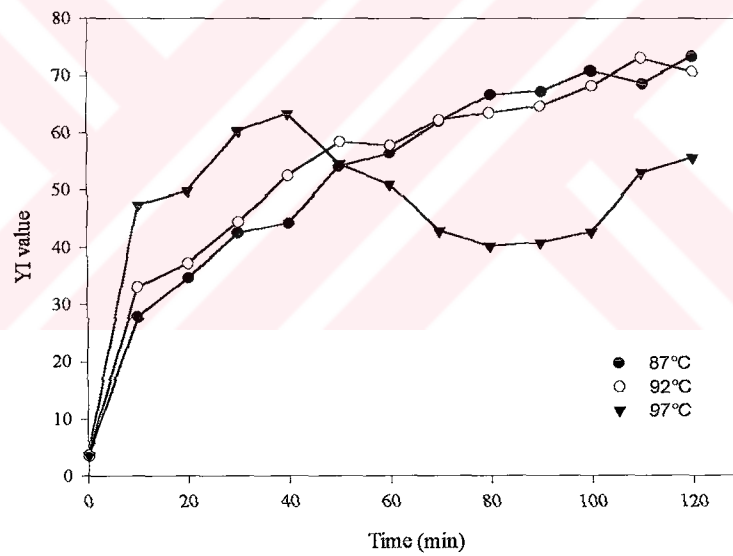


Figure 3.174 Change in YI-value of cooking water during atmospheric cooking of rye

3.2.3. Pressure cooking

3.2.3.1. Pressure cooking of soybean

Soybean and rye were cooked under pressure i.e. 10 (108°C), 15 (114°C) and 18 psig (118°C) at each of 3, 6 and 9 minutes after the soaking operation. These parameters were selected from study of Bayram (1997) which were used in study on pressure cooking of wheat to produce bulgur. During the pressure cooking operation, samples were not in contact with water, but with live-steam.

To obtain 40% moisture in soybean, optimum soaking was determined as 30°C for 20 minutes (in de-ionized water and pH 7). The aim of soaking of soybean and rye was to reach 40% moisture before pressure cooking operation. It was previously explained that, the effect of pH on physical properties of soybean and rye was not significant. Therefore, pH 7 was selected as optimum soaking pH value. In order to decrease the effect of the soaking temperature on physical and chemical properties of soybean and rye during the soaking operation 30°C was preferred and optimum soaking time was determined as based on moisture content i.e. 40%. In order to perform parallel study with soybean, soaking of rye was carried out at 30°C (pH 7). As explained previously rye did not reach to 40% of moisture during 120 minutes of soaking. Therefore, prolonged soaking of rye 160 minutes at 30°C (pH 7) was made until it reached to 40% moisture (Figures A1-A8).

Dimensions, weight, density, moisture content, color and texture of soybean and rye were determined after and before pressure cooking. In contrast to soaking and atmospheric cooking operations, there was no change in properties of cooking water during pressure cooking. Live steam were in contact with food. Therefore, there were no leaching occurred during process. In this section, zero time in figures related with initial values of the responses before pressure cooking (i.e. point that after optimum soaking).

3.2.3.1.1. Determination of cooking degree of soybean

During pressure cooking, the cooking degree of soybean was determined at 10, 15 and 18 psig using ΔH values (Table 3.3) and calibration curve (Figure 3.129). The cooking degrees were given in Figure 3.175.

The 100% cooking degree was not obtained at 10 psig and 99.78% cooking was obtained at 18 psig for 3 minutes cooking. As expected, increasing pressure decreased ($P<0.05$) the cooking time (i.e. increase the cooking degree). According to the cooking degree values, optimum cooking time (for 100% of cooking) for soybean was determined as nearly 6 minutes at 15 psig.

Table 3.3 Values of ΔH of soybean at 10, 15 and 18 psig for pressure cooking

Time (min)	ΔH (J/g)		
	Pressure (psig)		
	10	15	18
3	-151.470	-140.242	-139.454
6	-145.275	-139.272	-139.241
9	-141.158	-139.079	-139.008

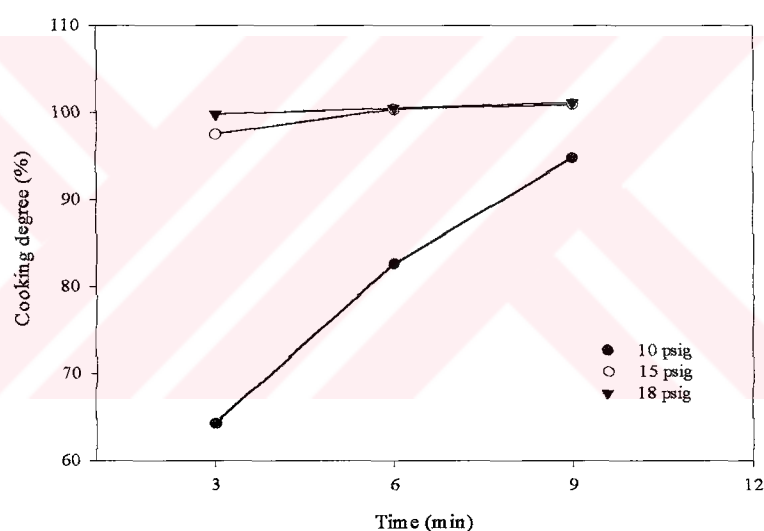


Figure 3.175 Cooking degree of soybean at 10, 15 and 18 psig for pressure cooking

3.2.3.1.2. Changes in the physical attributes of soybean

There was no direct contact of water with sample. Therefore, there were only changes in the physical attributes of soybean but not in water in contrast to the soaking and atmospheric cooking operations.

a. Changes in the dimensions of the soybean kernel

During pressure cooking, changes in three dimensions of the soybean kernel were given in Figures 3.176-3.178. It was found that cooking time and pressure had significant effect ($P<0.05$) on each dimension of the soybean kernel.

The x-value of the soybean kernel at 10 and 18 psig increased ($P<0.05$) up to 3 minutes of cooking, then decreased ($P<0.05$). Negative percent change in the x-value was obtained at 15 psig, and it decreased ($P<0.05$) with increase in cooking time. Thus, the major change was observed at 15 psig of cooking. It was found that shrinkage occurred in length of the soybean kernel during pressure cooking.

Similar shrinkage also occurred in the y-value of the soybean kernel (Figure 3.177) and negative percent changes were obtained in y-value at all pressures during soaking. It was interesting that the minor change occurred in z-value of the soybean kernel (Figure 3.178) at 15 psig in contrast to the x and y-values. In addition, increase in cooking degree generally decreased ($P<0.05$) the percent changes in all dimensions.

Fluctuations were observed in the changes of dimensions (x, y and z-values) during pressure cooking (Figures 3.176-3.178). This may be partially due to the unsteady discharge pressure from cooker as explained previously at the end of the cooking operation. As a result, shrinkages may be occurred in dimensions of the soybean kernel during the pressure cooking operation due to unsteady pressure discharging and pressure differences. During pressure cooking, shrinking of the kernel increases its firmness so that, it may have higher resistance to deformation.

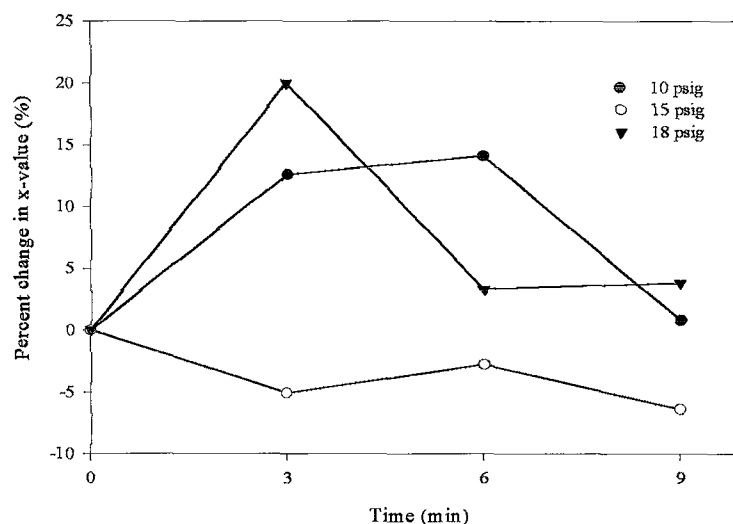


Figure 3.176 Percent change in x-value of the soybean kernel during pressure cooking

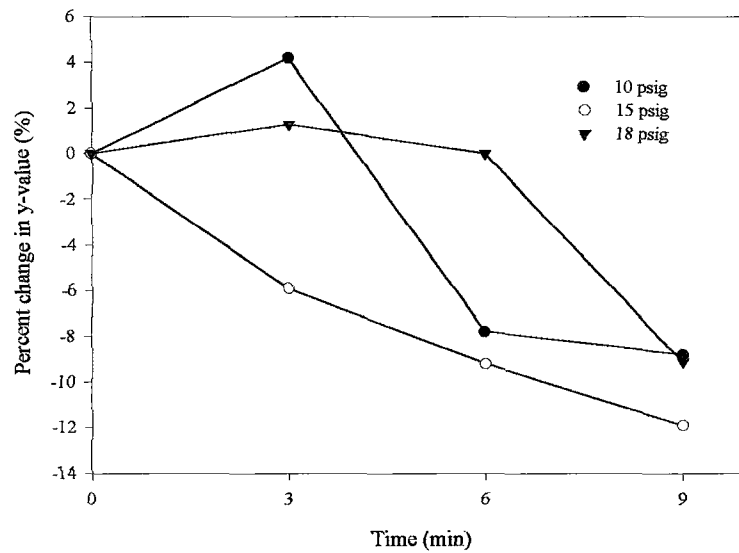


Figure 3.177 Percent change in y-value of the soybean kernel during pressure cooking

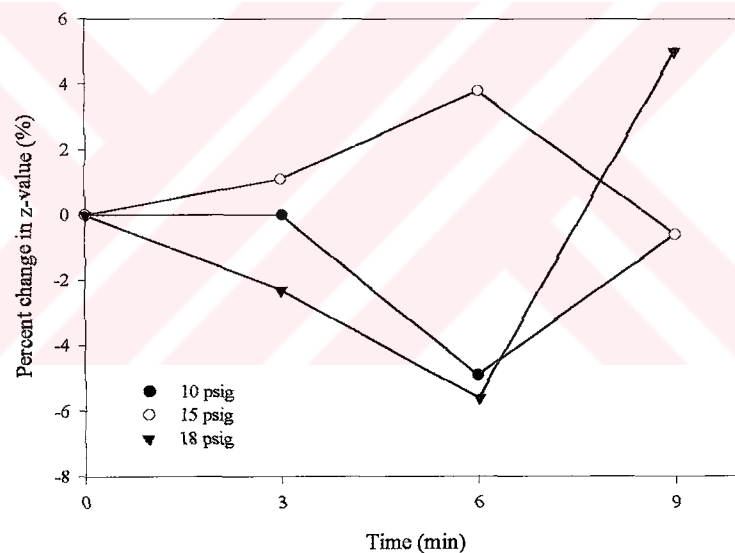


Figure 3.178 Percent change in z-value of the soybean kernel during pressure cooking

b. Changes in weight, volume and density of the soybean kernel

The percent change in weight, volume and density were given in Figures 3.179, 3.180 and 3.181, respectively. Cooking time and pressure had significant effect ($P < 0.05$) on the change of weight, volume and density.

The percent change in weight at 10 psig, decreased ($P < 0.05$) during cooking (Figure 3.179), which may be due to incomplete cooking of soybean and shrinkage effect at

this pressure. Increase in cooking degree increased ($P<0.05$) the change in weight. Therefore, water-holding capacity of soybean kernel decreased with increased cooking degree of soybean. This can be correlated with the changes in weight of the soybean kernel at 15 and 18 psig. Because, 100% cooking degree was obtained at nearly 6 minutes for both pressure applications. Thus, change in weight decreased ($P<0.05$) up to 100% cooking degree, then it increased ($P<0.05$) due to overcooking. It can be said that, change in weight decreased until cooking of soybean due to low water-holding capacity, then increased due to overcooking of soybean after optimum cooking.

The change in volume of the soybean kernel decreased ($P<0.05$) during pressure cooking at all pressures (Figures 3.180). After 6 minutes of cooking at each pressure, negative volume changes were obtained due to shrinkage of the soybean kernel. In addition, the change in volume was higher than that in weight of the soybean kernel. Cooking conditions were more effective on volume than weight. During the soaking and atmospheric cooking operations that previously explained, the change in volume (as positive) was higher than that in weight, vice versa it (as negative) was more decreased than weight during the pressure cooking operation. Also, during the soaking and atmospheric cooking operations negative density change in the soybean kernel was obtained due to this larger change in volume than weight. Until the optimum cooking degree is reached (100%), the change in density was not important and it was nearly zero, but afterwards (after 6 minutes of cooking) it increased significantly (Figure 3.181). These findings are important in designing industrial cookers.

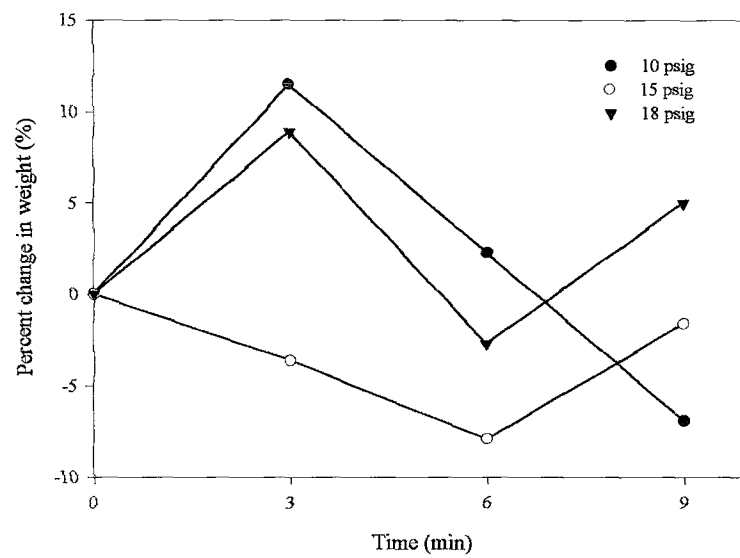


Figure 3.179 Percent change in weight of the soybean kernel during pressure cooking

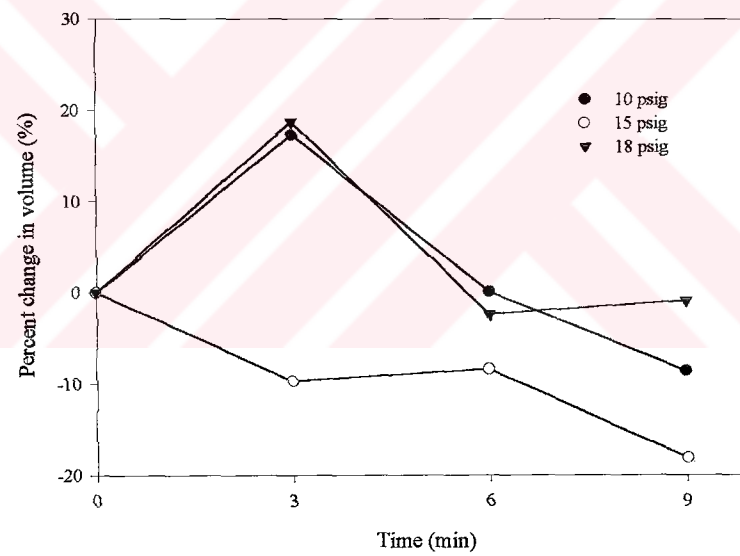


Figure 3.180 Percent change in volume of the soybean kernel during pressure cooking

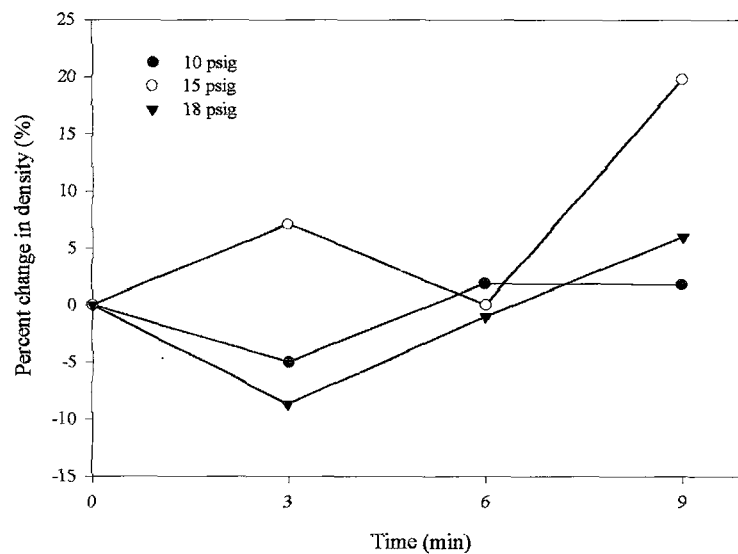


Figure 3.181 Percent change in density of the soybean kernel during pressure cooking

c. Moisture content of soybean during pressure cooking

The change in moisture content of soybean was given in Figure 3.182. Cooking time and temperature had significant effect ($P < 0.05$) on the moisture content of soybean. As explained in previous section, before the pressure cooking operation, soaking should be made to increase the moisture of sample to nearly 40%. Therefore, soaking of soybean was carried out at 30°C for 20 minutes, and 43.1% of moisture was obtained to achieve the pressure cooking of soybean.

During pressure cooking, increasing cooking time decreased ($P < 0.05$) the moisture of soybean. The lowest moisture content was obtained at 18 psig at 6 and 9 minutes. The moisture content at 18 psig was lower than initial moisture content of soybean (i.e. 43.1%) at optimum cooking degree. This decrease in the moisture was good for subsequent drying operation due to decrease duty of dryer. Moisture at all pressure and time was nearly 43%. So, it was found that pressure cooking did not change ($P < 0.05$) the amount of moisture in soybean after cooking operation. Besides shorter processing time, decreasing drying duty and water usage are important advantages of pressure cooking.

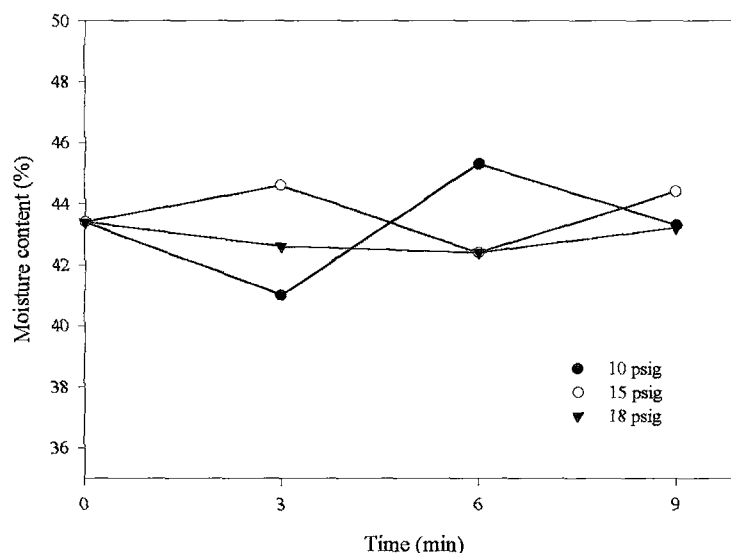


Figure 3.182 Moisture content of soybean during pressure cooking

d. Color of soybean during pressure cooking operation

The color changes were given in Figures 3.183, 3.184, 3.185 and 3.186 for L, a, b and YI-values, respectively. For all color values, cooking time and pressure were significantly effective ($P < 0.05$).

During cooking period, the L-value of soybean decreased ($P < 0.05$) with increasing cooking pressure. It means that, increase in pressure (or increase in cooking temperature due to pressure) decreased ($P < 0.05$) the lightness of soybean. As expected due to browning of soybean. At optimum cooking degree, the L-value was nearly same with initial L-value of soybean and is better than that for atmospheric cooking.

The positive a-value was obtained during cooking which means that redness exist in soybean (Figure 3.184). The a-value at 10 and 18 psig increased ($P < 0.05$) between 3 and 9 minutes of cooking in contrast to decreasing at 15 psig. As expected, the a-value of soybean at optimum cooking degree was greater than initial a-value, that illustrated the increase in redness due to browning.

The b-value decreased ($P < 0.05$) when compared with initial b-value of soybean before pressure cooking. The b-value of soybean at 10 and 18 psig increased

($P < 0.05$) between 3 and 6 minutes in contrast to decrease at 15 psig, then it decreased ($P < 0.05$) at 15 and 18 psig in contrast to increase at 10 psig (Figure 3.185). During overall cooking period, the b-value at 10 psig increased ($P < 0.05$) gradually. It may be due to incomplete cooking of soybean that may cause dominant white appearance on sample (i.e. cooking degree was less than 100%). At 15 and 18 psig, the b-value started to decrease after optimum cooking degree, may be due to overcooking of soybean at these pressures after 6 minutes of cooking.

As explained previously, the YI-value shows the degree of clarity, where low YI-value indicates high clarity and pressure cooking increased ($P < 0.05$) clarity of soybean (Figure 3.186). It may be due to the effect of gelation, since gelation increases transparency of soybean. Clarity of soybean during pressure cooking at 15 psig increased ($P < 0.05$) steadily, although at 10 psig decreased ($P < 0.05$). Interesting to note that during cooking at 18 psig, clarity decreased ($P < 0.05$) until 6 minutes (100% of cooking degree) then increased ($P < 0.05$) which may be explained by overcooking of soybean.

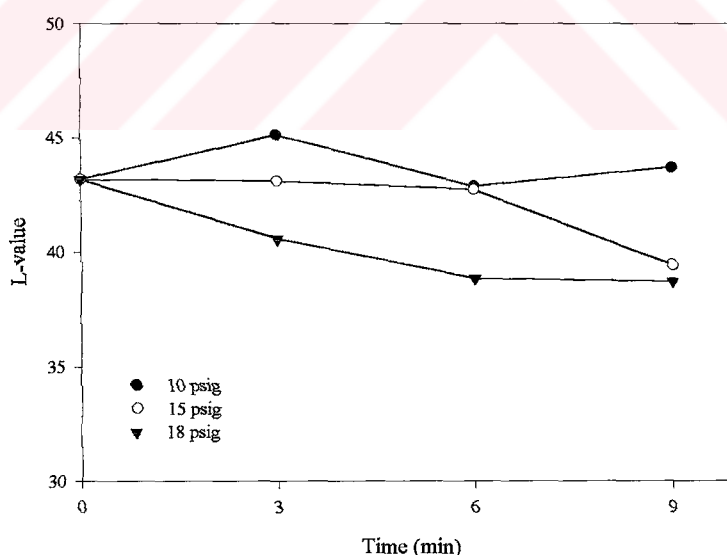


Figure 3.183 Change in L-value of soybean during pressure cooking

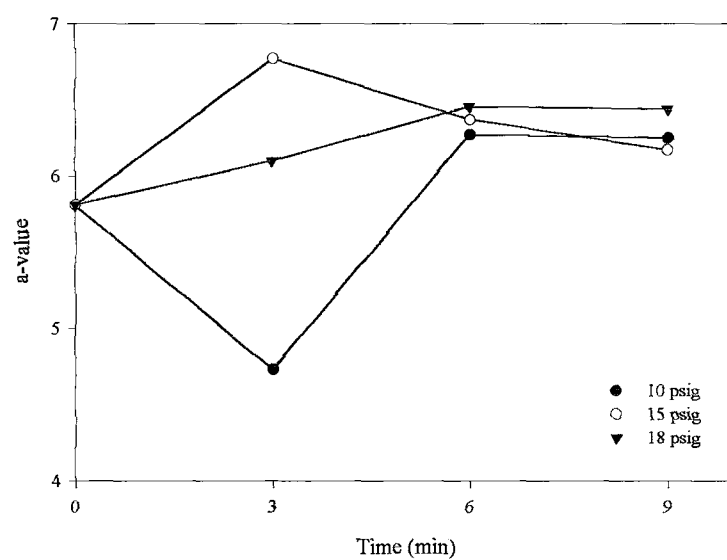


Figure 3.184 Change in a-value of soybean during pressure cooking

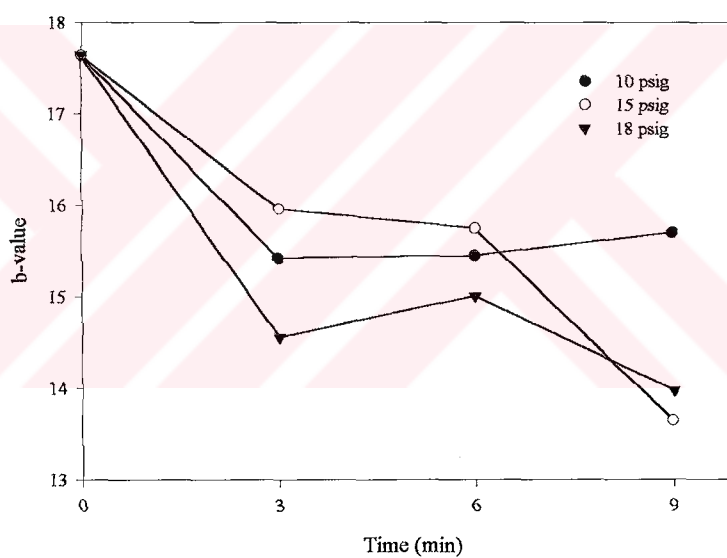


Figure 3.185 Change in b-value of soybean during pressure cooking

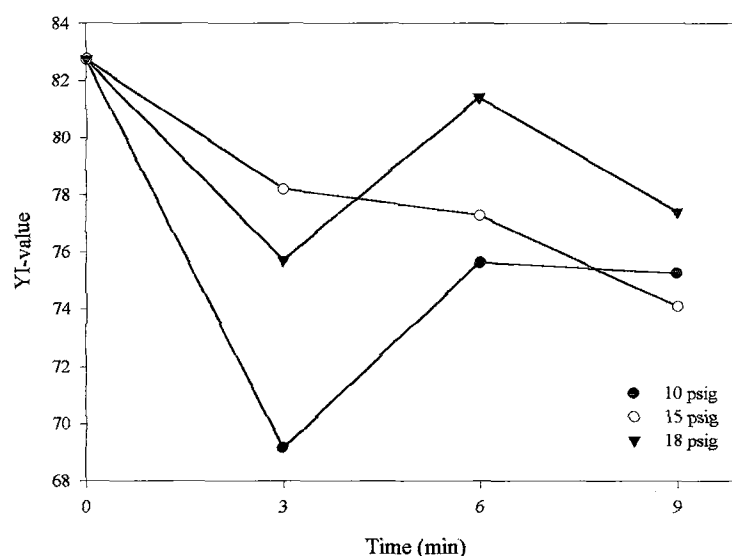


Figure 3.186 Change in YI-value of soybean during pressure cooking

e. Change in texture of soybean during pressure cooking

The $F_{\max}$ and A_p -values were given in Figures 3.187 and 3.188, respectively. It was found that cooking time and pressure had significant effect ($P < 0.05$) on both textural values. During cooking, both $F_{\max}$ and A_p -values decreased ($P < 0.05$) at all pressures. In turn, hardness of soybean decreased ($P < 0.05$). Increase in cooking-pressure decreased ($P < 0.05$) the $F_{\max}$ and A_p -values, as explained.

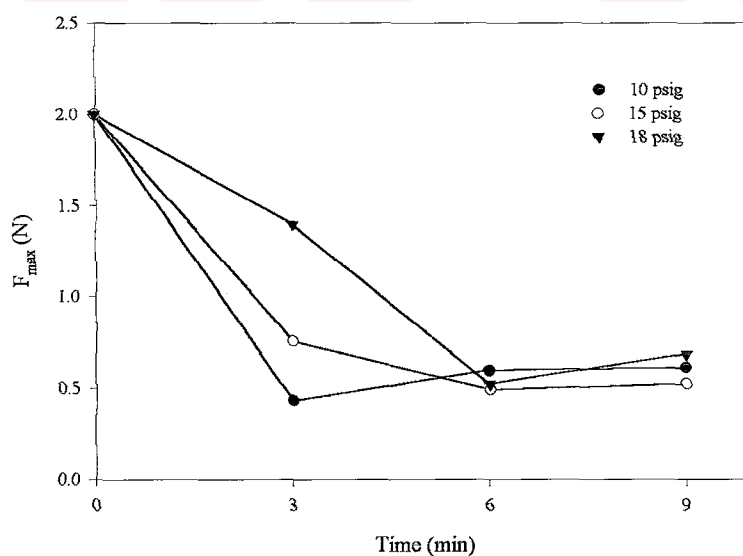


Figure 3.187 Change in $F_{\max}$ of soybean during pressure cooking

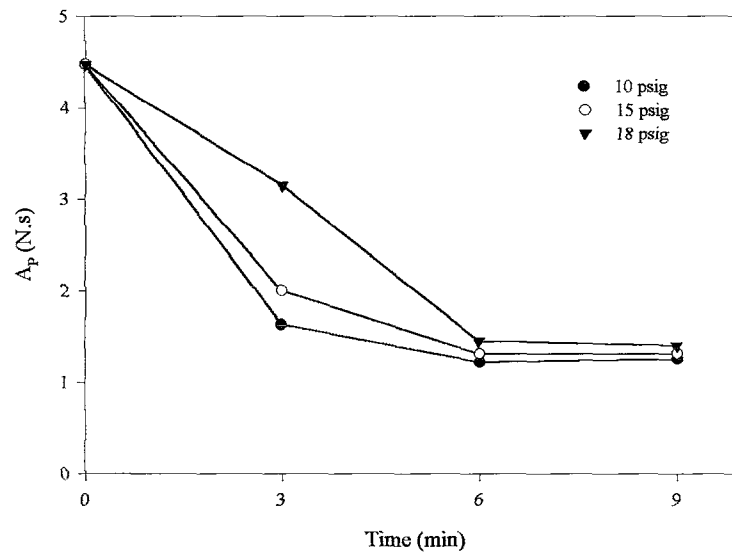


Figure 3.188 Change in A_p of soybean during pressure cooking

3.2.3.2. Pressure cooking of rye

3.2.3.2.1. Determination of cooking degree of rye

The cooking degree of rye during pressure cooking was determined at 10, 15 and 18 psig using ΔH (Table 3.4) and calibration curve (Figure 3.130). The cooking degree values of rye were given in Figure 3.189. It was found that optimum cooking time at 100% of cooking degree for rye was determined as 9 minutes at 15 psig. Similar with soybean, cooking degree did not reach 100% at 10 psig during pressure cooking and it was 100% at 18 psig (at 6 and 9 minutes cooking). In order to perform parallelism on study and decrease the effects of the cooking pressure on product, 15 psig was selected rather than 18 psig for rye (similar to soybean).

Table 3.4 Values of ΔH of rye at 10, 15 and 18 psig for pressure cooking

Time (min)	ΔH (J/g)		
	Pressure (psig)		
	10	15	18
3	-275.765	-252.972	-244.516
6	-269.376	-246.984	-243.199
9	-259.558	-243.237	-242.548

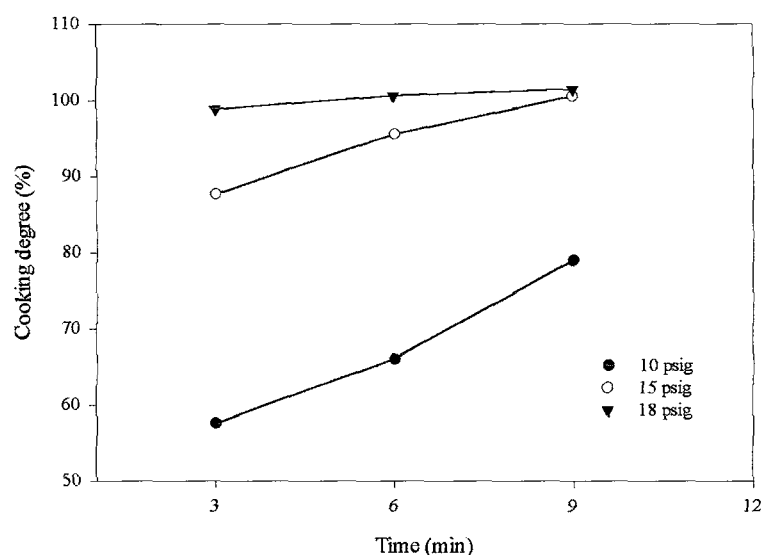


Figure 3.189 Cooking degree of rye at 10, 15 and 18 psig for pressure cooking

3.2.3.2.2. Changes in the physical attributes of rye

a. Changes in the dimensions of the rye kernel

The percent changes in dimensions (x, y and z-value) were given in Figures 3.190-3.192. Cooking time and pressure had significant effect ($P < 0.05$) on the change of dimensions of the rye kernel.

Negative change in the x-value was obtained at 3 and 6 minutes for all pressures (Figure 3.190). When cooking was carried out for 9 minutes at each pressure, the change in the x-value increased ($P < 0.05$) positively. Negative change in the a-value illustrates decrease in length. It was found that increasing cooking pressure decreased ($P < 0.05$) the change in the x-value.

The effect of cooking pressure was found to be the same the y and z-values. The major changes in both values were observed at 15 psig, in contrast to minimum changes at 10 psig. The effect of 18 psig of cooking on the y and z-values were between 10 and 15 psig. It may be due to overcooking effect of 15 psig on rye.

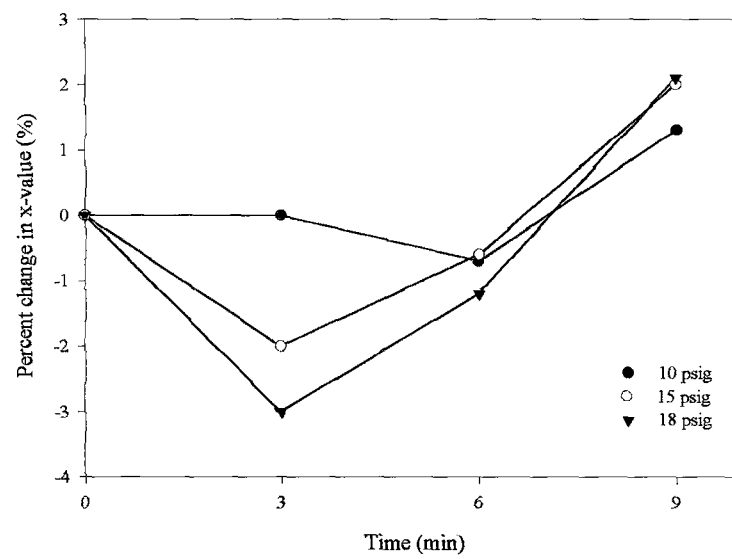


Figure 3.190 Percent change in x-value of the rye kernel during pressure cooking

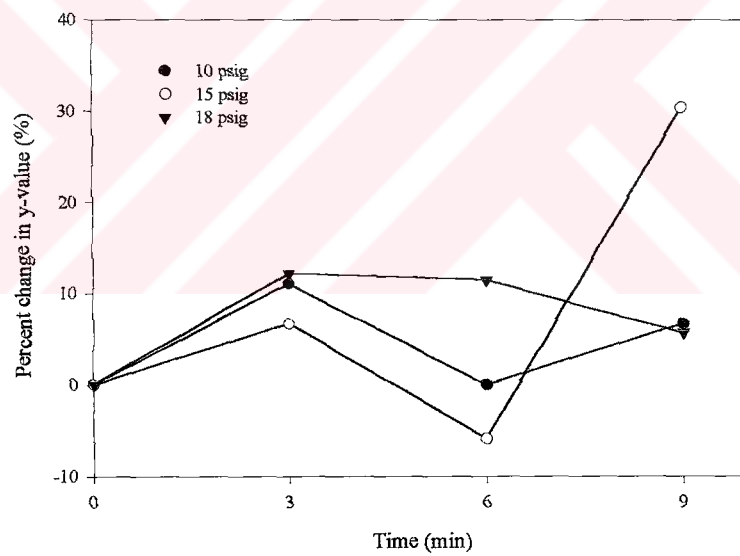


Figure 3.191 Percent change in y-value of the rye kernel during pressure cooking

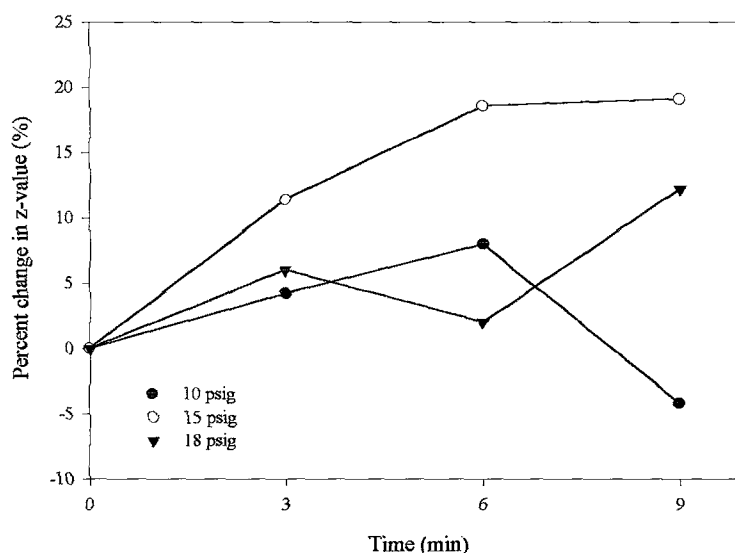


Figure 3.192 Percent change in z-value of the rye kernel during pressure cooking

b. Changes in weight, volume and density of the rye kernel

Percent change in weight, volume and density were given in Figures 3.193, 3.194 and 3.195, respectively. Cooking time and pressure had significant effect ($P < 0.05$) on each one properly.

The change in weight at 15 psig increased ($P < 0.05$) during cooking. Trends at 10 and 18 psig were similar (Figure 3.193) and the change in weight at both pressures increased ($P < 0.05$) up to 6 minutes, and then decreased ($P < 0.05$) steadily.

Statistically significant change ($P < 0.05$) in volume was obtained at 15 psig, which was similar to the change in weight ($P < 0.05$) (Figures 3.193 and 3.194). The change in volume during cooking at 10 psig decreased ($P < 0.05$) gradually due to incomplete cooking of rye and shrinkage (i.e. $< 100\%$). Similar trend was obtained also at 15 and 18 psig. and after the cooking of rye completed, volume started to increase (Figure 3.194). The change in volume was lower than that in weight, except 9 minutes of cooking at 15 psig, which was similar in pressure cooking of soybean as described previously. This fluctuation at 15 psig might be due to un-controlled pressure discharging rate after completion of the pressure cooking operation.

The change in density increased ($P<0.05$) up to 6 minutes of cooking then, decreased ($P<0.05$) gradually at 9 minutes at all pressures (Figure 3.195) due to different rate of the changes in volume and weight.

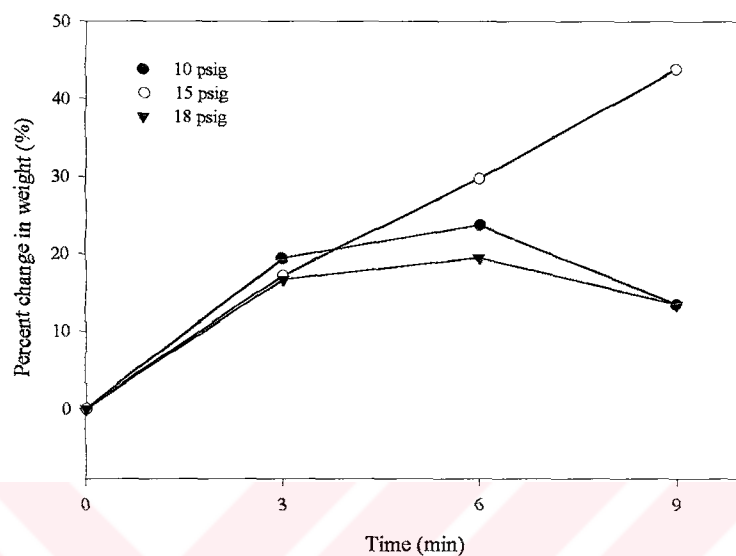


Figure 3.193 Percent change in weight of the rye kernel during pressure cooking

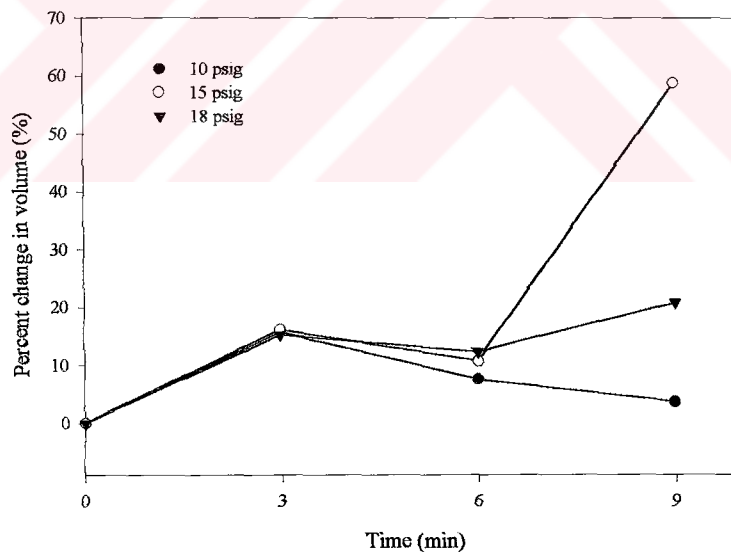


Figure 3.194 Percent change in volume of the rye kernel during pressure cooking

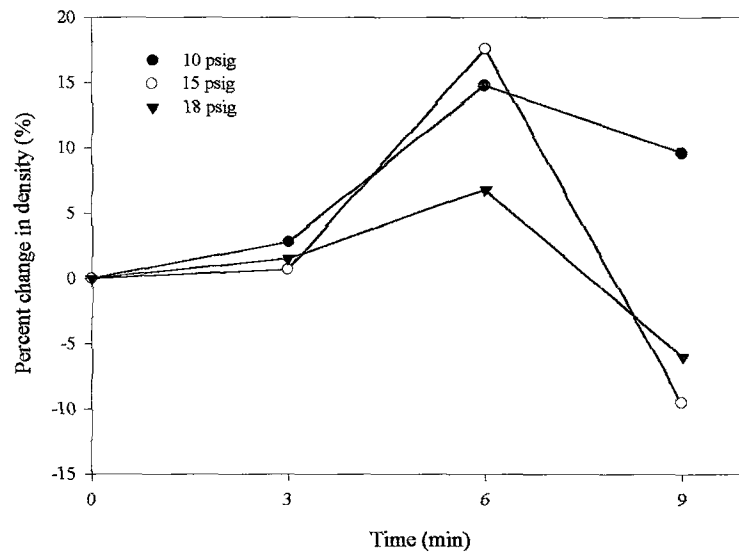


Figure 3.195 Percent change in density of the rye kernel during pressure cooking

c. Moisture content of rye during pressure cooking

Moisture content was determined as 40.1% after optimum soaking operation (i.e. 160 minutes, 30°C, pH 7). In other words, initial moisture content of rye before pressure cooking was 40.1%. Moisture content results were illustrated in Figure 3.196. It was found that cooking time and pressure had significant effect ($P < 0.05$) on the moisture content of rye.

Moisture content of rye during cooking increased ($P < 0.05$) gradually at each pressure. It was interesting that trend at 15 psig had nearly the same as in weight change (Figure 3.193). At each pressure and time, the moisture of rye was found in the range of 36-42%. Pressure cooking could be a more suitable method for cooking of rye than traditional atmospheric cooking because of advantage of drying operation (i.e. obtaining nearly 40% moisture).

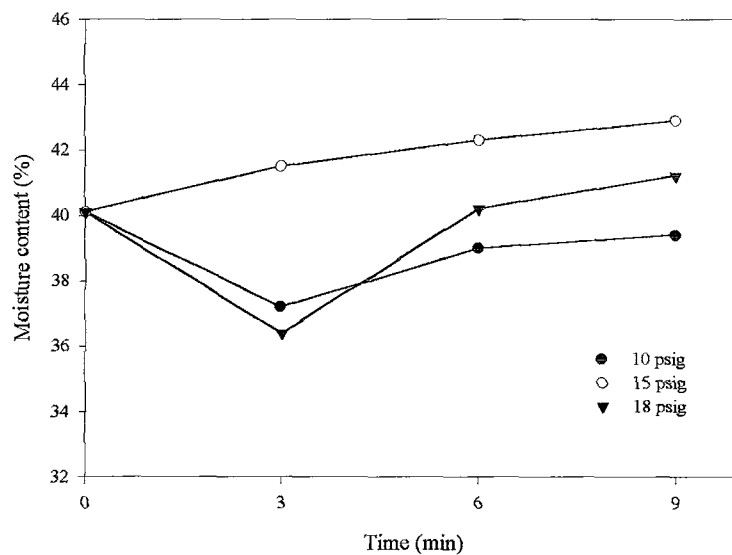


Figure 3.196 Moisture content of rye during pressure cooking

d. Color of rye during pressure cooking operation

The L, a, b and YI-value were illustrated in Figures 3.197, 3.198, 3.199 and 3.200, respectively. Statistically, there were significant effects of cooking time and pressure ($P < 0.05$) on all color values. The L-value at 10 psig decreased ($P < 0.05$) during cooking. It may be due to incomplete cooking of rye. It was interesting that L-value at 15 psig decreased ($P < 0.05$) up to 6 minutes then became nearly constant. But, the L-value at 18 psig increased ($P < 0.05$) up to this point then decreased ($P < 0.05$), gradually. According to these trends at different pressure levels, lightness of rye (L-value) had nearly similar values (nearly L was 36) at 100% of cooking degree (i.e. 100% of cooking degree at 9 minutes/15 psig, and 6 minutes/18 psig). Additionally, the L-value at optimum cooking degree was similar with its initial value (i.e. 35.98).

As can be seen from Figure 3.197 for 18 psig of cooking that the L-value started to decrease after optimum cooking degree level, in other words between 6 and 9 minutes. As a result, it can be said that loss of lightness of rye started after optimum cooking degree, and it can be due to overcooking of product under pressure.

The a-value at 10 psig (Figure 3.198) decreased ($P < 0.05$) during cooking. But, the a-value at 15 and 18 psig decreased ($P < 0.05$) up to 6 minutes, then increased ($P < 0.05$). It may be related with the level of the cooking degree at certain points. Also, it was

found that in contrast to a-value of soybean, the a-value of rye decreased after pressure cooking operation when compared with its initial value (i.e. after optimum soaking operation). As it has been mentioned in the previous sections, it may be due to degradation of carotenoids and reddish pigments in rye or chemical difference between rye and soybean. Since, in soybean, chlorophyll is dominant pigment and redness is low when compared with rye. Therefore, in soybean, browning reactions may cause to increase the redness of product during pressure cooking of soybean.

Similar decrease in the a and L-values at 10 psig was also observed in the b and YI-values (Figures 3.199 and 3.200). Both b and YI-values at 18 psig increased ($P<0.05$) gradually during cooking. But, both of them at 15 psig, decreased ($P<0.05$) up to 6 minutes then increased ($P<0.05$) until 9 minutes. And, their initial values were greater than their cooked values; it may be due to degradation of yellowish pigment in rye during pressure cooking.

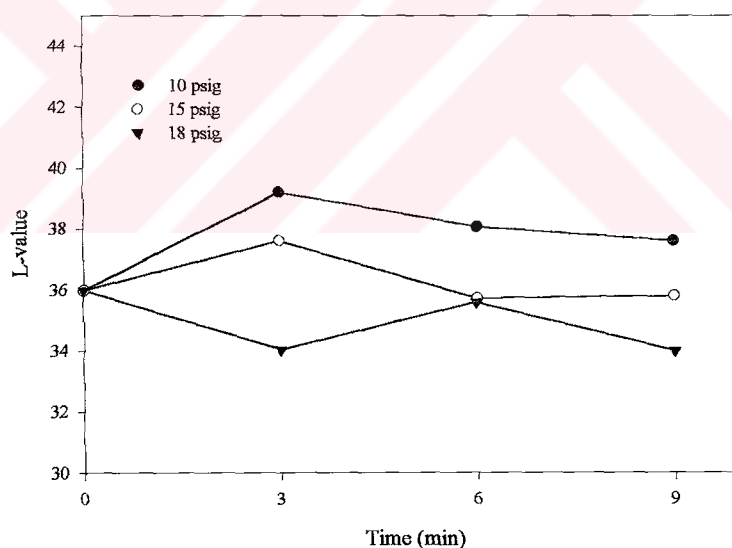


Figure 3.197 Change in L-value of rye during pressure cooking

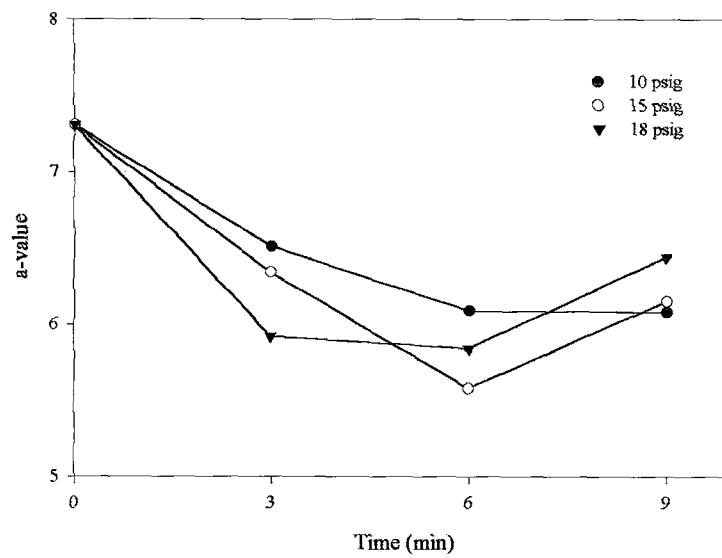


Figure 3.198 Change in a-value of rye during pressure cooking

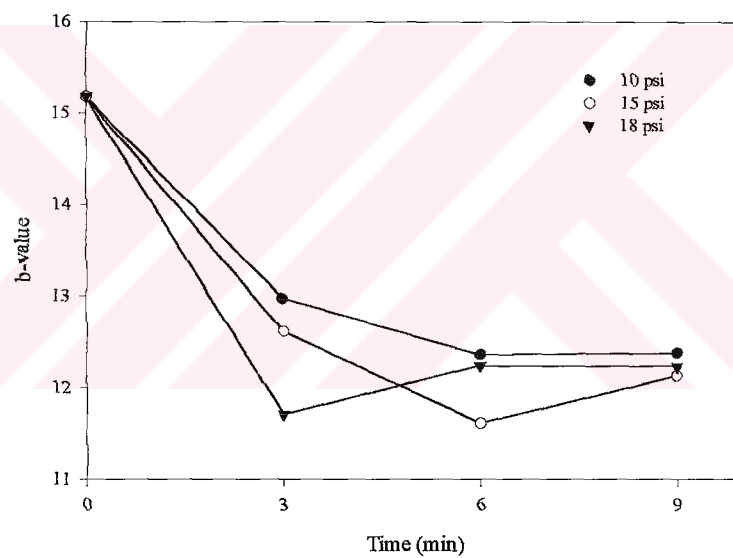


Figure 3.199 Change in b-value of rye during pressure cooking

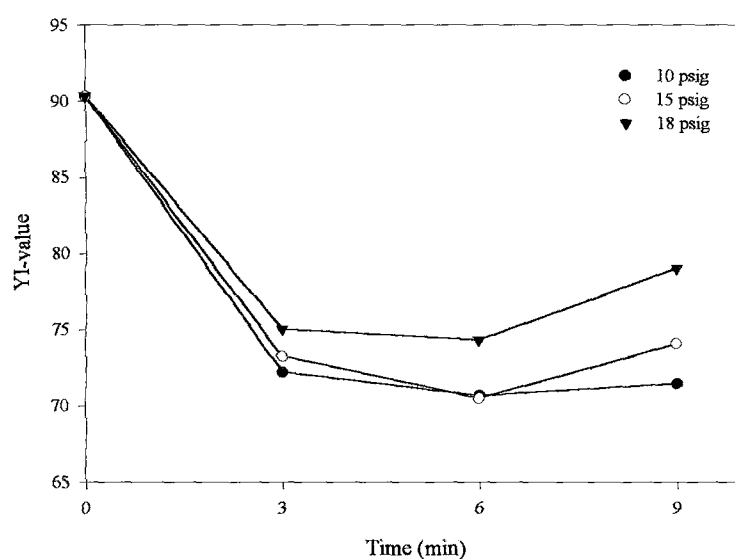


Figure 3.200 Change in YI-value of rye during pressure cooking

e. Change in texture of rye during pressure cooking

The $F_{\max}$ and A_p measurements were given in Figures 3.201 and 3.202, respectively. It was found that, there were significant effects ($P < 0.05$) of cooking time and pressure on both textural properties. The results of the cooking of soybean, as described previously, were similar to the results of the cooking of rye (i.e. softening during cooking).

The $F_{\max}$ and A_p -values decreased ($P < 0.05$) during cooking due to softening of rye. Due to incomplete cooking at 10 psig, $F_{\max}$ and A_p -values of rye at 10 psig was greater than other pressure applications.

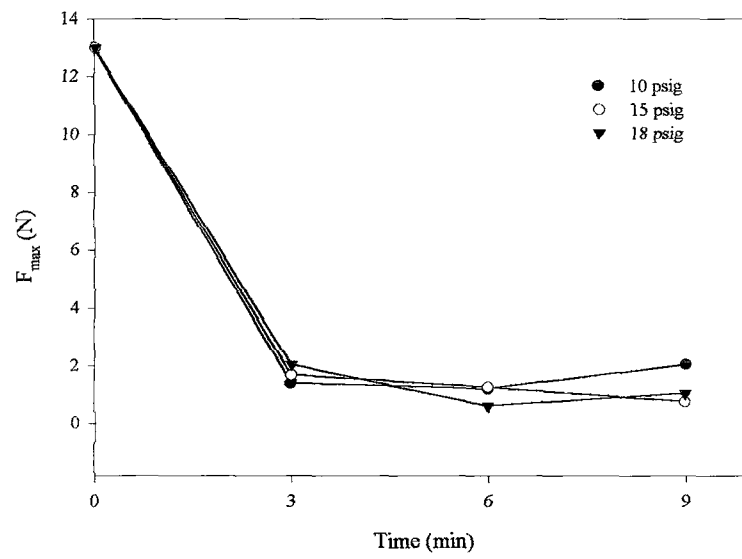


Figure 3.201 Change in $F_{\max}$ of rye during pressure cooking

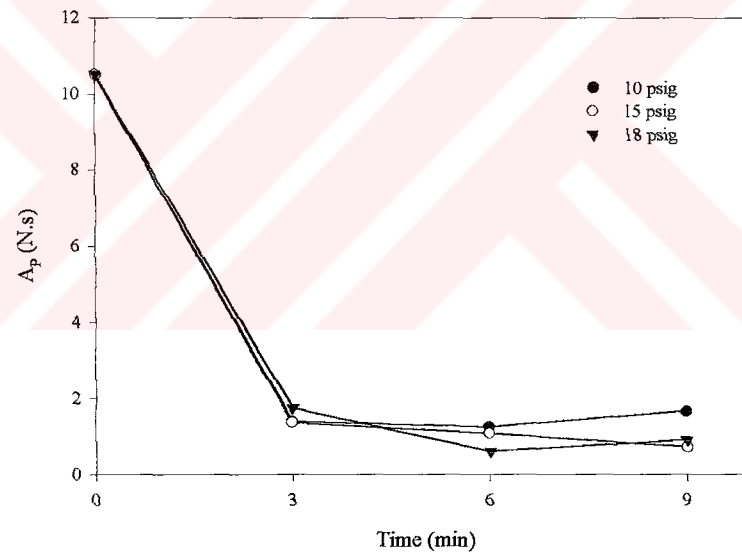


Figure 3.202 Change in A_p of rye during pressure cooking

3.2.4. Microwave cooking

In this section of study, microwave cooking was carried out at 350, 490 and 700 W after soaking operation (at optimum soaking time and temperature), similar to the pressure cooking operation. These parameters were obtained from study of Bayram (1997) on bulgur that produced from wheat. In general, food materials are cooked in water during processing with microwave. However, during cooking of food products using microwave system, moisture content of food products cannot be held at a specified level, which is a major disadvantage for bulgur production. Soaking was made to raise moisture content of soybean and rye to nearly 40% before microwave cooking. Soaking water was drained and then soybean and rye were cooked in microwave. During microwave cooking, simultaneous cooking and drying process occurs, which such product with lower moisture content (in turn, lesser further drying requirement) when compared with other cooking processes.

3.2.4.1. Microwave cooking of soybean

3.2.4.1.1. Determination of cooking degree of soybean

The cooking degrees of soybean were determined at 350, 490 and 700 W using ΔH values (Table 3.5) and calibration curve (Figure 3.129). Obtained cooking degrees were given in Figure 3.203. It was found that 100% of cooking degree was obtained at 490 and 700 W for nearly 6 minutes. At 700 W and 6 minutes, partial burning and charring of soybean was observed. Similar problem was also observed at 490 W and 9 minutes. At 350 W, 100% of cooking degree was not reached. Optimum cooking parameters were determined as 490 W for 6 minutes for microwave cooking of soybean.

Table 3.5 Values of ΔH of soybean at 350, 490 and 700 W for microwave cooking

Time (min)	ΔH (J/g)		
	Microwave power level (W)		
	350	490	700
3	-147.620	-141.966	-139.684
6	-145.265	-139.197	-139.042
9	-142.239	-138.849	-

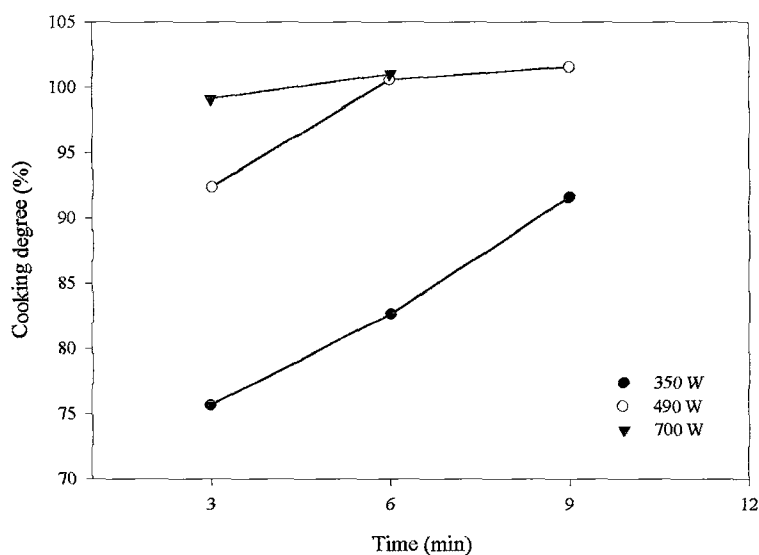


Figure 3.203 Cooking degree of soybean at 350, 490 and 700 W for microwave cooking

3.2.4.1.2. Changes in the physical attributes of soybean

a. Changes in the dimensions of the soybean kernel

The changes in the x-value of the soybean kernel at 350, 490 and 700 W were illustrated in Figure 3.204. It was found that cooking time and microwave power level had significant effect ($P < 0.05$) on the x-value. During microwave cooking at all microwave power levels, the x-value decreased ($P < 0.05$) except at 350 W and at 9 minutes of cooking. Therefore, decrease in the x-value can be explained by shrinkage of the soybean kernel due to drying together with cooking, as it is well known that food materials can shrink during drying (Geankoplis, 1984).

Similarly, both width of the soybean kernel (y and z-values) decreased ($P < 0.05$) during microwave cooking at all microwave power levels and negative changes were obtained due to shrinkage, where shrinkage was more effective on the y-value than the z-value (Figure 3.205 and 3.206). According to Duncan's multiple range test results finding the trends in the changes of the dimensions as a function of cooking time and microwave power level were difficult due to shrinkage of the kernel.

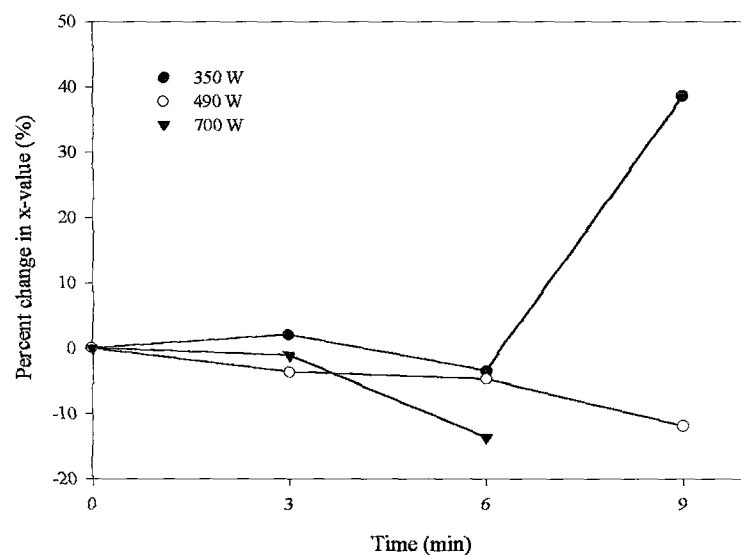


Figure 3.204 Percent change in x-value of the soybean kernel during microwave cooking

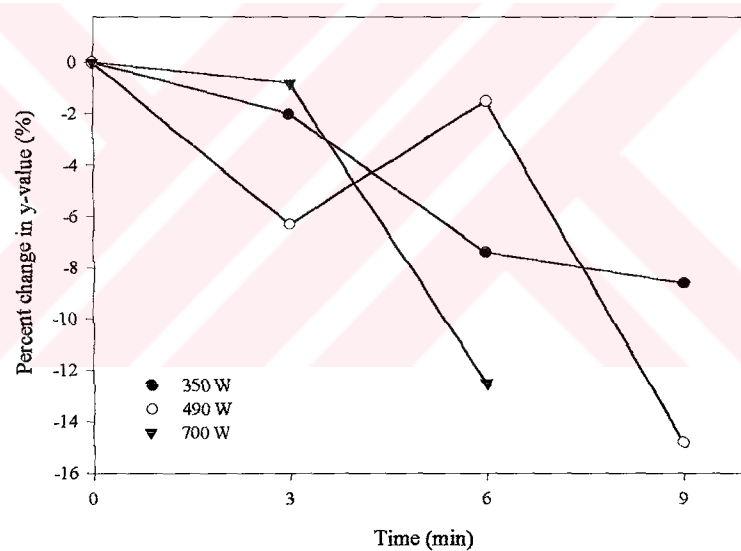


Figure 3.205 Percent change in y-value of the soybean kernel during microwave cooking

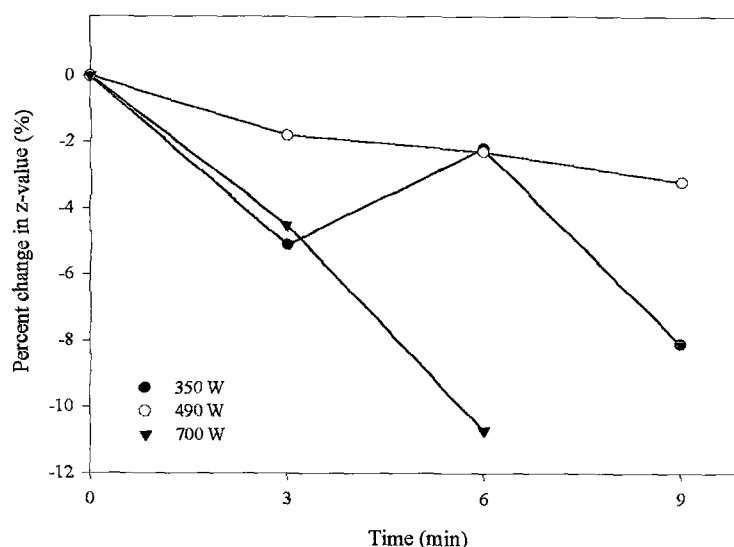


Figure 3.206 Percent change in z-value of the soybean kernel during microwave cooking

b. Changes in weight, volume and density of the soybean kernel

Change in weight, volume and density of the soybean kernel were given in Figures 3.207, 3.208 and 3.209, respectively. It was found that cooking time and microwave power level had significant effect ($P < 0.05$) on all values.

Increase in cooking time decreased the changes in weight and volume of the soybean kernel due to drying effect of microwave cooking in this study. And, negative density change was obtained due to higher change in volume of the soybean kernel than weight except at 700 W and at 6 minutes (because, burning of soybean started). Additionally, sharp increase in volume ($P < 0.05$) that caused to sharp decrease in density at 350 W for 9 minutes was due to increase in the x-value of the soybean kernel at this condition (Figure 3.204).

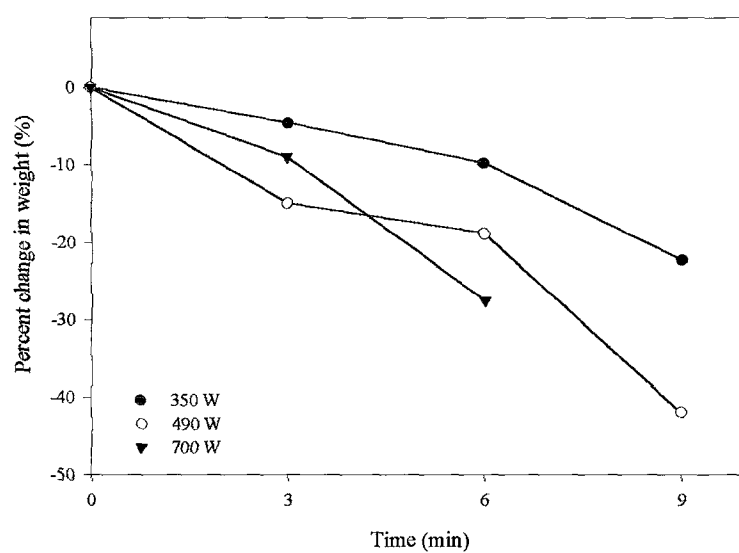


Figure 3.207 Percent change in weight of the soybean kernel during microwave cooking

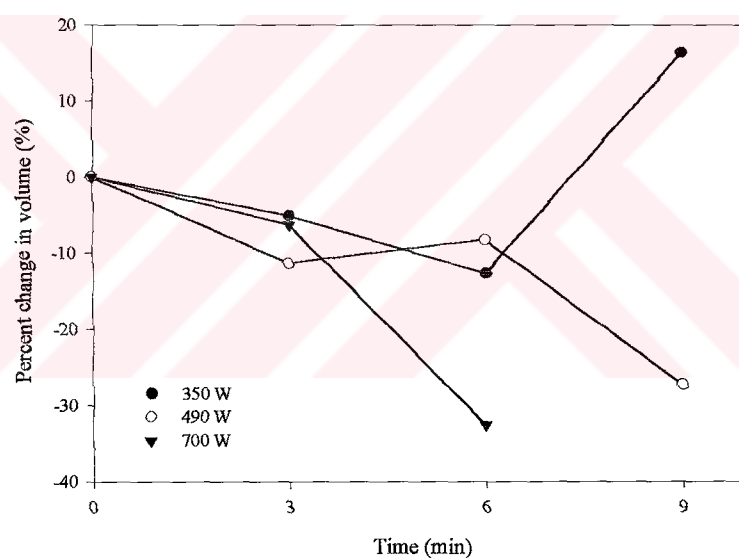


Figure 3.208 Percent change in volume of the soybean kernel during microwave cooking

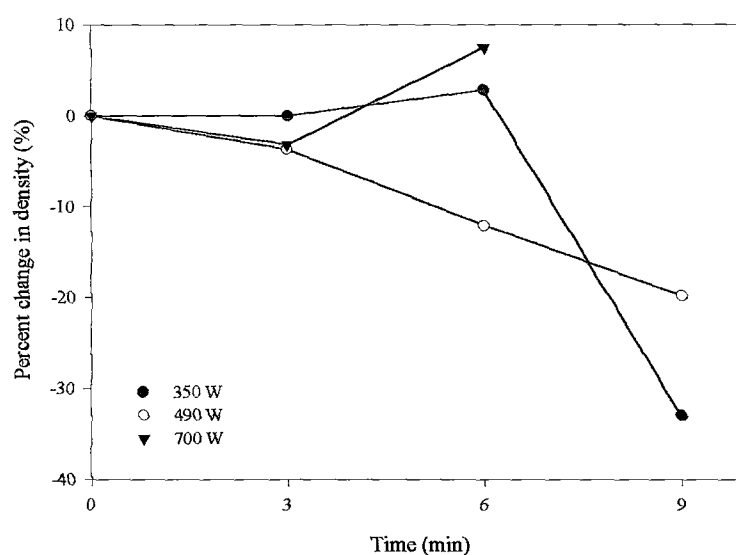


Figure 3.209 Percent change in density of the soybean kernel during microwave cooking

c. Moisture content of soybean during the microwave cooking

As explained previously, moisture content is the most important parameter for the cooking operation. In contrast to other cooking methods (atmospheric and pressure cooking operation), moisture content decreased ($P < 0.05$) during microwave cooking due to drying effect of microwave system (Figure 3.210). At 9 minutes, for all microwave power levels, moisture content reduced to nearly 3% of moisture. This value was not suitable for the bulgur production.

At optimum cooking condition (i.e. 6 minutes at 490 W), moisture content was determined as approximately 10%. In industrial applications, after drying operation, moisture content of product is between 10 and 13%. Therefore, microwave cooking for 6 minutes at 490 W can be used for simultaneous cooking and drying of soybean.

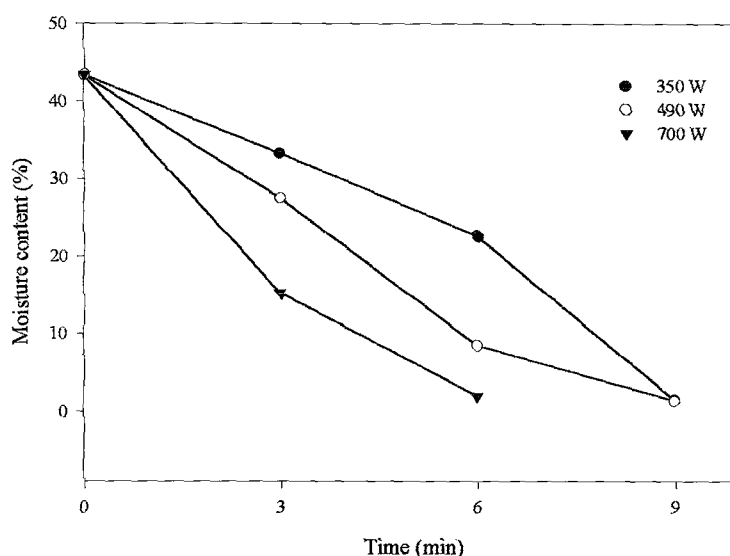


Figure 3.210 Moisture content of soybean during microwave cooking

d. Color of soybean during the microwave cooking operation

The L-value of soybean for microwave cooking was given in Figure 3.211. It was found that cooking time and microwave power level had significant effect ($P < 0.05$) on the L-value of soybean. The L-value at 3 and 6 minutes for all microwave power levels was greater ($P < 0.05$) than initial L-value of soybean due to cooking of soybean.

Increase in cooking time decreased ($P < 0.05$) the L-value of soybean, i.e. 9 minutes due to partial burning of soybean. As can be seen from Figure 3.211, the best L-value was obtained at optimum cooking condition (i.e. 6 minutes at 490 W).

The changes in the a and b-values were illustrated in Figures 3.212 and 3.213. Both values significantly affected ($P < 0.05$) from cooking time and microwave power level. The a-value of soybean increased ($P < 0.05$) gradually with increased cooking time and microwave power level. Increase in the a-value was expected result due to increased browning reactions. Also, fluctuations were observed in the b-value of soybean due to partial burning of soybean at long cooking time. Also, it was found that the b-value of soybean continued to increase up to 100% of cooking degree then started to decrease due to overcooking or burning of soybean. Therefore, the control of microwave cooking is very important to produce product with good color quality.

Similar to the change in the a-value, the YI-value increased ($P<0.05$) with increase in microwave power level and cooking time, which indicates that clarity in soybean decreased ($P<0.05$) during the microwave cooking operation. This reduction in clarity was a disadvantage for microwave system.

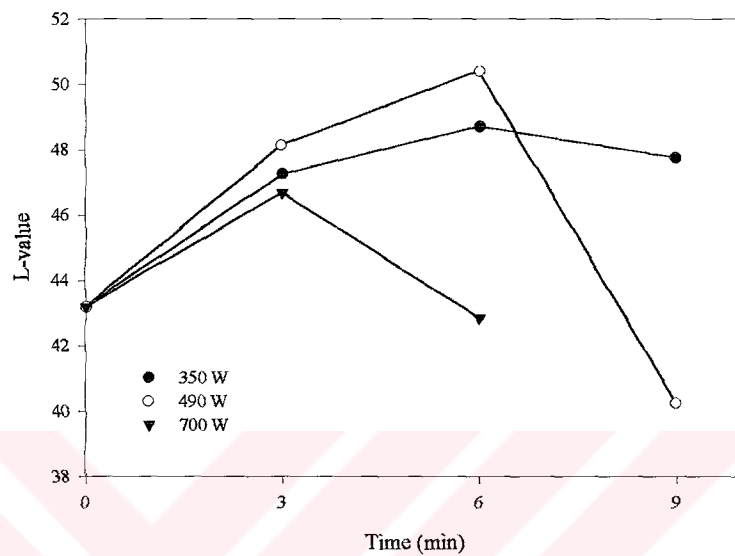


Figure 3.211 Change in L-value of soybean during microwave cooking

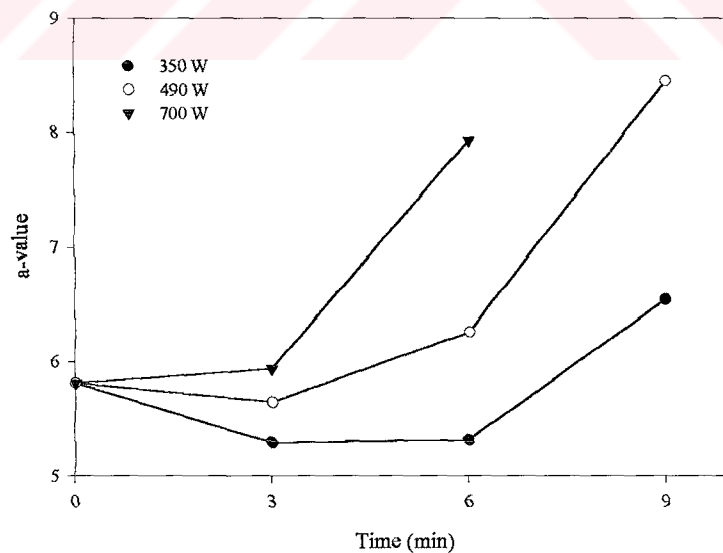


Figure 3.212 Change in a-value of soybean during microwave cooking

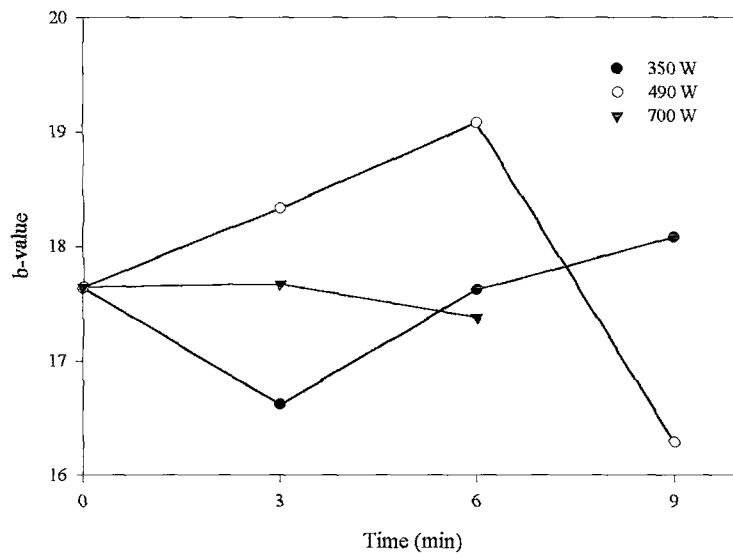


Figure 3.213 Change in b-value of soybean during microwave cooking

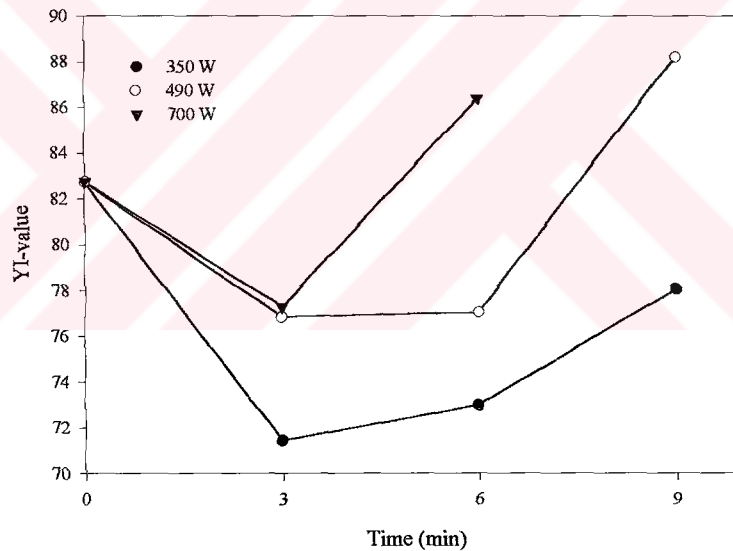


Figure 3.214 Change in YI-value of soybean during microwave cooking

e. Change in texture of soybean during microwave cooking

The $F_{\max}$ and A_p -values were illustrated in Figure 3.215 and 3.216, respectively. Cooking time and microwave power level had significant effect ($P < 0.05$) on both textural values. At 700 W, hardness of soybean increased ($P < 0.05$) at 3 minutes of cooking due to cooking and drying effect of microwave then decreased ($P < 0.05$) at 6 minutes sharply due to the starting of burning of soybean partially (at 6 minutes and at 700 W, soybean was divided into two parts because of inflexible structure of

soybean during texture analysis). The hardening due to loss of water from kernel (i.e. drying) and softening due to cooking occurred together during microwave cooking, but rate of hardening was higher than that of softening according to results of texture analysis (high $F_{\max}$ and A_p values).

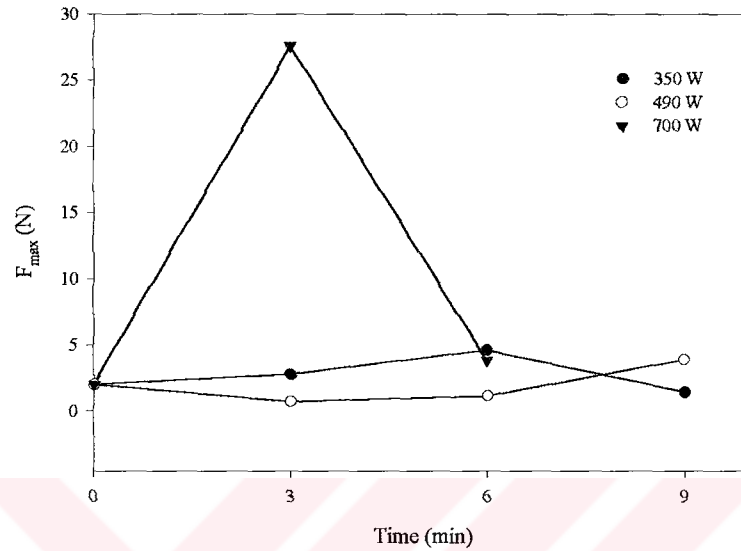


Figure 3.215 Change in $F_{\max}$ of soybean during microwave cooking

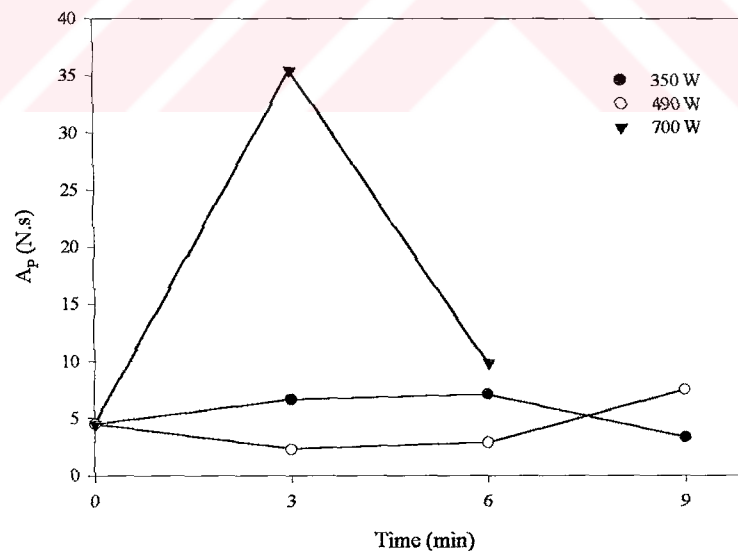


Figure 3.216 Change in A_p of soybean during microwave cooking

3.2.4.2. Microwave cooking of rye

3.2.4.2.1. Determination of cooking degree of rye

Cooking degree of rye during microwave cooking were determined using ΔH values (Table 3.6) and calibration data (Figure 3.130) and were given in Figure 3.217. Rye completely burned for 9 minutes at 700 W.

Table 3.6 Values of ΔH of rye at 350, 490 and 700 W for microwave cooking

Time (min)	ΔH (J/g)		
	Microwave power level (W)		
	350	490	700
3	-261.465	-251.397	-244.607
6	-256.810	-245.947	-243.017
9	-2350.481	-243.267	-

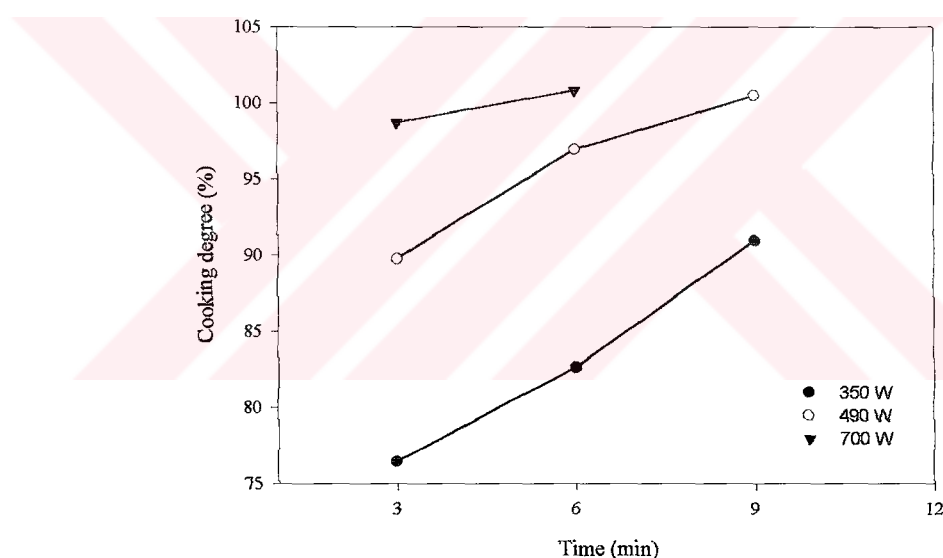


Figure 3.217 Cooking degree of rye at 350, 490 and 700 W for microwave cooking

3.2.5.2.2. Changes in the physical attributes of rye

a. Changes in the dimensions of the rye kernel

The percent changes in the x, y and z-values of rye were illustrated in Figures 3.218, 3.219 and 3.220, respectively. It was found that there were significant effects ($P < 0.05$) of cooking time and microwave power level on all dimensions of the rye kernel. The x-value of the rye kernel decreased ($P < 0.05$) gradually due to shrinkage during microwave cooking. As explained previously, shrinkage occurred due to loss of water from sample because of drying effect of microwave together with cooking.

Therefore, negative change in the x-value was obtained. Duncan's multiple range test results indicated that increase in microwave power level and cooking time significantly increased ($P<0.05$) the change in the x-value of the rye kernel.

The y-value at 700 W decreased ($P<0.05$) due to shrinkage and effect of crease (Figure 3.219). Also, at 490 W it was decreased ($P<0.05$) until 6 minutes of cooking due to shrinkage then increased ($P<0.05$) again due to completion of cooking of rye. At optimum cooking degree, the change in the y-value was nearly zero.

The z-value of the rye kernel at 350 and 490 W increased ($P<0.05$) at 6 minutes (in contrast to 700 W) then sharply decreased ($P<0.05$) at 9 minutes due to shrinkage (i.e. drying) effect of microwave cooking.

In general, the changes in the dimensions of rye during microwave cooking were negative similar to microwave cooking of soybean, as explained. It can be said that dimensions of grains (legumes and cereals) during microwave cooking (not contact with water) decreased due to shrinkage and drying effect.

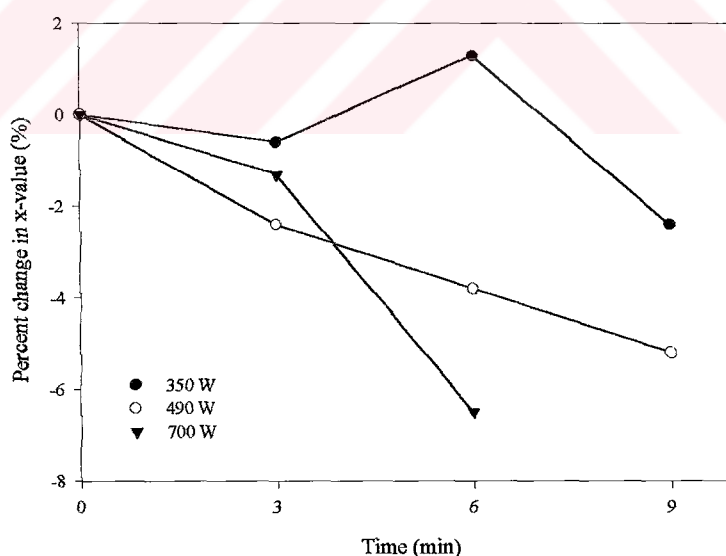


Figure 3.218 Percent change in x-value of the rye kernel during microwave cooking

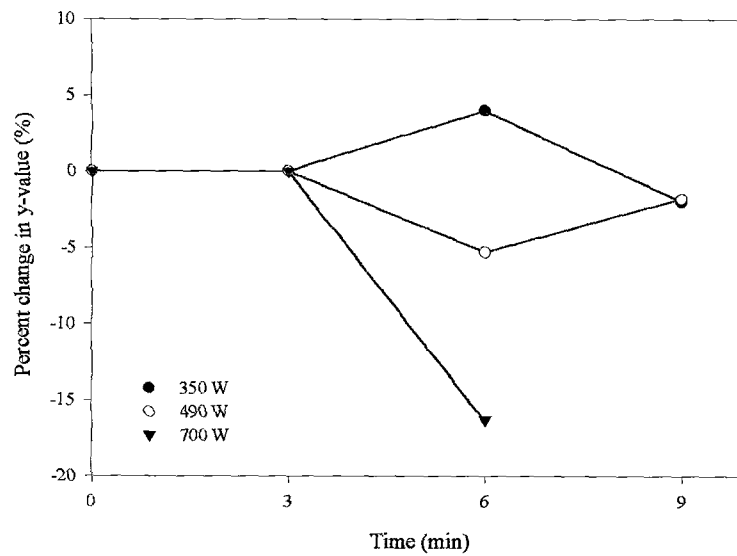


Figure 3.219 Percent change in y-value of the rye kernel during microwave cooking

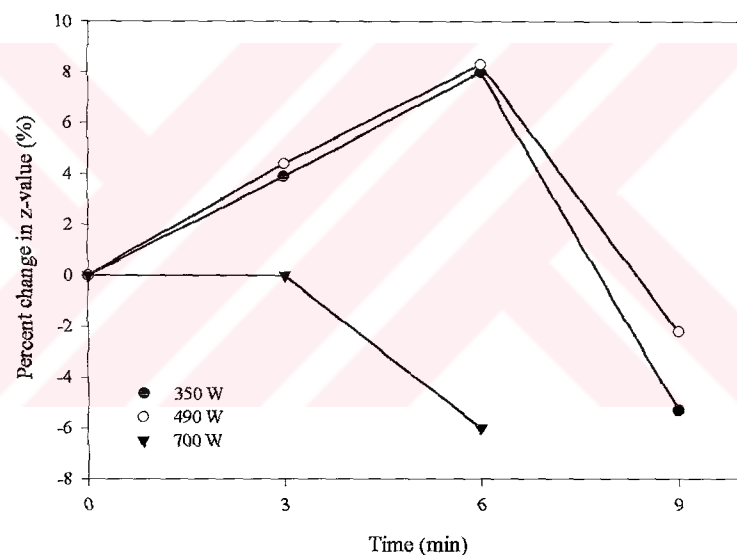


Figure 3.220 Percent change in z-value of the rye kernel during microwave cooking

b. Changes in weight, volume and density of the rye kernel

The weight, volume and density of the rye kernel decreased ($P < 0.05$) similar to the change in dimensions due to shrinkage and loss of water during microwave cooking (Figures 3.221-3.223). The major change in each one occurred at 9 minutes due to loss of large amount of water from rye. According to Duncan's multiple range test results the minor change in weight and density was obtained ($P < 0.05$) at 350 W in contrast to major change in volume ($P < 0.05$) at this microwave power level. Vice versa, the major change in weight and density was obtained ($P < 0.05$) at 490 W in

contrast to volume. Figures 3.221 and 3.223 also illustrates similar trends for weight and density of rye.

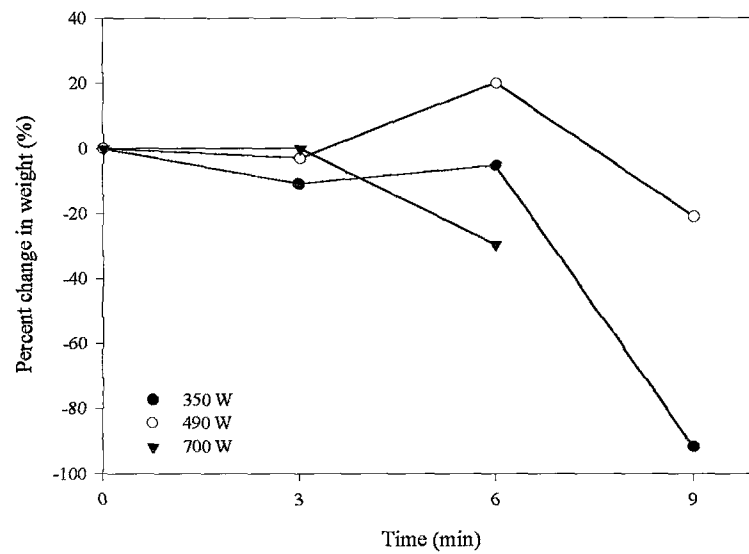


Figure 3.221 Percent change in weight of the rye kernel during microwave cooking

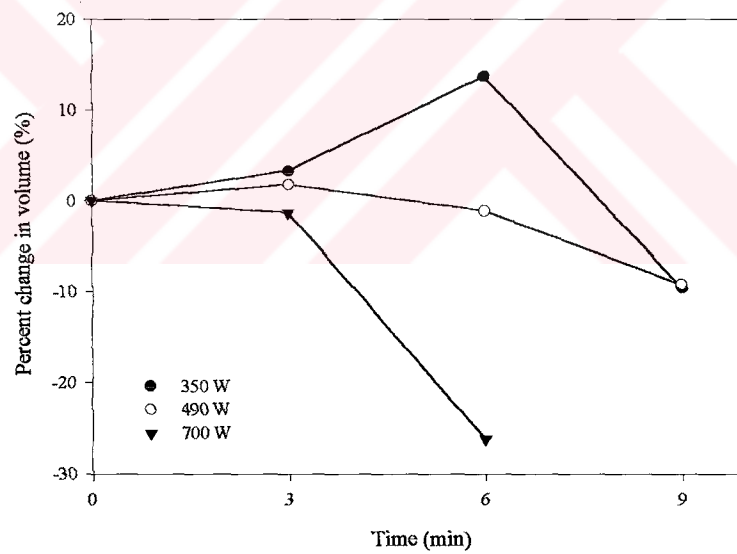


Figure 3.222 Percent change in volume of the rye kernel during microwave cooking



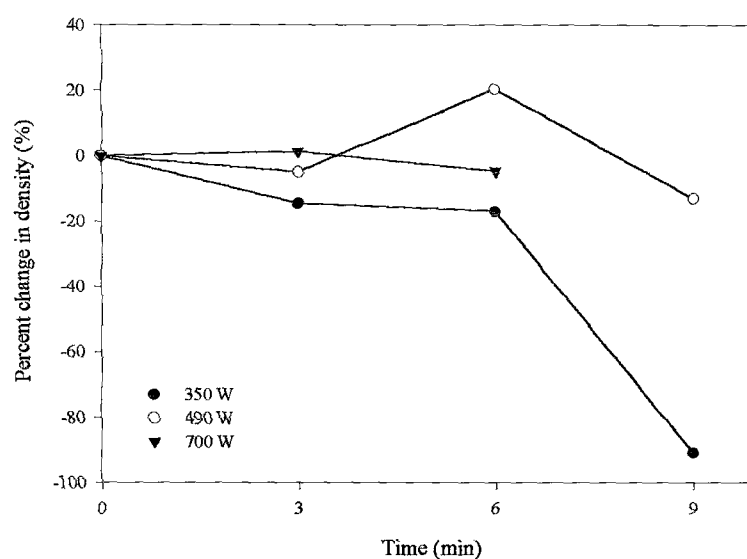


Figure 3.223 Percent change in density of the rye kernel during microwave cooking

c. Moisture content of rye during microwave cooking

The change in moisture content of rye during microwave cooking was given in Figure 3.224). Moisture content of rye during microwave cooking decreased ($P < 0.05$) gradually at all cooking time and microwave power levels (Figure 3.224). Increase in cooking time and microwave power level decreased ($P < 0.05$) the moisture content of rye. Similar to microwave cooking of soybean, the loss of water was observed during microwave cooking. It was interesting that at optimum cooking degree (i.e. 9 minutes at 490 W) moisture content reached to nearly 2%. This moisture content carries significant risks to control the cooking of rye, because at this moisture content, preventing burning of rye will be more difficult during microwave application. Additionally, this low moisture content is not suitable for bulgur production, industrially and economically. It was concluded that, above 10% moisture content, complete cooking of rye was not possible and rate of cooking and water loss was nearly same at optimum cooking degree.

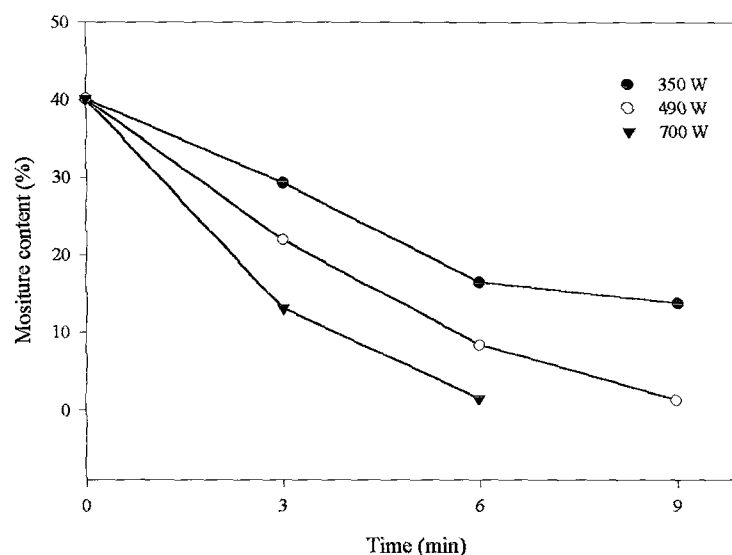


Figure 3.224 Moisture content of rye during microwave cooking

d. Color of rye during the microwave cooking operation

The color values (L, a, b and YI-values) of rye during microwave cooking at all microwave power levels were given in Figures 3.225, 3.226, 3.227 and 3.228, respectively. It was found that there were no significant effect ($P>0.05$) of cooking time and microwave power level on the color values according to results of ANOVA and Duncan's multiple range tests. This may be due to original dark color of rye. And, during microwave cooking together with its drying effect, darkening of rye continued at each microwave power level. Additionally, this insignificant change ($P>0.05$) in the color values can also be used to explain the unburning of rye at optimum cooking degree that its moisture content was nearly 2%.

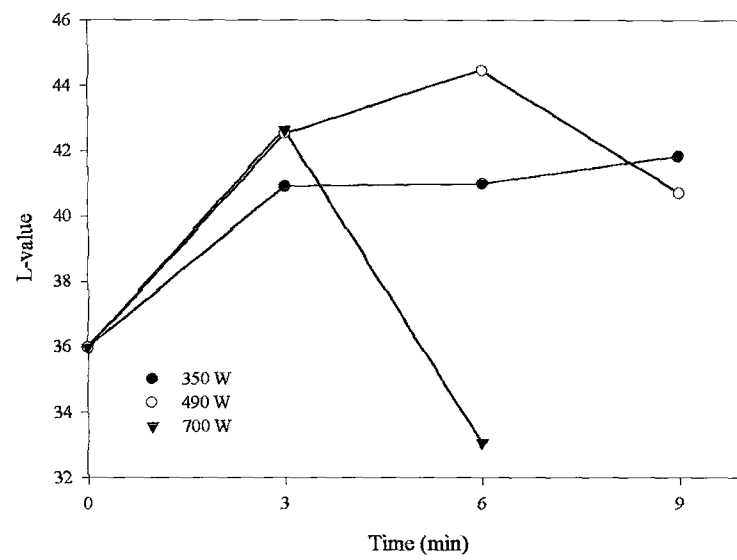


Figure 3.225 Change in L-value of rye during microwave cooking

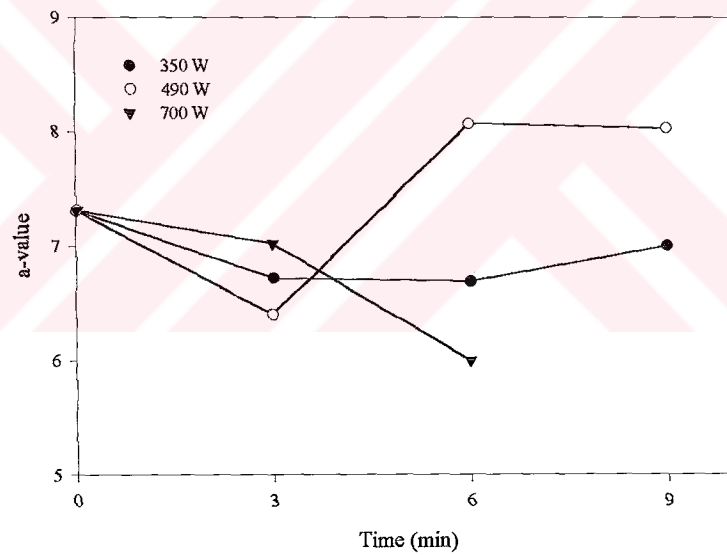


Figure 3.226 Change in a-value of rye during microwave cooking

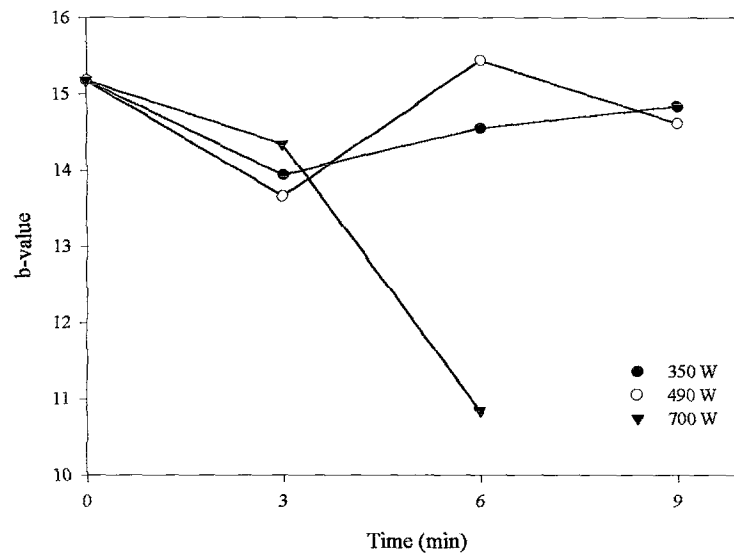


Figure 3.227 Change in b-value of rye during microwave cooking

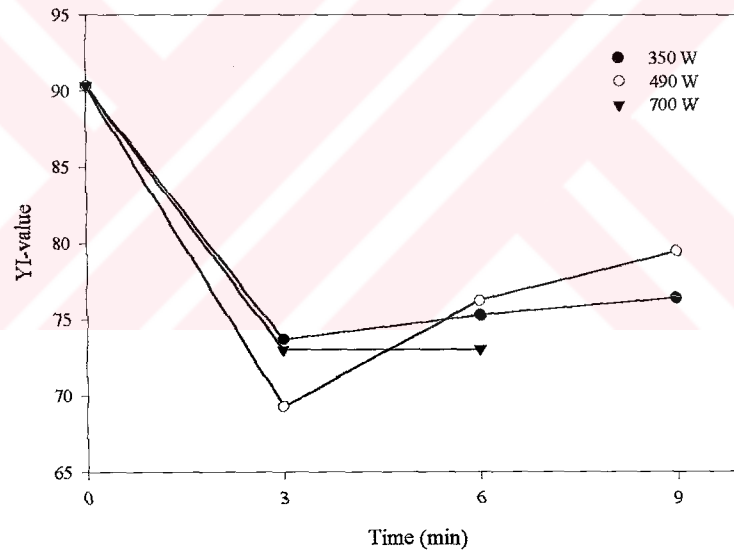


Figure 3.228 Change in YI-value of rye during microwave cooking

e. Change in texture of rye during microwave cooking

The $F_{\max}$ and A_p -values of rye were given in Figures 3.229 and 3.230, respectively. Both were significantly affected ($P < 0.05$) from cooking time and microwave power level. Hardness of rye at 350 W increased ($P < 0.05$) due to the loss of water from rye during microwave cooking. Also, at 490 W, hardness of rye increased ($P < 0.05$) at 6 minutes, but it decreased ($P < 0.05$) at 9 minutes due to dividing of the rye kernel into two parts during texture analysis (i.e. loss of water “moisture content was nearly 2%

at 9 minutes” inhibited the flexibility of the rye kernel against texture analyzer probe). Similar was observed at 700 W.

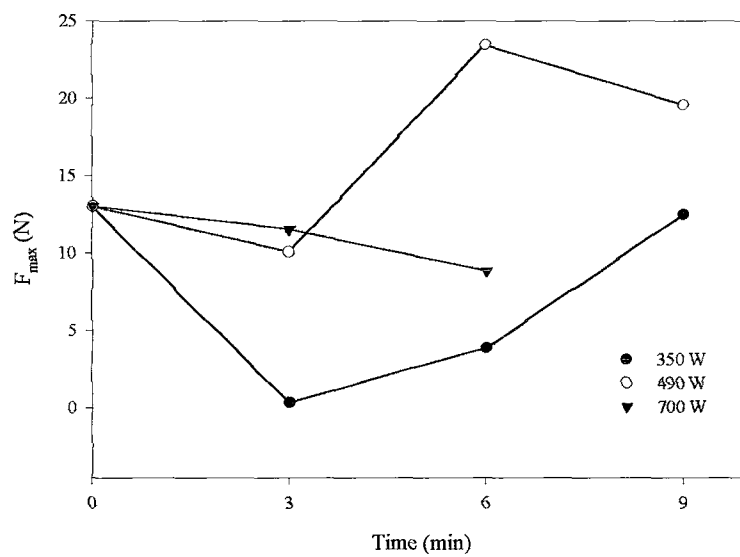


Figure 3.229 Change in F_{max} of rye during microwave cooking

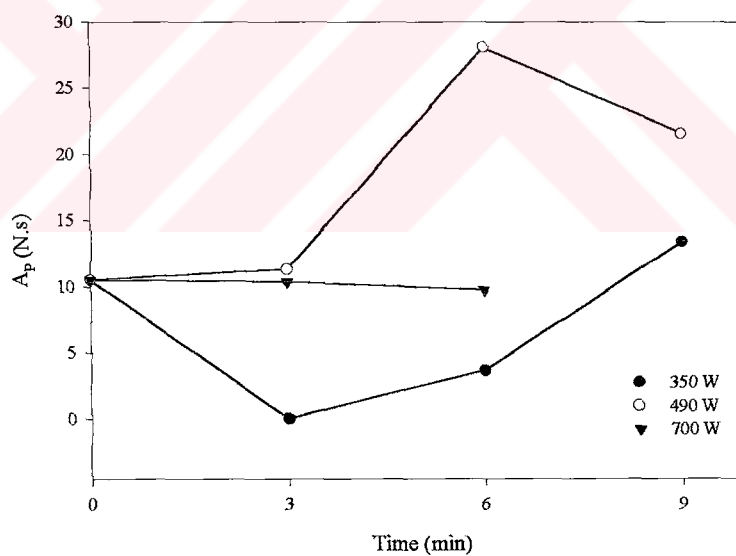


Figure 3.230 Change in A_p of rye during microwave cooking

CHAPTER IV

CONCLUSIONS

The study on the production of the semi-ready-to-eat food products using bulgur production method with soybean and rye revealed the following conclusions:

1. During soaking, dimensions, weights, volumes and moisture contents of soybean and rye increased ($P < 0.05$).
2. Soaking time had significant effect ($P < 0.05$) on the x , W , V , ρ , mc , F_{max} , A_p , L , a , b and YI values of soybean and rye.
3. Soaking temperature had significant effect ($P < 0.05$) on the x , W , V , ρ , mc , F_{max} , A_p , L , a , b , and YI values of soybean and x , W , V , ρ , mc , F_{max} , A_p , a , b , and YI values of rye.
4. It was found that, in general, soaking time and temperature had significant effects on the physical properties of soybean and rye but the effect of the initial soaking pH of the soaking water at a range of 5-9, was not important for the physical properties except moisture contents of soybean and rye, and L , b and YI values of rye.
5. The effect of crease, joint, bran, chemical compositions (protein, starch content etc.) and hardness had important roles to change the dimensions of rye and soybean.
6. During soaking of soybean and rye, absorption of water and leaching of solubles into soaking water occurred simultaneously and pH, soluble solids content, conductivity and absorbance were significantly affected by soaking time, temperature and pH.
7. After approximately 10 minutes of soaking process, soaking water pH becomes constant around 6.20-6.80 and 5.80-6.80 for soybean and rye, respectively due to the leaching of buffering compound.

8. Increasing the soaking temperature increased the leaching of solubles but did not increase the leaching of organic compounds due to their gelation in the soybean and rye structures.
9. During soaking, color of soaking water especially changed at each temperature, which means that coloring compounds leached into water and lightness of water decreased during soaking of soybean in contrast to increase during soaking of rye because of its different bran structure and chemical composition.
10. The optimum soaking time, temperature and pH were determined as 20 minutes, 30°C and 7 for soybean; and 160 minutes, 30°C and 7 for rye, respectively.
11. During atmospheric cooking operation which is the most common method in the industry, cooking time (for 100 % cooking) was 110, 80 and 40 minutes for soybean at 87, 92 and 97°, respectively. 100% cooking degree of rye was not obtained at 87°C during 120 minutes of cooking. Cooking of rye was achieved for 90 and 70 minutes at 92 and 97°C, respectively.
12. During atmospheric cooking, the x, z, W, V, mc and YI values of soybean increased steadily in contrast to decrease in the y, z, W, V, mc, a and YI values of rye.
13. Soluble solids content, absorbance and conductivity of cooking water of soybean and rye increased during atmospheric cooking.
14. According to cooking degree values of pressure cooking, the optimum cooking conditions were determined as 6 and 9 minutes at 15 psig for soybean and rye.
15. One hundred percent of cooking degree for soybean and rye was obtained at 490 W power supply for nearly 6 minutes during microwave cooking. At 700 W power supply, soybean and rye burned.
16. Moisture contents of soybean and rye were higher than 40% (i.e. 60%) at the end of the atmospheric cooking operation. 40% moisture was obtained during the pressure cooking operation. The optimum cooking method was determined as pressure cooking due to product quality and optimum moisture level.
17. Column type dryer was used to dry soybean and rye and constant and falling rate periods were obtained for rye, however soybean had only falling rate

period. Drying times of rye were 2.67, 2.42 and 2.00 hours to reach the equilibrium moisture content that were shorter than that of soybean which were 5.33, 3.83 and 3.50 hours at 70, 80 and 90°C, respectively.

18. Hectoliter-weight of soybean and rye increased during soaking. Hectoliter of soybean decreased after drying operation. Also, it was lower than its initial hectoliter. But, hectoliter of rye was increased at the end of the drying operation.

Structural changes in soybean and rye start to take place during soaking, due to water absorption, and continue throughout the cooking step with the added effect of the cooking temperature, thus rendering soybean and rye edible for human consumption. Absorption of water during soaking supplies minimum required moisture content (40%) for further cooking operations.

Most of the diets in developing countries, where protein rich foods and their mix are lacking, have the disadvantage of being low in total protein and deficiency in lysine. Thus, logical supplement for such diets is soy bulgur, which has a high protein content and essential aminoacids (lysine and tryptophan; generally these type of essential compounds are lacking in cereals). Additionally, soy-bulgur can be used for gluten-intolerant humans (celiac disease) instead of wheat-bulgur. As a result, bulgur production method can be successfully used to develop the new food products from legumes and cereals as semi-ready-to-eat and/or ready-to-eat product.

As a recommendation, the major nutritional property of bulgur is the re-absorption of the solubilized substances. But, this study shows that, some nutritionally important compounds (minerals, water soluble vitamins etc.), remain in the soaking and cooking waters and are unabsorbed by legumes and cereals. Therefore, the quantity of soaking and cooking waters should be regulated very well to prevent the loss of the nutrients by the discharge of residual water.

These results also might be used to evaluate the re-use of soaking water for the next soaking and/or cooking operations and to predict the environmental discharge levels. Legumes and cereals processing's usually require an initial hydration stage in order

to facilitate quicker cooking and to improve the appearance and the extent of protein denaturation.

The present quantitative data on the effect of processing variables are necessary to systematically design the food processing machines and processes. Kinetics deal with the physical and chemical changes in a system, their associated levels, the rate at which the changes occurs and the mode and mechanism by which the changes are affected. Understanding water properties during soaking and cooking of legumes and cereals is of practical importance since it governs the subsequent operations and quality of the final product. Determination of the soaking, cooking and drying mechanisms and the prediction of occurred events are essential to the design of the large-scale soaking, cooking and drying equipments and to control these operations.



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APPENDICES

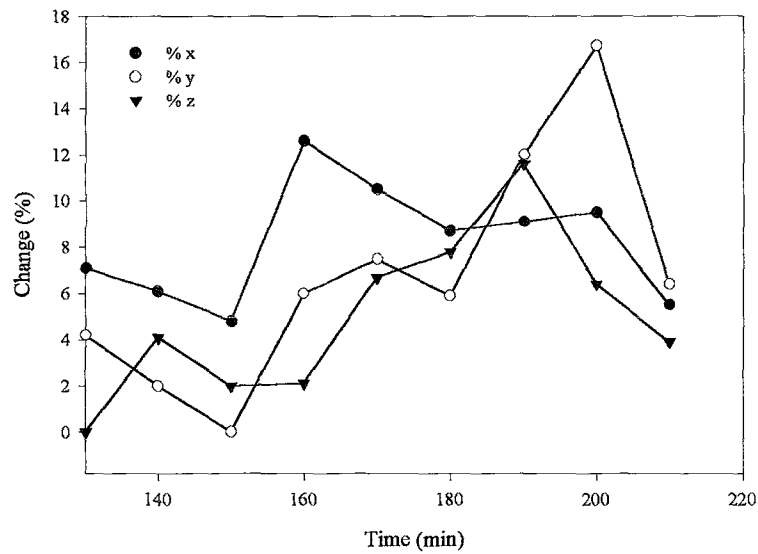


Figure A1 Percent change in three dimensions of the rye kernel during prolonged soaking period at 30°C

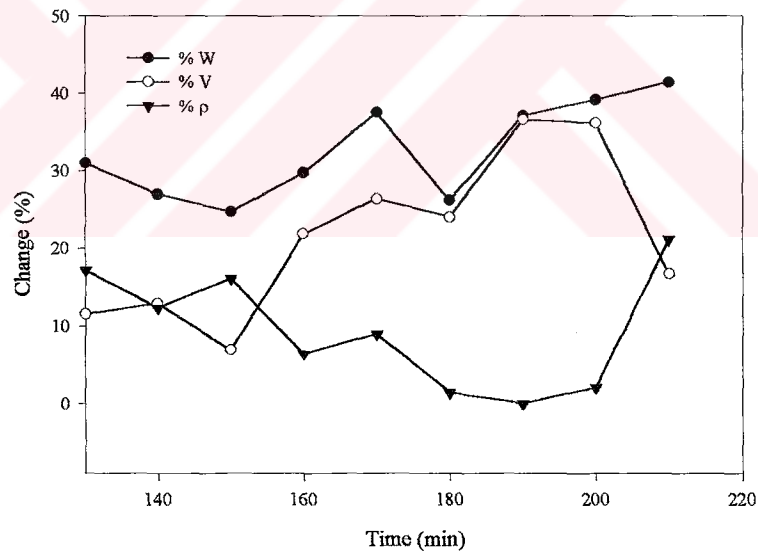


Figure A2 Percent change in weight, volume and density of the rye kernel during prolonged soaking period at 30°C

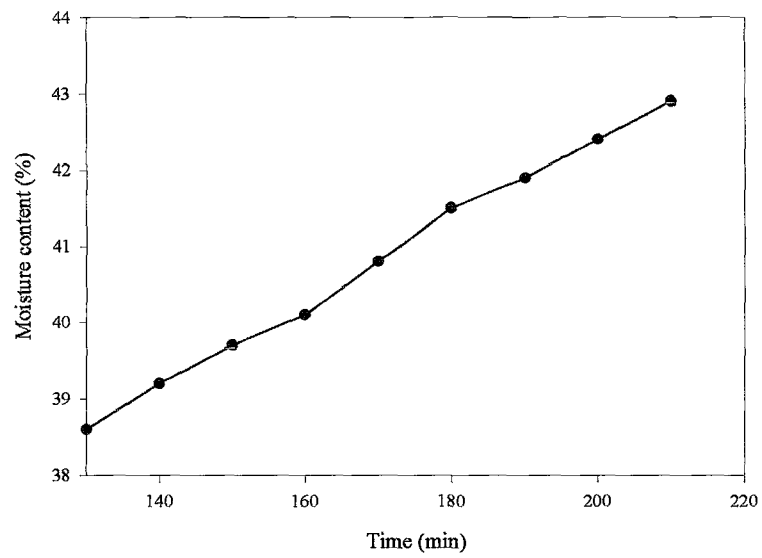


Figure A3 Change in moisture content of rye during prolonged soaking period at 30°C

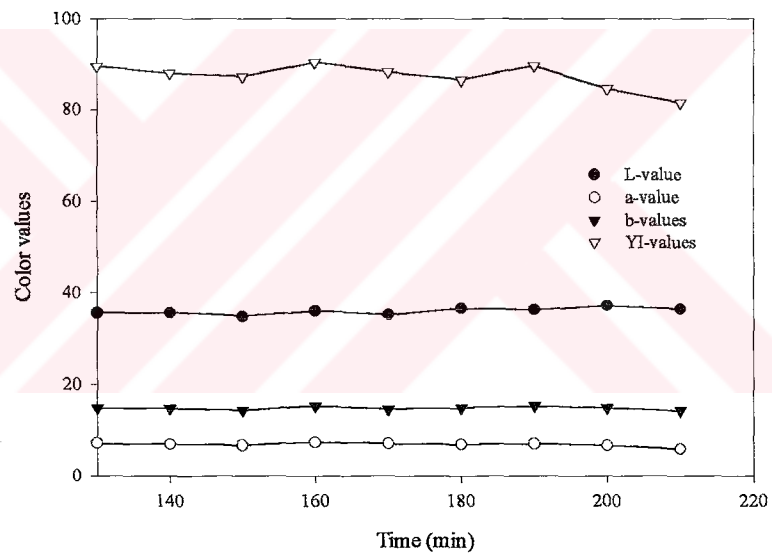


Figure A4 Change in color values of rye during prolonged soaking period at 30°C

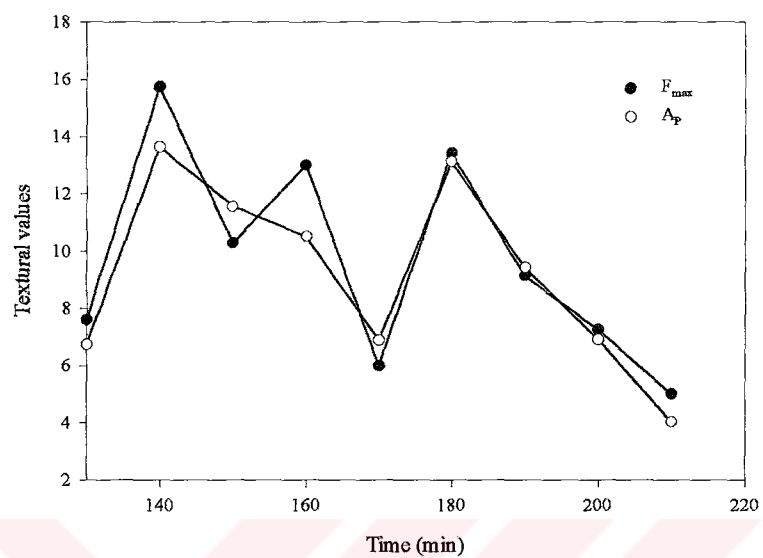


Figure A5 Changes in F_{max} and A_p -values of rye during prolonged soaking period at 30°C

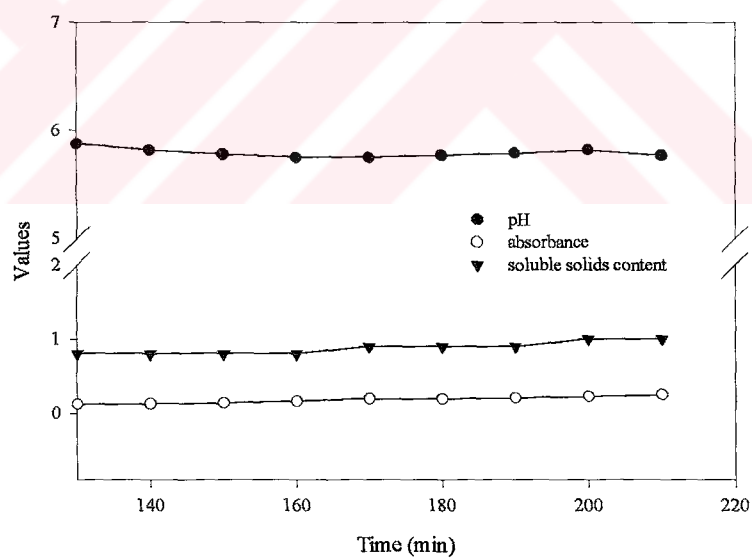


Figure A6 Changes in pH, absorbance and soluble solids content of soaking water of rye during prolonged soaking period at 30°C

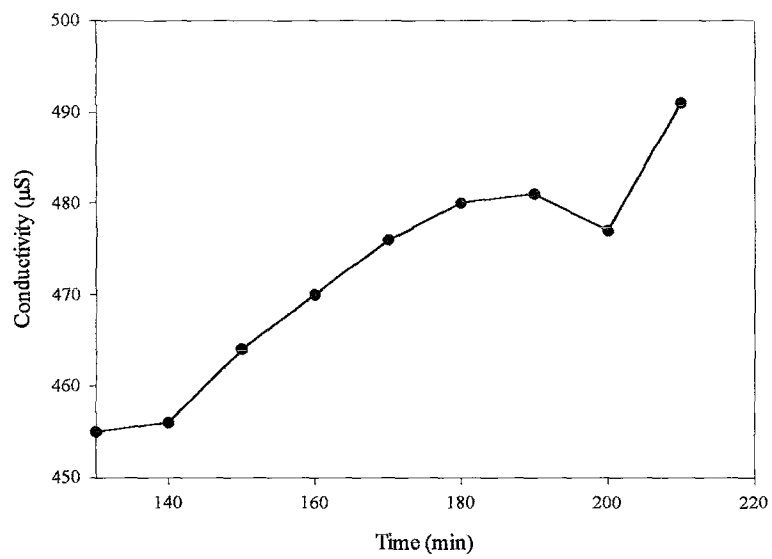


Figure A7 Change in conductivity of soaking water of rye during prolonged soaking period at 30°C

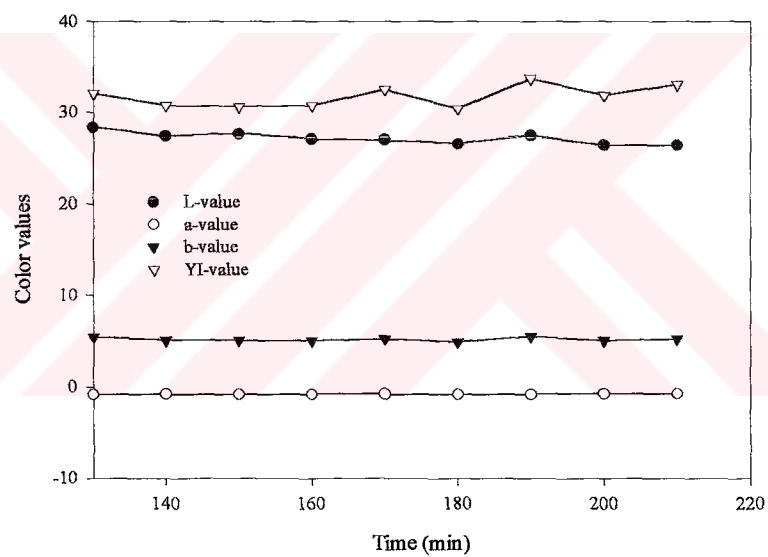


Figure A8 Change in color values of soaking water of rye during prolonged soaking period at 30°C

VITA

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3.3. Drying of Soybean and Rye

Drying or dehydration of biological materials, especially foods, has been used as a preservation technique for years. It has been a great deal of human being to prolong the shelf life of foods. The human being has found that the absence of water in foods, decrease the growth of microorganisms that cause food spoilage, decreasing activity of enzymes, and inhibition or decreasing of rate of chemical changes in foods. It is known that the microorganisms are not active when the water content is below 10%. However, it is usually necessary to lower the moisture content below 5% in foods to preserve flavor and nutrients. The developments in technology have also increased the usage area of the drying.

Before drying operation, soybean and rye were first soaked for 20 and 160 minutes at 30°C and pH 7 (i.e. at optimum soaking condition) and then cooked for 6 and 9 minutes under 15 psig using pressure cooking system (i.e. using optimum cooking system at optimum condition), respectively. Initial moisture contents before the drying operation were determined as 40.6 and 41.1 % (w.b.) for soybean and rye, respectively

3.3.1. Drying of soybean

The change of the free moisture content of soybean during drying was given in Figure 3.231. Free moisture content of soybean decreased gradually during drying. Increasing drying temperature decreased the drying time and it was found that moisture of soybean reached to equilibrium in 5.33, 3.83 and 3.5 hrs, at 70, 80 and 90°C, respectively.

Drying rate (Equations 4 and 5) vs free moisture content plot was illustrated in Fig 3.232. Drying rate increased with increasing temperature. Constant rate period was not observed for soybean. It was found that soybean drying had two falling rate periods at 70, 80 and 90°C drying temperatures. The absence of a constant-rate period during drying of soybean may be resulted due to thickness of soybean kernel and firm bran covering soybean. Since unavailability of porous structure and available tough bran on the soybean kernel, water could be evaporated in falling-rate period that was supplied from the interior of the soybean kernel.

Outlet T_{wb} and T_{db} of drying air showed no change with time at 70°C , but change was observed at higher temperatures (i.e. 80°C and 90°C). Especially, at 90°C , T_{db} varied significantly (Figures; 3.233, 3.234, 3.235). Increased in the drying air temperature affected the L and T_{db} -values during drying.

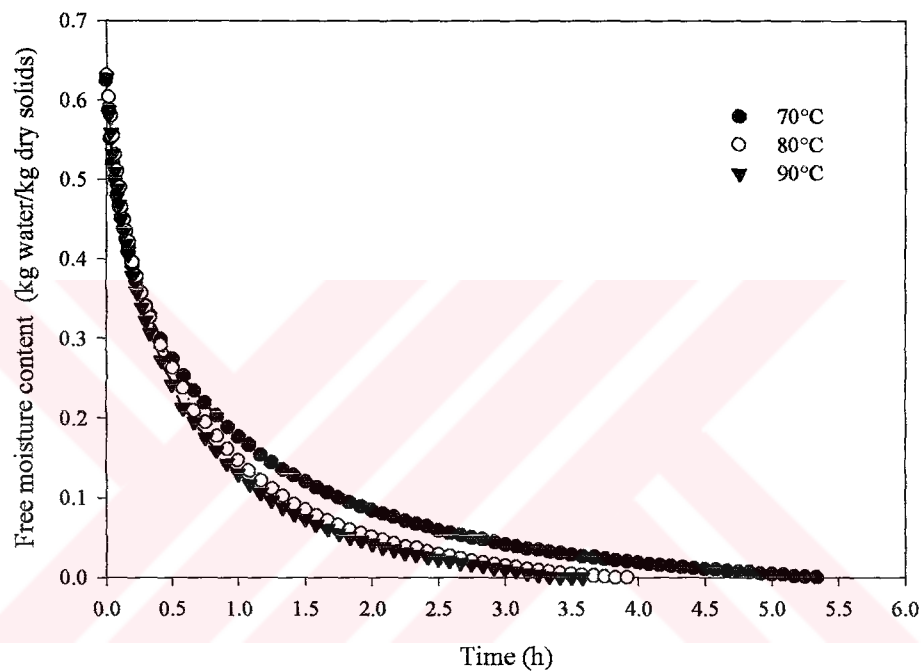


Figure 3.231 Plot of drying data for soybean as free moisture versus time

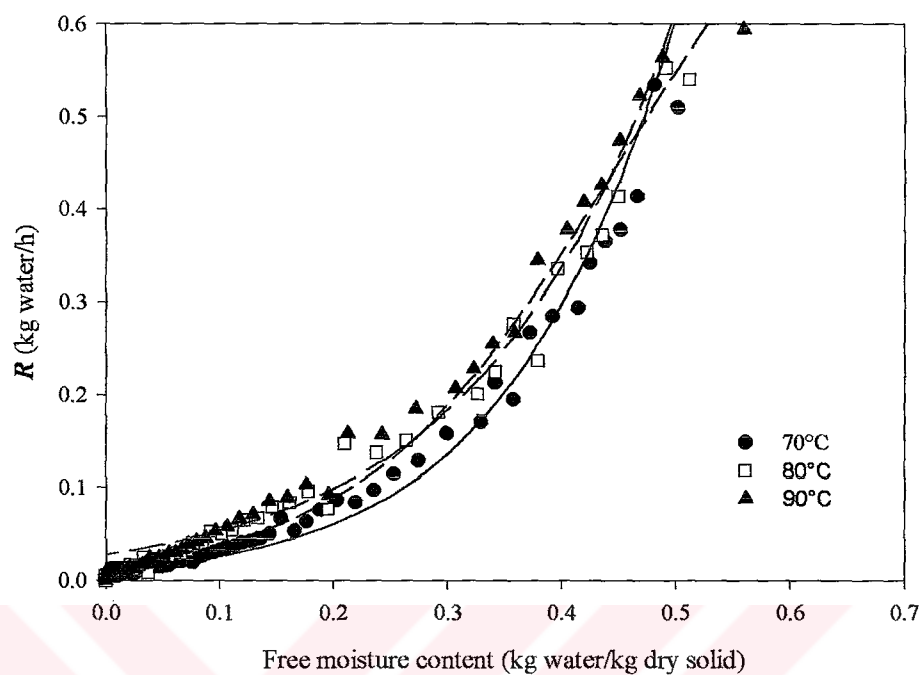


Figure 3.232 Plot of drying rate for soybean against free moisture

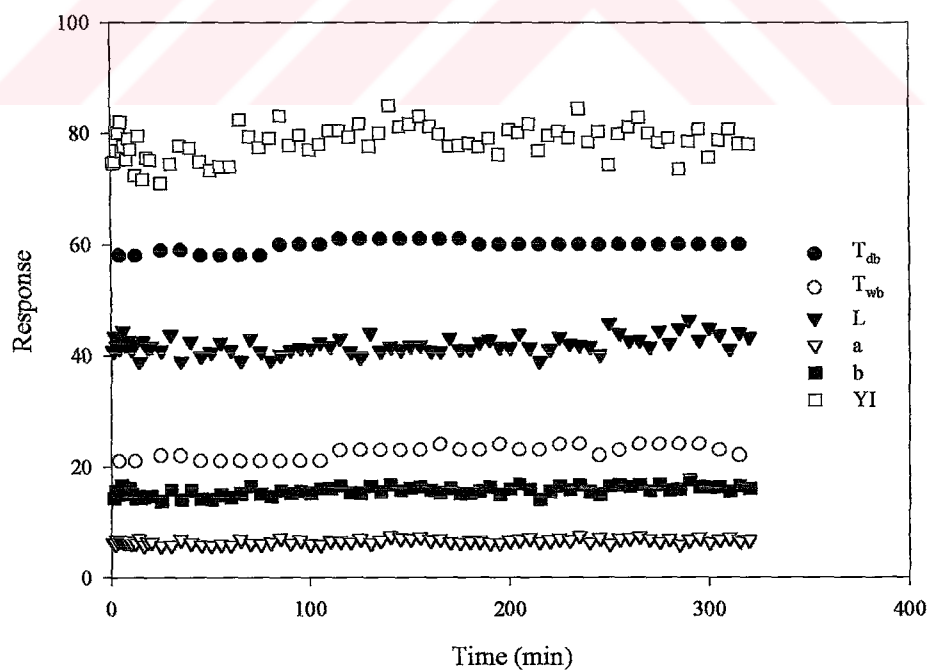


Figure 3.233 Change of color, dry and wet bulb temperatures during drying of soybean at 70°C

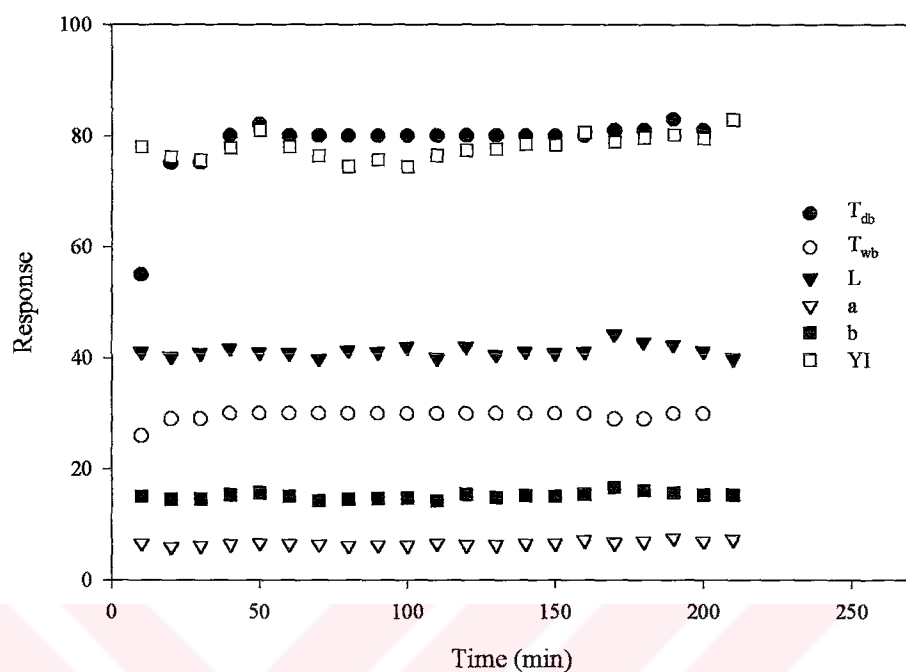


Figure 3.234 Change of color, dry and wet bulb temperatures during drying of soybean at 80°C

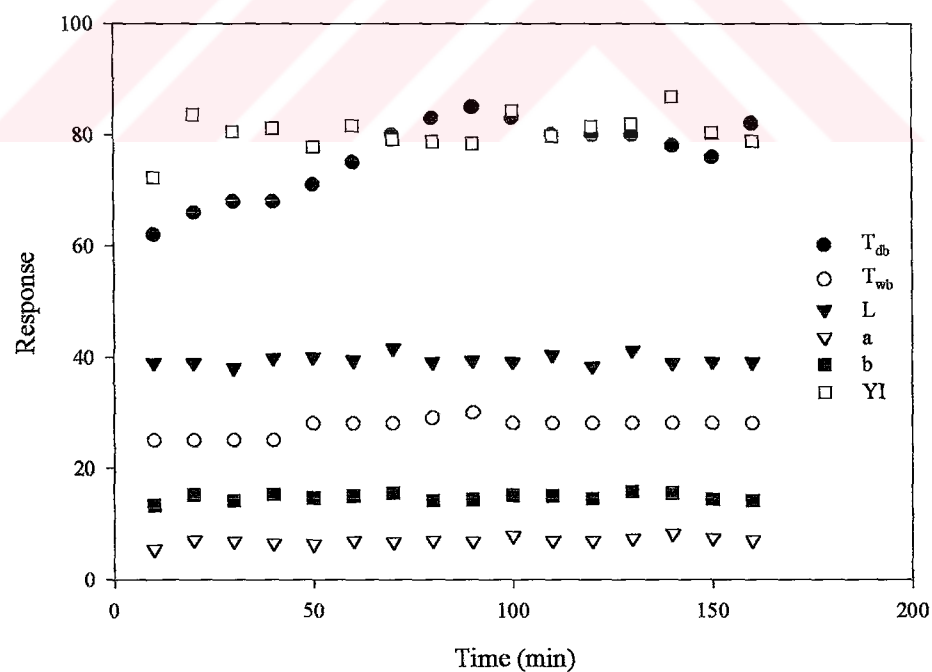


Figure 3.235 Change of color, dry and wet bulb temperatures during drying of soybean at 90°C

3.3.2. Drying of rye

During drying of rye, the moisture content decreased gradually as it was expected. The moisture content decreased in a faster manner as the temperature increased. The time required to dry rye at 70°C was twice longer than that at 90°C (Figure 3.236).

One constant and two falling-rate periods were observed (Figure 3.237). The constant-rate period was detectable, where a continuous film of water was present on the surface and thin permeable bran layer was available on rye. The water present on the surface was entirely unbound water and it acted as if the solid was not present.

The constant rate period can be affected by the process variables. These are usually; air velocity, gas humidity, gas temperature and thickness of solid being dried (Geankoplis, 1993). The effect of thickness of kernel and tough bran layers being dried can be helpful to explain the absence of a constant rate period in the drying of soybeans.

When the color properties of rye were analyzed (Figures 3.238, 3.239, 3.240.), the L, a, b and T_{wb} values did not change as in the case of drying of soybeans. During drying at 90°C the T_{db} and YI showed significant fluctuation, which could be resulted from the high temperature.

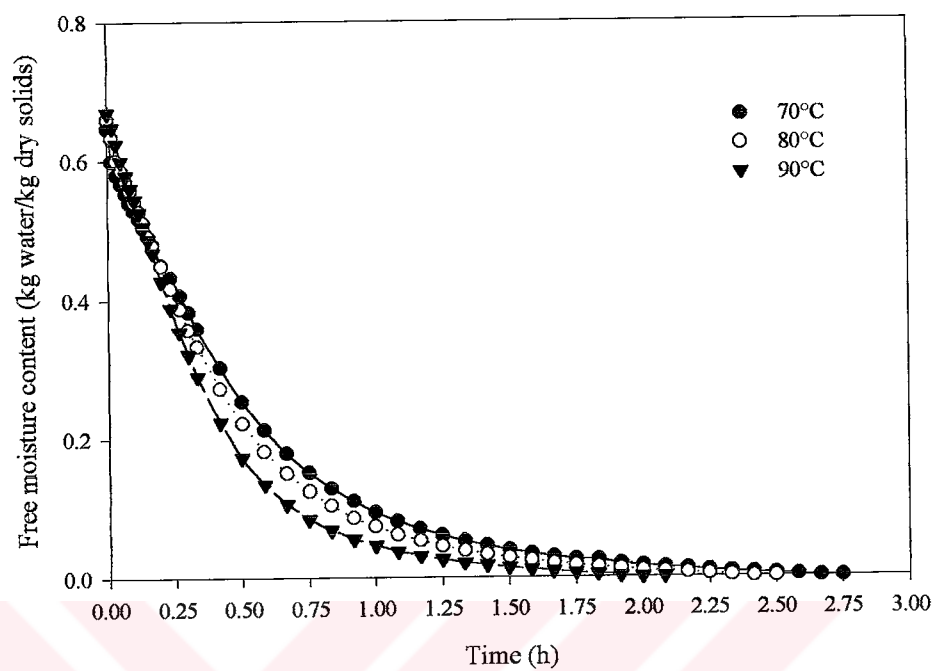


Figure 3.236 Plot of drying data for rye as free moisture versus time

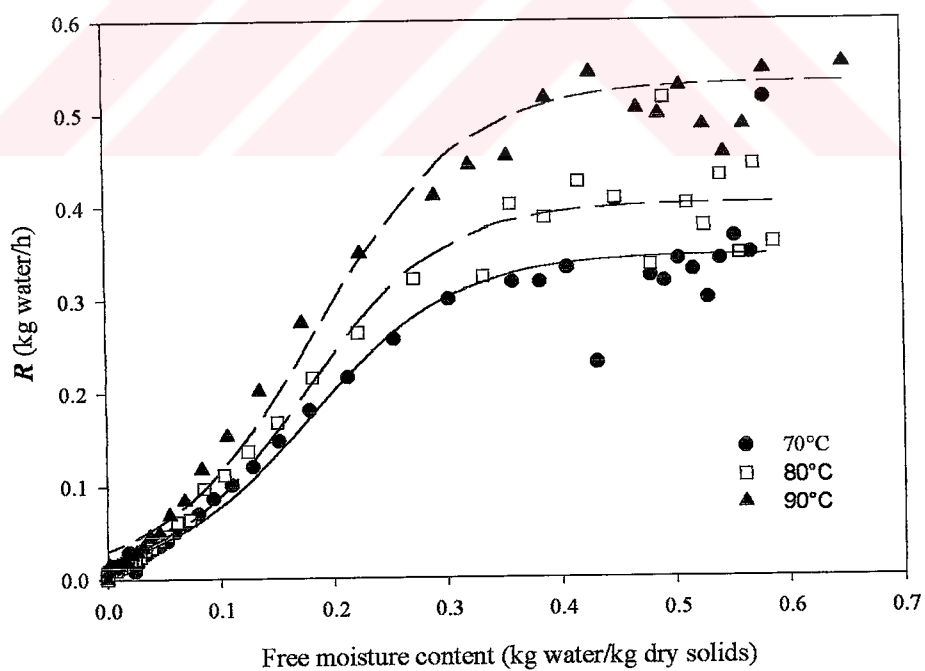


Figure 3.237 Plot of drying rate for rye against free moisture

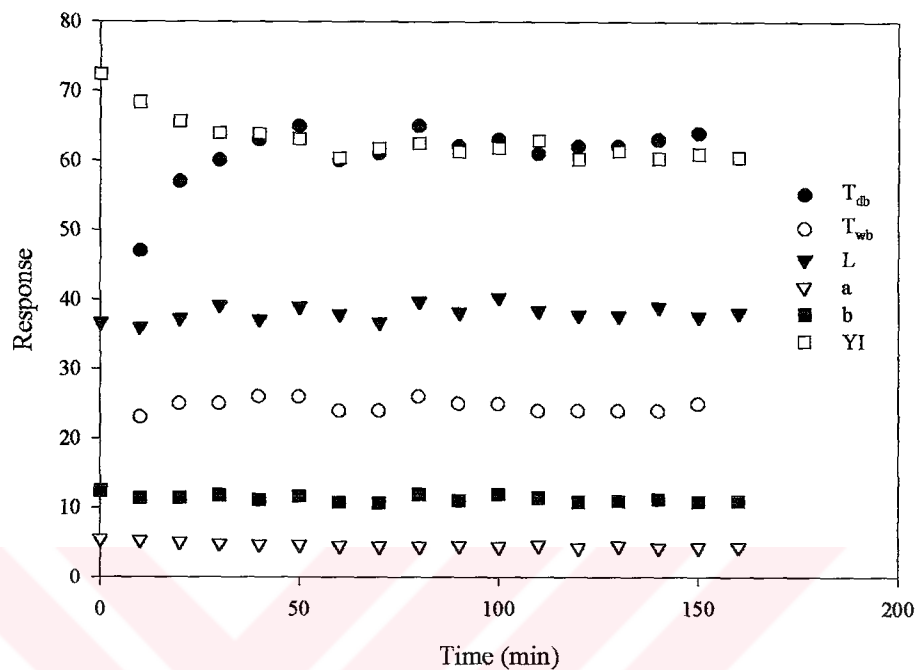


Figure 3.238 Change of color, dry and wet bulb temperatures during drying of rye at 70°C

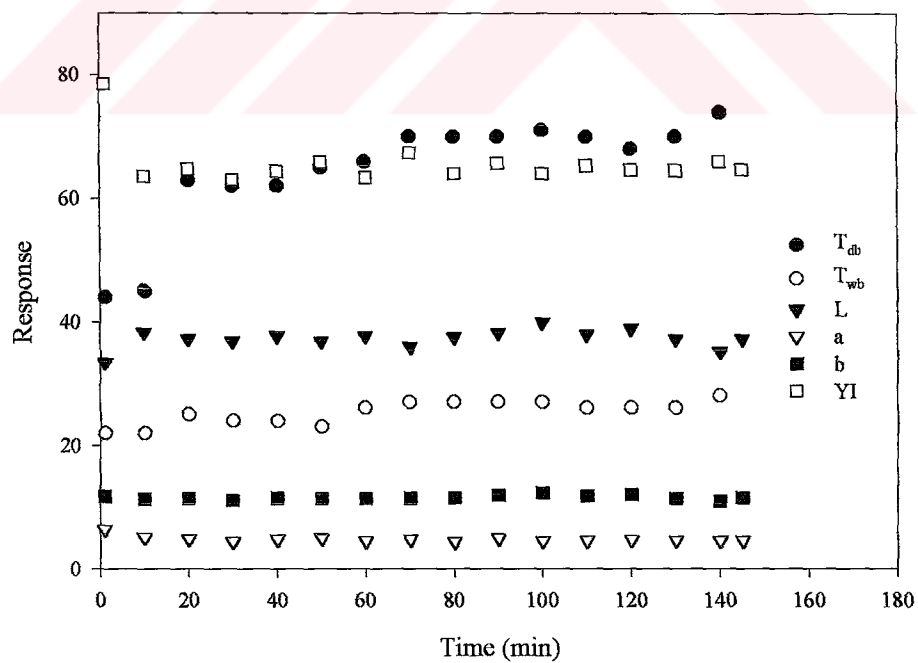


Figure 3.239 Change of color, dry and wet bulb temperatures during drying of rye at 80°C

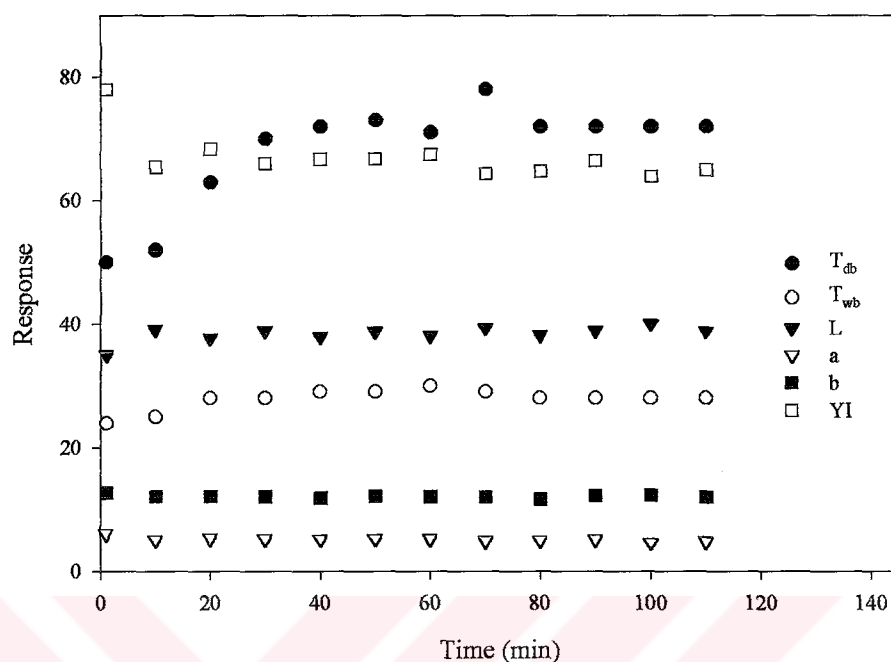


Figure 3.240 Change of color, dry and wet bulb temperatures during drying of rye at 90°C

Consequently it could be stated that the drying behaviors of rye and soybean were different. The major difference was the absence of a constant rate period in the drying of soybeans. Moreover, the time required to dry soybean was twice longer than that of rye. This may be due to larger size, higher protein content and toughness of bran of soybean that gave a rise to poor mass and heat transfer.

However, the color properties showed the similar behavior both in drying of soybean and rye. To minimize color losses, lower drying temperature should be preferred whenever it is possible.

3.4. Power and Energy Consumptions of the Used Systems

Energy consumptions and power of the systems are very important parameters for the engineering design and consumer (at home). Therefore, these values were measured and calculated using PAV system.

3.4.1. Power and energy consumption of the soaking system

Initial temperature of soaking water was adjusted to $20\pm1^{\circ}\text{C}$ before the soaking operation. Circulation pump of soaking system worked at 231 Volt and 0.9 Ampere. In Table 3.7, measured Voltage (V), Ampere (A) and Power (P) values were given as the summation of the energy required for circulation pump and heating system. Energy was calculated by multiplying power with time.

Table 3.7 Power and energy values of the soaking system

Temperature ($^{\circ}\text{C}$)	Period	Time (sec)	Voltage (V)	Ampere (A)	Power (kW)	Energy (kJ)
30	heating	300	228	2.8	0.04	12
	holding	1200	228	2.8	0.03	36
50	heating	870	236	2.8	0.14	122
	holding	1200	236	2.8	0.05	60
70	heating	1550	236	2.8	0.24	372
	holding	1200	236	2.8	0.06	72

3.4.2. Power and energy consumption of the atmospheric cooking system

Initial temperature of cooking water was adjusted to $20\pm1^{\circ}\text{C}$ before the atmospheric cooking operation. Voltage, ampere, power and energy consumption values of the atmospheric cooking system were illustrated in Table 3.8. Circulation pump of the atmospheric cooking system worked at 231 Volt and 0.9 Ampere

Table 3.8 Power and energy values of the atmospheric cooking system

Temperature (°C)	Period	Time (sec)	Voltage (V)	Ampere (A)	Power (kW)	Energy (kJ)
87	heating	2410	229	1.8	0.300	723
	holding	600	229	1.8	0.025	15
92	heating	2825	229	1.8	0.330	932
	holding	600	229	1.8	0.031	19
97	heating	3170	229	1.8	0.370	1173
	holding	600	229	1.8	0.040	24

3.4.3. Power and energy consumption of the pressure cooking system

The cooker was preheated from 20°C to 97°C before loading samples. Preheating time was measured as 1170 seconds. During preheating, measured voltage, ampere and power were 226 V, 7.4 A and 0.53 kW, respectively. After loading of samples (nearly 500 g of sample), heating values were measured. They were given in Table 3.9. During holding period there was no energy consumption by cooker due to isolation of cooking system.

During experiments, 500 g of sample was used in pressure cooker. But, its chamber could take nearly 5 kg of sample. Therefore, during energy calculation as kJ per kg of feed, this high capacity value should be used (i.e. 5 kg).

Table 3.9 Power and energy values of the pressure cooking system

Pressure (psig)	Period	Time (sec)	Voltage (V)	Ampere (A)	Power (kW)	Energy (kJ)
10	heating	270	229	1.8	0.300	81
	holding	-	-	-	-	-
15	heating	395	229	1.8	0.330	131
	holding	-	-	-	-	-
18	heating	475	229	1.8	0.370	176
	holding	-	-	-	-	-

3.4.4. Power and energy consumption of the microwave cooking system

Due to properties of microwave system, the cooker was passed to directly holding period (i.e. cooking). Also, there was a little heating period (nearly 10-20 seconds), but it could not be measured. During the microwave cooking, energy was consumed by microwave system to supply the setting microwave levels (Table 3.10). When the setting value was obtained, system automatically passed to stand-by position for 1 or 3 seconds. At stand-by position voltage and ampere values were 231 V and 0.3 Ampere, respectively.

During experiments, 500 g of sample was used in microwave cooker. But, it could take nearly 1.5 kg of sample. Therefore, during energy calculation as kJ per kg of feed, this high capacity value should be used (i.e. 1.5 kg).

Table 3.10 Power and energy values of the microwave cooking system

Microwave power (W)	Time (min)	Time (sec)	Voltage (V)	Ampere (A)	Power (kW)	Energy (kJ)
350	3	180	227	5.6	0.03	5.4
	6	360	227	5.6	0.06	21.6
	9	540	227	5.6	0.09	48.6
490	3	180	227	5.7	0.05	9.0
	6	360	227	5.7	0.10	36.0
	9	540	227	5.7	0.15	81.0
700	3	180	227	5.8	0.06	10.8
	6	360	227	5.8	0.12	43.2
	9	540	227	5.8	0.18	97.2

3.4.5. Power and energy consumption of the drying system

Voltage, ampere, power and energy consumption values of the drying system were given in Table 3.11. During experiments, 752 g of sample was put into the drying chamber. But, it could take nearly 1.5 kg of sample. Therefore, during energy

calculation as kJ per kg of feed, this high capacity value should be used (i.e. 1.5 kg). By this way, power and energy consumption per feed can be reduced by twice with increasing amount of feed due to unsaturation of the drying air (i.e. high differences between the dry and wet bulb temperatures) during the drying operation in available dryer that used in this study.

Table 3.11 Power and energy values of the drying operation

Temperature (°C)	Period	Time (sec)	Voltage (V)	Ampere (A)	Power (kW)	Energy (kJ)
70	heater on	3600	222	7.6	1	3600
	heater off		226	0.05	-	-
80	heater on	3600	225	7.6	1.16	4176
	heater off		230	0.05	-	-
90	heater on	3600	227	7.7	1.29	4644
	heater off		227	0.04	-	-

3.5. Hectoliter-weight (Bulk Density) of Soybean and Rye

Hectoliter-weight (bulk density) is another important parameter for the industrial designs (design of tanks, silos, conveyors, cookers etc.). In general, hectoliter-weight was given as gram per 100 mL (i.e. this equals to weight (kg) of 100 liter of sample). Therefore, in this study, hectoliter-weights of soybean and rye were determined at initial and optimum points.

Hectoliter-weights of unprocessed soybean and rye were determined as 72.8 and 79.9, respectively. When the moisture contents of soybean and rye were increased to nearly 40% using the optimum soaking conditions, hectoliter-weights of soybean and rye decreased to 65.5 and 69.3, respectively. This decrease in hectoliter-weights was also correlated with negative percent change in the particle density of the soybean and rye kernel, as described previously.

After the optimum cooking of soybean and rye using the pressure cooking for 6 and 9 minutes at 15 psig (nearly 40% moisture content), hectoliter-weights of soybean and rye were measured as 64.8 and 72.2, respectively. Hectoliter of rye increased a

little in contrast to decrease in that of soybean. It could be due to a small difference in the moisture content of soybean and rye after the optimum pressure cooking condition.

Hectoliter-weights of soybean and rye were determined as 60.46 and 74.01, respectively at 10% moisture content at the end of the drying operation. It was interesting that hectoliter-weight of soybean decreased after drying operation. Also, it was lower than its initial hectoliter-weight. But, hectoliter-weight of rye increased at the end of the drying operation. This difference between soybean and rye could be due to their chemical and physical properties. It is well known that decrease in hectoliter-weight shows the decrease in size and increase in surface area of granular food products like differences between hectoliter-weights of wheat and flour with respect to their size difference (i.e. hectoliter of wheat is greater than hectoliter of flour due to their sizes). However, this evidence is true for ground products due to increase in surface area. There were no grinding of soybean, but its shrinkage was lesser than rye. According to hectoliter-weight results, it can be said that during drying, soybean (as a legume) and rye (as a cereal) have different shrinkage from each other due to physical and chemical properties, i.e. presence of crease in the kernel, and starch and protein contents in samples.