PILOT SCALE WHEAT GERM STABILIZATION IN A SPOUTED BED

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

MERT MEHMET OYMAK

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CHEMICAL ENGINEERING

APRIL 2006

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Canan ÖZGEN
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Nurcan BAC
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis and for the degree of Master of Science.

Dr. Cevdet ÖZTİN
Co-Supervisor

Prof. Dr. N. Suzan KINCAL

Examining Committee Members

Prof. Dr. Güniz Gürüz	METU, CHE
Prof. Dr. Suzan Kıncal	METU, CHE
Dr. Cevdet Öztin	METU, CHE
Assoc. Prof. Dr. Esra Yener	METU, FDE
Asst. Prof. Dr. Füsun Yöndem-Makasçıoğlu	METU, TVSHE

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Mert Mehmet OYMAK

ABSTRACT

PILOT SCALE WHEAT GERM STABILIZATION IN A SPOUTED BED

OYMAK, Mert Mehmet

M.S., Department of Chemical Engineering

Supervisor: Prof. Dr. N. Suzan KINCAL

Co-Supervisor: Dr. Cevdet ÖZTİN

April 2006, 97 pages

Wheat germ, a nutritionally rich by product of wheat milling, has poor storage stability due to its content of essential fatty acids along with oxidative enzymes. A pilot scale conventional spouted bed was designed and constructed as a high temperature – short time treatment unit to bring about drying and roasting effects. By facilitating the use of high temperature inlet air, yet maintaining the bed solids at a temperature below the degradation temperature, spouted bed dryers achieve thermal efficiencies unachievable by other dryers.

The inlet diameter, diameter of the column and the angle of the cone were 6.2 cm, 16 cm and 65˚ respectively. Thermocouples were placed on the inlet, exit and discharge gate of the column. Temperature profiles were recorded during drying, roasting and cooling of wheat germ. The drying temperatures ranged between 201 and 243˚C, operation times between 6.5 and 12 minutes, and air flow rate between 55 and 65 m^3/h. It was seen that the degree of roasting was closely related to the exit temperature of the air. The exit air temperature range was determined as 155-160˚C.

Sensory evaluation tests were carried out. Wheat germ processed at 60 m^3/h – 209˚C for 12 min and 55 m^3/h – 216˚C for 7 min were selected as the samples for storage studies, on the basis of the results of sensory evaluation tests. Reproducibility runs were carried out for the selected conditions. The bed height increase study was carried out at 60 m^3/h – 240 to 243˚C. The processed and raw wheat germ was stored in paper pouches at 40˚C, to estimate the shelf life on the basis of earlier studies.

Peroxide values of both raw and processed samples were followed during the storage period. The initial peroxide values of raw germ, processed samples, and reproducibility samples were 1.1 meq peroxide / kg oil. The peroxide value formation data were found to follow zero order rate kinetics. Comparison of the peroxide value changes in the processed and raw samples indicated that in the studied range of 55-60 m^3/h – 209-216˚C – 7-12 min, about 8–10 fold increase in the shelf life due to stabilization was achieved. The color parameters of each run were determined using the CIELAB (L*, a*, b*) system. Total color difference (ΔE*) values due to processing were calculated using L*, a* and b* values, to be between 2.3 and 58.6.

Keywords: Spouted bed, Wheat Germ, Stabilization, Roasting, Peroxide value, Color analysis

ÖZ

PİLOT ÖLÇEKLİ FISKIYELİ YATAK KULLANARAK BUĞDAY RÜŞEYMİ STABİLİZASYONU

OYMAK, Mert Mehmet

Yüksek Lisans, Kimya Mühendisliği Bölümü

Tez Danışmanı: Prof. Dr. N. Suzan KINCAL

Yardımcı Tez Danışmanı: Dr. Cevdet ÖZTİN

Nisan 2006, 97 sayfa

Besleyici değeri yüksek buğday rüşeymi, içerdiği oksitlenmeye müsait yağ asitlerinin ve oksitleme enzimlerinin etkisiyle çok kısa raf ömrüne sahip bir un fabrikası yan ürünüdür. Kurutma ve kavurma işlemleri için, yüksek sıcaklık – kısa süreli işleme için bir pilot ölçek fıskiyeli yatak ünitesi tasarımı yapılarak kurulmuştur. Malzemenin bozunma sıcaklığının altında kalarak, yüksek sıcaklıkta hava girişine olanak sağlayan fıskıyeli yataklı kurutucular diğer kurutucular tarafından başarılamayan termal verimlilik oranlarına ulaşmaktadır.

Fıskiyeli yatağın giriş çapı, kolon çapı ve konik kısmın açısı sırasıyla 6.2 cm, 16 cm ve 65˚ olarak seçilmiş, kolon girişine, malzeme boşaltma bölgesine ve kolon çıkışına termokapıllar yerleştirilmiştir. Sıcaklık profilleri, kurutma, kavurma ve soğutma süreleri boyunca kaydedilmiştir. Hava giriş sıcaklıkları 201˚ ve 243˚C arasında, hava hızı 55 ve 65 m^3/saat değiştirilmiş, buğday rüşeymi 7 dakika ile 12 dakika arasında işleme tabi tutulmuştur. Kavrulma düzeyinin havanın çıkış sıcaklığı ile önemli ölçüde bağlantılı olduğu görülmüştür. Çıkış hava sıcaklığı aralığı 155-160˚C olarak belirlenmiştir.

Algı değerlendirme testleri yapılmıştır. 60 m^3/saat – 209˚C – 12 dakika ve 55 m^3/saat – 216˚C – 7 dakika koşullarında işlem görmüş buğday rüşeymleri algı değerlendirme testleri sonuçları baz alınarak depolama çalışmaları için seçilmiştir. Seçilmiş koşullar için yeniden üretim çalışmaları yapılmıştır. 60 m^3/saat hava hızı ve 240–243˚C hava giriş sıcaklıkları arasında yatak yüksekliği arttırma çalışmaları yapılmıştır. Raf ömrünü hesaplamak için önceki çalışmalar baz alınarak işlem görmüş ve ham buğday rüşeymleri kağıt poşetlerde 40˚C de depolanmıştır.

Depolama süresi boyunca ham ve işlem görmüş buğday rüşeymlerinin peroksit değerleri izlenmiştir. Başlangıç peroksit değerleri ham ve işlem görmüş buğday rüşeymleri için 1.1 miliekivalan peroksit / kg yağ olarak bulunmuştur. Peroksit oluşum değerlerinin sıfırıncı dereceden bir reaksiyon kinetiğini izlediği görülmüştür. İşlem görmüş ve ham buğday rüşeymlerinin peroksit değerlerinin karşılaştırılması ile 55–60 m^3/saat, 209–216˚C ve 7–12 dakika aralığında, stabilizasyon sonucunda raf ömrü süresinde 8–10 katlık bir artış elde edildiği görülmüştür. Yapılmış çalışmaların renk parametreleri CIELAB (L*, a*, b*) sistemi kullanılarak belirlenmiştir. L*, a* ve b* değerleri kullanılarak hesaplanan net renk değişimi (ΔE*) değerleri 2.3 ile 58.6 arasında bulunmuştur.

Anahtar kelimeler: Fıskiyeli yatak, buğday rüşeymi, stabilizasyon, kavurma, peroksit değeri, renk analizi

To My Parents

ACKNOWLEDGEMENTS

I would like to express sincere appreciation to my supervisor Prof. Dr. N. Suzan Kıncal and my co-supervisor Dr. Cevdet Öztin for their guidance and insight throughout the research. I offer sincere thanks to Asst. Prof. Dr. Tunay Dik, Asst. Prof. Dr. Füsun Yöndem Makasçıoğlu, Assoc. Prof. Dr. Esra Yener and Dr. Aytanga Ökmen for their theoretical suggestion and constructive criticisms about the study.

I also thank to the technical staff especially Nevzat Bekçi, Kerime Güney, İsa Çağlar, Süleyman Nazif Kuşhan, Ertuğrul Özdemir, Selahattin Battal, and Gülten Orakçı for their encouragement, and theoretical and practical assistances.

I also express my appreciation to Ankara Un Sanayi A.Ş. for providing me the experimental materials.

I would also like to thank to all my friends, especially to Irem Kocaoğlu, Gediz Korkmaz, Özgür Avşar, and Berker Fıçıcılar for their help and moral supports in all stages of this research. Finally, I wish to thank to my family for their encouragement throughout my education.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Completed)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Completed)

NOMENCLATURE

d_P : Particle diameter

M : Molarity of the sodium thiosulphate solution,

PV : Peroxide value, meq of peroxide / kg of oil

V : Volume of sodium thiosulphate solution used for sample, ml

V_0 : Volume of sodium thiosulphate solution used for blank, ml

W : Weight of the original sample, g

W_A : Weight of the ash, g

W_D : Dry weight of the sample, g

W_{Fat} : Weight of the fat, g

W_W : Wet weight of the sample, g

ΔE^* : Total color difference

CHAPTER 1

INTRODUCTION

1.1 WHEAT

Wheat is grown on more land area worldwide than any other cereal crop and is a close third to rice and corn in total world production [WORC, 2002]; it is one of the most important foods sold in the market. It was one of the first grains domesticated by man. The cultivation of wheat is thought to have had its origin in the Fertile Crescent of Middle East, carbonized remains of wheat grains and imprints of grains in baked clay have been found in the Neolithic site of Jarno in northern Iraq having an estimated radiocarbon date of 6700 B.C. [Inglett, 1974]. Studies by Mangelsdorf also suggest that wheat had its origin in the Caucasus-Turkey-Iraq area [Huges et al., 1957].

1.2 CLASSIFICATION OF WHEAT

Wheat belongs to the grass family Gramineae (Poaceae) and the genius Triticum [Wilson, 1955]. The two important groups from that genus are:

Triticum vulgare (aestivum): It is also called the common wheat. Aestivum is the most widely cultivated form of wheat and it is used for bread making.

Triticum durum: Sometimes called macaroni wheat but more correctly referred to as durum wheat [Wilson, 1955].

The market classification of wheat is based upon the uses made of different types and does not necessarily have any relationship to their botanical groupings [Wilson, 1955]. This classification varies according to country mainly color;

hardness and session are important items for classification. The American classification, which is commonly accepted worldwide, is given in Table 1.1

Table 1.1 American Classification of Wheat

Type of Wheat	**Protein Content**	**Purpose of Usage**
Hard Red Spring	High	Bread, hard baked good
Hard Red Winter	Very high	The best wheat for bread making
Soft Red Winter	Medium	Bread and baking, pastry
Durum	Highest	Not very popular, have no place in pasta production
Red Durum	Highest	Not very popular, have no place in pasta production
White	Medium	Bread and brewing
Mixed	Low	Bread, baking

However the classification of wheat in Turkey slightly differs from the American version. In Turkey there are nine classes of wheat, which are based on the region of planting, hardness, color and shape of kernels. These classes are:

Milling Wheat:

- Anatolian Hard White
- Anatolian Red White
- Semi Hard Red
- Semi Hard White
- Others (White – Red)
- Feed Wheat

Durum Wheat

- Anatolian Durum
- Other Durum
- Low Quality Durum

Hard wheat is higher in protein and gluten content so they are usually used for making breads. Soft wheat is used in the patisseries. All-purpose flour is made from soft and hard wheat. Pasta or macaroni is made from durum wheat so it is sometimes called as the “Pasta Wheat”.

1.3 WORLD WHEAT PRODUCTION

Wheat is an important cereal crop. The worldwide wheat production for the year 2003 is almost 600 million tons. Wheat is well adapted to harsh environments and is mostly grown on everywhere any time. Wheat is harvested somewhere in the world in nearly every month of the year [Pomeranz, 1987].

Top five wheat producers in the world are:

- China
- India
- United States
- France
- Russia

1.4 WHEAT PRODUCTION IN TURKEY

Wheat is the most important cereal crop in Turkey. Turkey covers nearly 3 % of the world wheat production. Wheat production in Turkey is summarized between 1980 and 2000 in Table 1.2

Table 1.2 Turkey's Wheat Production (FA0, 2005)

WHEAT	1980	1985	1990	1995	2000
Production (tons)	16 554 000	17 032 000	20 022 000	18 015 000	18 000 000
Harvested area (ha)	8 956 000	9 274 500	9 432 309	9 400 000	8 650 000
Yield (kg/ha)	1 848	1 836	2 122	1 916	2 080
Import (tons)	-	781 923	2 180 731	1 253 331	963 000
Export (tons)	338 049	268 923	24 975	232 847	1 782 048
Consumption (kg/per/yr)	201.0	207.6	201.8	197.0	187.4

Wheat germ comprises 2.5–3.5 % of the kernel. Production of wheat germ amount can be calculated approximately by using the percentage weight of the germ in the kernel. It shows that wheat germ production is around 450.000 - 630.000 tons for the production in the year 2000. By using the wheat consumption value for each person, it can be said that the wheat germ amount is around 4.7–6.6 kg per person.

1.5 WHEAT KERNEL

The kernel of wheat is diagrammatically shown in Fig 1.1. The kernels average about 8 mm length and weigh about 35 mg. Wheat kernels are rounded on the dorsal side (the same side as the germ) and have a longitudinal crease the length of the ventral side (opposite the germ) [Hoseney, 1990]. At the apex or small end of the grain is a cluster of short, fine hairs known as brush hairs. The dry fruit coat is the outer bran part (pericarp) of the kernel and consists of totally four layers. The inner bran part is the rest containing the aleurone layer (the layer just covers the endosperm). The remaining tissues of the grain are the endosperm and the embryo. In a well-filled wheat kernel, the germ comprises 2-3% of the kernel, the bran 13-17%, and the endosperm the remainder. The inner bran layers are high in protein, whereas the outer bran is high in cellulose and minerals. The germ is high in proteins, lipids, and minerals and also quite high in vitamin E and B; the endosperm consists largely of starch granules embedded in a protein matrix [Pomeranz, 1987].

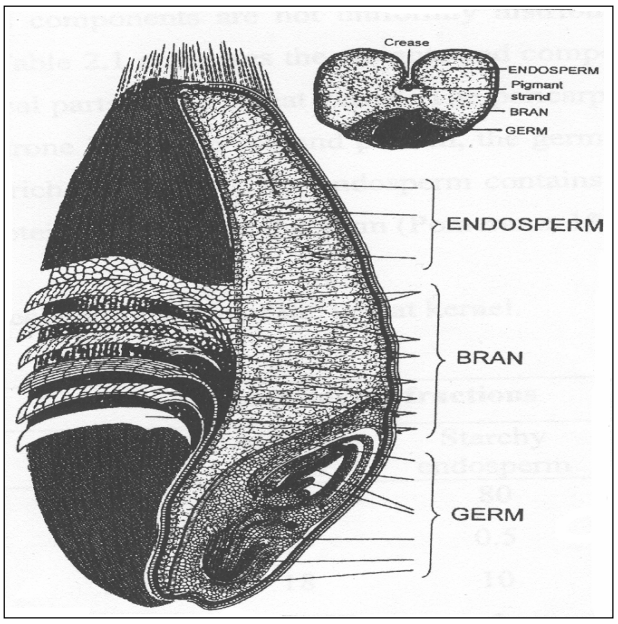

Figure 1.1 Longitudinal and cross section through a wheat kernel [Pomeranz, 1987].

The various components are not uniformly distributed in the kernel structure. Table 1.3 compares the weights and the compositions of the main anatomical parts of the wheat kernel. The pericarp is high in cellulose; the aleuron is high in ash and protein, the germ is high in lipid content and rich in proteins. The endosperm contains the starch and is lower in protein content than the germ [Pomeranz, 1987]. This rich composition of wheat make it uniquely suited in the production of wholesome, nutritional, and consumer-acceptable food.

Table 1.3 Chemical composition of the wheat kernel.

	Pericarp	Aleurone layer	Starchy endosperm	Germ
Weight (%)	9	8	80	3
Ash (%)	3	16	0.5	5
Protein (%)	5	18	10	26
Lipid (%)	1	9	1	10
Crude Fiber (%)	21	7	0.5	3

1.6 WHEAT GERM

The germ of wheat comprises 2.5–3.5 % of the kernel. It is readily separated from the endosperm and bran by milling [Hoseney, 1990]. The embryonic axis and the scutellum together constitute the embryo. The embryonic axis is the plant of the next generation. It consists of primordial roots and shoots with leaf initials. It is connected to and couched in the shield-like scutellum (storage organ), which lies between it and the endosperm [Kent and Evers, 1994].

Wheat germ contains about of 28 % protein, 10 % fat, 42 % carbohydrates, 2 % fiber and 4 % mineral. Wheat germ has a high lipid content especially linoleic acid, stearic acid and oleic acid. It also contains essential linolenic acid which lacks in many cereals. It also contains essential amino acids lysine, methionine, and threonine. Wheat germ comprises high vitamin content of E and B. By considering the high nutritional value of wheat germ, it can be used as additive in many foods to increase the nutritive value of the product.

1.7 RANCIDITY

The most important cause of deterioration in fats and fatty foods is oxidation. Oxidation of fats results in the replacement of an oxygen ion for a hydrogen ion in the fatty acid molecule. This substitution destabilizes the molecule and makes it possible for other odd chemical fragments to find a place along the chain. The result is an unpleasant change in the flavor and odor of a food, called rancidity. Unsaturated fats are more susceptible to oxidation than the saturated fats.

The presence of water is also required for the hydrolysis of triacylglycerols to free fatty acids; therefore reduction of moisture content will also contribute to the slowing down of rancidity development. A high temperature – short time drying operation is required because of the heat sensitive nature of the polyunsaturated fatty acids, which amount to almost 70% of the fat in wheat germ.

1.8 SPOUTED BED

Spouted bed is a kind of fluidized bed, consisting of a cylindrical vessel with a conical bottom fitted with only one inlet nozzle for the gas injection [Mujumdar and Passos, 1987].

In the central core dilute phase – called spout region - the solid particles are carried upwards by the gas jet. There are two zones in this region: one close to the jet inlet, where the solid particles are accelerated and the drag force is higher than the net gravitational force, and the other a few centimeters above the jet inlet, where the particles begin to be decelerated and the drag force approaches to the gravitational force. The deceleration in the jet is due to the entrained solids (loading the jet and consuming the gas momentum) and a decrease in the gas flow rate (gas dispersion in the annulus).

For the spouting condition, the particles reach the top of the bed with a velocity to develop a fountain. In this region the particles continue to be decelerated until reaching the terminal settling velocity. Up to this point, the particles change their direction, falling back on the annulus surface. The fountain is characterized by solid crowding and collisions; the particle downward trajectories approach to a parabolic curve. The predominant forces in this region are the gravity and the inertia. The drag force can be neglected.

The annulus region behaves in a manner similar to a loosely packed bed. The solid particles travel slowly downward (counter currently with the percolated gas) and inwards until reaching again the spout region. This cyclic pattern of solid flow contributes to improve the gas-solid contact. The solid flow in this region is not controlled by the magnitude of gas inlet velocity but by the particle properties such as shape, size, and roughness.

The spouted bed technique originally developed by Mathur and Gishler for drying wheat has found numerous applications in the drying, heating, and cooling of granular materials, the drying of suspensions or solutions in beds of inert particles, the granulation of melts or solutions, including reaction, coating of tablets, solids blending, comminution and grinding. [Mujumdar and Passos, 1987]

1.9 GENERAL COMPARISON WITH OTHER COMMON DRYING SYSTEMS

Dryers for granular materials are classified by their heat supply methods, as:

- Convective: In this type, heat requirement is supplied by the hot gases. This group represents 80 % of industrial applications.
- Direct Contact: In this type, the wall of a heater is responsible for the heating. This group contributes 15 % in industrial use. Because of their potential for higher thermal efficiency, direct contact dryers are rapidly increasing in their acceptance by industry.
- Radiative: In this type, infrared radiators are the source of energy. These dryers are responsible for 4 % of industrial use.
- Electromagnetic: In this type, the heat is supplied by an electromagnetic field.

In grain drying, the grain temperature limits the quality of the dried product; convective dryers are more suitable for this kind of drying. Convective dryers can be classified as follows:

- Nonactive Aerodynamic Regime
    - Stationary Bed (fixed bed of particles)

    Examples: Tray and Band dryers
    - Moving Bed (packed bed of particles moving by gravity)
    - Free-Falling Particles (particles fall through relatively quiescent air)

    Examples: Rotary and Spray dryers

- Active Aerodynamic Regime (suspended state of bed from the force exerted by gas on the particles)
    - Dense Suspended State

    Examples: Fluid Bed, Spouted Bed, and Vibrated Bed
    - Stream Dryers

    Examples: Flash (or pneumatic) Vortex, Spin-Flash, and Impact dryers

For Active Aerodynamic Regime, the heat and mass transfer is higher because of better contact between gas and solid particles. For the subgroup of dense suspended state, which represents high solid circulation rates, additional heating could be supplied by direct contact. It results in an increase in the drying efficiency.

Spouted bed dryers require a high pressure drop and high inlet air velocity (but lower than fluidized bed). Further, the possibility of working with high gas inlet temperature increases the heat transfer efficiency [Mujumdar and Passos, 1987]. The advantages and limitations of conventional spouted bed dryers are listed in Table 1.4.

Table 1.4 Advantages and Limitations of Conventional Spouted Bed Dryers

Advantages	Limitations
Can handle particles (d_p > 1 mm)	Limited throughput of gas
Predictable and reproducible solids and gas flow patterns	Gas flow rate governed by the requirements of spouting rather than the heat / mass transfer
Intensive particle circulation at low gas flow rates	Low bed-to-wall or bed-to-surface heat transfer
Uniformity in the bed temperature and moisture content of product	High pressure drop prior to onset of spouting
Elimination of back mixing and localized overheating points	Limitations on geometry and capacity for efficient operation
Low gas residence time	Difficult to scale up
High inlet gas temperature without thermal damage of product	
Low investment cost	
Reduced space for installation	

CHAPTER 2

LITERATURE SURVEY

Wheat germ, a by-product of the flour milling industry has great potential as a highly nutritious food supplement in many countries. When compared to flour, wheat germ is three times richer in protein content, which can be used instead of protein; seven times richer in fat content, and six times richer in mineral content. Wheat germ has a very poor shelf life of only a few days, because of high enzyme activity and unsaturated nature of fats present.

Generally, heat is used to inactivate enzyme activity prior to other preservation treatments. High temperature-short time processing can yield heat-preserved foods of superior quality because heat-induced flavor, color, and nutrient losses are minimized. Roasting of wheat germ is practiced to impart specific organoleptic characteristics and also for ease of grinding and extraction. It is a time-temperature dependent process involving physical and chemical changes. The degree of roasting plays a major role in determining the flavor characteristics of the wheat germ.

Many agricultural grains require drying for safe storage over long periods. For such coarse grains, spouted beds are invariably the best choice [Mathur and Epstein, 1974]. By facilitating the use of high temperature inlet air, yet maintaining the bed solids at a temperature below the degradation temperature, spouted bed dryers achieve thermal efficiencies unachievable by other dryers and also high evaporation rates for a given dryer volume, resulting in compact dryer size and less capital cost. Furthermore, due to good mobility of solids, feeding and discharge of solids to and from the spouted bed dryer is smoothly achieved.

2.1 ROASTING

Nagaraju et al. (1995) studied roasting of coffee beans in an experimental spouted bed roaster using hot air as the heating medium. Conditions for optimum roasting have been evaluated. They found that the best quality product was obtained at an air temperature of 250°C for a roasting time of 5 min. The behavior of the system can be represented by an unsteady state heat transfer mechanism. Based on the time-temperature relationship, the overall heat transfer coefficient was found to be 12.023 W/(m^2 K).

Nicoli et al. (1996) studied the antioxidant properties of coffee in relation to roasting degree. In particular, he evaluated the extent of the chain-breaking activity and oxygen scavenging properties of Maillard reaction products contained in coffee brews. Samples showed very high chain-breaking and oxygen consumption activities, which did not increase linearly with increasing roasting degree. He found the highest antioxidant properties for the medium-dark roasted coffee brews.

Nagaraju et al. (2002) studied on the development of a laboratory spouted bed roaster for roasting of coffee beans. The spouted bed had a specific advantage of handling coffee beans of various variety, size, shape and blends. Increased yield, enhanced bean swelling ratio, higher soluble solids and increased aroma and flavor resulted in *Arabica* and *Robusta* coffee beans when roasted in the model roaster developed as compared to conventional process. Physical, chemical and organoleptic properties of the spouted bed and conventionally roasted product were compared. They found that the quality standards of the product (ground instant coffee) are comparable with the commercial sample.

Fryer et al. (2003) studied the roasting of barley on a spouted-bed roaster. They developed a model of the roasting process to enable automatic control methods. The model uses parameters measured by other workers in fields such as grain drying

and allows the change in temperature and moisture content of the barley to be predicted throughout the roasting period: a good fit between theory and experiment is obtained without recourse to any fitted parameters. This will enable changes in product characteristics to be modeled as a function of roasting control parameters such as temperature and time.

2.2 COLOR CHANGES DURING ROASTING

Özdemir et al. (2000) studied the kinetics of color changes during hazelnut roasting for a temperature range of 100-160°C for 60 min. The rate of color differences was significantly affected by temperature and time over the experimental conditions. Roasted hazelnut samples produced significantly lower L-value and b-value in ground-state color measurements compared to whole-kernel measurements. They described the color changes during hazelnut roasting by a third-degree polynomial with an Arrhenius-type temperature dependence of the model coefficients. Activation energy for the L-value of color was found to be 62.3 kJ/mol over the temperature range of the study. A generalized model for color changes during roasting of hazelnuts as a function of temperature and time was established.

Ibanoglu et al. (2002) studied color change during infrared heating of wheat germ at 100 - 150˚C for 5-40 min. An increase in L values and a decrease in a values were observed at increased time and temperature of heating. Scattered data were obtained for the b values. Results showed that the L and a values can be successfully modeled using a third-degree polynomial equation, which can be used to estimate the color changes during heating. The activation energy for the color changes in wheat germ based on the L values was found as 36.6 kJ/mol.

2.3 STABILIZATION – LIPASE, LIPOXYGENASE ACTIVITY

Rao et al. (1980) studied stabilization of wheat germ with different processing methods. They found that toasting of germ for 25 minutes at 150˚C in an air circulation oven, or for 5 minutes to a product temperature of 130˚C in a coffee roaster, resulted in a product of improved acceptability and having a residual lipase activity of 76.4 and 45.9 %, respectively. Steaming at atmospheric pressure, a five cm thick layer of germs spread on a wire-mesh bottom tray for 10 minutes totally inactivated lipase, lipoxidase and proteolyitic enzymes in the product, which though acceptable had a somewhat cooked taste. Drum-drying of slurry containing 33 % ground unprocessed (raw) germ at a steam pressure of 35 psi, corresponding to a drum temperature of 138˚C resulted in a highly acceptable and ready-to-eat product wherein all the three enzymes were completely inactivated. Defatting of germ with n-hexane did not affect the enzyme activity but resulted in a product with taste inferior to that of unprocessed germ.

Both the processed and the unprocessed germ samples packed in hermetically sealed cans were stored in a freezer at -10˚C. These samples served as controls for subsequent periodical evaluation of corresponding stored samples for odour, taste and overall acceptability by a panel of six judges. When packed in polyethylene pouches, unprocessed germ turned unacceptable within 2 weeks of storage while defatting of germ improved the shelf-life to 12 weeks. Drum-drying extended the shelf-life to 20 weeks, whereas toasting or steaming increased it further to 26 weeks. Packing in polyethylene or polycel pouches or hermetically sealed cans followed a similar pattern.

Vetrimani et al. (1992) studied the microwave treatment on rice bran, wheat germ and soybean. They showed that microwave treatment led to considerable inactivation of lipase and complete inactivation of lipoxygenase present in these materials. The persistence of about 30 % lipase activity even after 4 minutes

microwave treatment probably reflects the presence of heat stable lipase. The storage studies on microwave treated rice bran show that the bran is stabilized as judged from the much lower increase in its free fatty acid content after 1 month as compared to the untreated samples.

Virtalaine et al. (2000) studied rancidity in wheat germ. They evaluated volatile compounds in stored wheat germ using dynamic headspace gas chromatography and sensory analysis. They subjected wheat germ to microwave heating at 45 and 55 °C prior to storage at room temperature. The progress of oxidation was followed in untreated wheat germ for 4 weeks and in heat-treated wheat germ for 7 weeks by dynamic headspace gas chromatography and sensory evaluation. Significant ($p > 0.05$) changes in rancid odor and flavor were observed in the untreated wheat germ after 3 weeks, whereas no corresponding difference was observed in the microwave-heated wheat germ after 7 weeks of storage. They identified 36 volatile compounds according to their mass spectra and Kovats indices. The major volatiles were hexanal, R-pinene, 1-hexanol, and 3-carene. In addition to analysis of a short period of storage, they identified 30 volatile compounds from the headspace of wheat germ stored for >1 year.

Yöndem-Makascioglu et al. (2005) studied stabilization of wheat germ by heating in a spouted bed for 3-9 minutes with air at 140-200˚C. The lipase activity was decreased by 6–65 %. Wheat germ processed at 200˚C for 6 minutes was ranked highest in sensory evaluation, described as having 'a golden color' and 'nutty flavor', and its lipoxygenase activity had decreased by 91.2%. This product and raw wheat germ were stored in paper, polyethylene and vacuum-packed polyethylene pouches at 5 ˚C, room temperature (18-26 ˚C) and 40 ˚C, and the moisture contents, water activities, free fatty acid contents and peroxide values were followed for 20 weeks. The increases were faster in paper pouches than in the polyethylene ones; vacuum packaging in polyethylene did not bring about significant improvement. The peroxide values of raw samples exceeded 10 meq peroxide/kg on after 3-23 days

while those of the processed samples stored at room temperature or 5˚C were still less than 10 meq peroxide/kg after 20 weeks. The free fatty acid content and peroxide value changes were expressed by zero order kinetics, resulting in similar activation energies for the raw and processed samples.

2.4 CHARACTERIZATION

Kim et al. (2003) studied on hard red winter and hard red spring wheat milling co-products (bran, germ, shorts, and red dog) from three commercial flour mills, for differences in physical, chemical, and thermal properties. They determined the ranges of bulk density for bran, germ, and red dog at three moisture levels as 146.5 to 205.2 kg/m^3, 269.2 to 400.6 kg/m^3, and 298.9 to 398.1 kg/m^3, respectively. The true density ranking order is: Red dog > shorts = germ > bran, independent of the moisture level. Red dog had the smallest geometrical mean diameter with the highest variation (coefficient of variation of 23.8 %).

2.5 NUTRITIONAL VALUE OF WHEAT GERM

Wheat germ, a byproduct of the flour milling industry has great potential as a highly nutritious food supplement in many countries. Table 2.1 [Kirk and Sawyer, 1991] shows the chemical composition of wheat germ. In terms of macro nutrients, it supplies three times more proteins of high biological value, seven times more fat, six times more mineral content compared to flour from the endosperm [Jurkovic and Colic, 1993].

Jurkovic et al. (1993) studied the nutritive value of proteins in raw and roasted wheat germs (temperature: 130-150˚C for 20 min). They determined the protein quality evaluation by a biological method – feeding young growing rats. The rats were fed 10 % level protein diets, based on raw and roasted wheat germs. The results show that protein of roasted wheat germs has higher digestibility and protein

efficiency ratio than the raw wheat germs which proves that roasting destroyed digestion enzymes inhibitors. Furthermore, the net protein utilization has also been improved by roasting. Biological value of raw germs approximates to the value of roasted germs. They concluded that roasting saves and improves protein parameters in wheat germs.

Table 2.1 Chemical composition of wheat flours, wheat germ and wheat bran [Kirk and Sawyer, 1991].

	Flour (72 %)	Flour (80 %)	Wheat Germ	Wheat Bran
Moisture (%)	13 – 15	13 – 14.5	9 – 12	14
Protein (%)	8 – 13	8 – 14	25 – 30	12 – 16
Fat (%)	0.9 – 1.4	1.0 – 1.6	8.5 – 11	3.0 – 4.0
Carbohydrates (%)	65 – 70	64 – 70	39 – 45	-
Fiber (%)	0.1 – 0.3	0.2 – 0.4	2.0 – 2.5	9 – 12
Ash (%)	0.3 – 0.5	0.6 – 0.9	4.0 – 4.5	4.0 – 6.0

The lipids in wheat germ are relatively rich in the essential fatty acid, linoleic acid. Saturated fatty acids (mainly stearic) represent less than 20 % of the total fatty acids [Pomeranz, 1987]. As it can be seen in Table 2.2, more than 80 % of the total lipids consist of unsaturated fatty acids. Wheat germ fatty acids consist mainly of linoleic acid 58 %, stearic acid 18 % and oleic acid 15 %, with a favorable ratio of w-3/w-6 fatty acids of about 1/8.

Table 2.2 Fatty acid composition of wheat germ having 14 % moisture and 10.9 % total lipid [Pomeranz, 1987].

Fatty Acid		Weight (g/100 g germ)
Saturated	Myristic (14:0)	-
	Palmitic (16:0)	0.01
	Stearic (18:0)	1.81
	Arachidic (20:0)	0.06
Total saturated		1.88
Monounsaturated	Palmitoleic (16:1)	0.04
	Oleic (18:1)	1.54
Total monounsaturated		1.58
Polyunsaturated	Linoleic (18:2)	5.86
	Linolenic (18:3)	0.74
Total polyunsaturated		6.60
TOTAL		10.06

Wheat germ has a high concentration of protein rich in essential amino acids, such as lysine, methionine and threonine, which are lacking in many other cereal proteins [Gnanasambandam and Zayas, 1992]. The distribution of essential amino acids in germ is given in Table 2.3.

Table 2.3 Essential amino acid distribution of the germ containing 14 % moisture (Chromatographic determination, range of nine wheat) [Pomeranz, 1978].

Amino Acid	Percent Content (wt %)
Alanine	1.34 – 1.71
Arginine	1.77 – 2.09
Aspartic acid	1.92 – 2.25
Cysteine	0.43 – 0.61
Glutamic acid	3.65 – 4.59
Glycine	1.32 – 1.58
Histidine	0.59 – 0.82
Isoleucine	0.77 – 0.94
Leucine	1.50 – 1.75
Lysine	1.30 – 1.77
Methionine	0.39 – 0.58
Phenylalanine	0.86 – 1.01
Proline	1.13 – 1.52
Serine	1.05 – 1.28
Threonine	0.89 – 1.09
Tyrosine	0.65 – 0.78
Valine	1.01 – 1.37

Wheat germ also has high vitamin content. It is rich in vitamins B and E [Hoseney, 1990; Pomeranz, 1987]. Table 2.4 shows the vitamin content of wheat germ and some other cereal products.

Table 2.4 Vitamin contents of some cereals (mg/100 g edible portion) [Belitz and Grosch, 1987].

Food Product	E (mg)	B_1 (mg)	B_2 (mg)	B_3 (mg)
Wheat germ	27.6	2.01	0.72	3.3
Wheat flour	2.0	0.11	0.08	0.1
Rye flour	3.4	0.19	0.11	-
Corn flakes	0.43	-	-	0.07
Oat flakes	3.7	0.59	0.15	0.16

When wheat germ oil is compared to other oils from the point of vitamin E content; it is 30 times richer than olive oil, sunflower oil and soybean oil, 14 times richer than peanut oil and six times richer than sesame oil [Anon, 1993].

It is reported that mild heat processing or toasting of wheat germ improved its flavor, nutritional value (by destruction of anti-nutritional factors like hemagglutenin and trypsin inhibitor), and functional properties (by inactivation of glutathione) [Vani and Zayas, 1995].

2.6 COMMERCIAL USE

In view of its nutritional value and palatability, wheat germ provides an excellent source of proteins, minerals and vitamins; so it can be added into cakes, muffins, noodles, ready-to-eat breakfast foods, baby foods and any kind of meals. Bread enrichment with wheat germ was studied by Çakmaklı et al. (1995), who

reported that adding wheat germ decreased volume of the bread while increasing its weight.

Increasing market value of animal protein is a primary reason for investigations involving different types of unconventional protein sources in meat products. Concern of improving the protein quality of meat products, while lowering the cost of production, and attempts to develop new types of meat products resulted in considering plant proteins as alternatives to meat proteins. Wheat germ protein was tested successfully in comminuted meat products to increase yield, improve stability and modify textural properties. Frankfurters with wheat germ protein additive showed increased water- holding capacity and batter stability and decreased cooking loss [Gnanasambandam and Zayas, 1992]. Jurkovic and Colic (1993), studied the protein quality on the raw and roasted wheat germ (temperature 130 to 150˚C for 20 min). Their study resulted in the conclusion that roasting improves the protein quality and digestibility in wheat germ.

Wheat germ is the richest known source of vitamin E, lack of which causes sterility, loss of vitality, arthritis and some form of paralysis. It is a powerful antioxidant that can help retard ageing, protect muscles, blood, lungs and eyes, prevent blood clots and strengthen the immune system [Tolonen, 1990]. Some studies in rats and humans also showed that long term wheat germ intake lowered blood level of cholesterol [Cara et al., 1992]. Wheat germ oil is sold in soft gel capsules for intake by mouth, as it is a rich source of vitamins E and B group. Because of its high vitamin E content, wheat germ oil is also used in cosmetic industry in moisturizer creams, shampoos and soaps.

2.7 EFFECT OF ENZYMES ON THE KEEPING QUALITY OF WHEAT GERM

Enzymes are proteins with enormous catalytic activity. Like any other catalyst, an enzyme brings the reaction catalyzed to its equilibrium position more

quickly than would occur otherwise. Enzyme-catalyzed reactions proceed in many foods and thus enhance or deteriorate food quality [Belitz and Grosch, 1987].

Two types of enzymes are important in catalyzing breakdown of lipids: Lipase and lipoxygenase. By the action of lipase the triglycerides (triacylglycerols) are hydrolyzed and free fatty acids are formed, and these free fatty acids are oxidized and peroxides are produced by the action of lipoxygenase. Both contribute the development of rancidity in cereals; thus both hydrolytic and mainly oxidative rancidity are recognized [Kent and Evers, 1994]. Lipase activity is important because a free fatty acid is more susceptible to oxidative rancidity than it is in a triglyceride form [Hoseney, 1990]. Lipoxygenase can only catalyze degradation of free fatty acids and mono glycerides and therefore follows lipolysis. The problem of rancidity is greatest in cereals, which have high oil content like wheat germ [Kent and Evers, 1994]. Acyl lipid constituents, such as oleic, linoleic and linolenic acids have one or more allyl groups within the fatty acid molecule and thus are readily oxidized to hydroperoxides. Therefore, under the usual conditions of food storage, unsaturated acyl lipids can not be considered as stable food constituents. [Belitz and Grosch, 1987].

CHAPTER 3

MATERIALS AND METHODS

3.1 MATERIALS

The raw wheat germ used in this study was obtained from Ankara Un Sanayi A.Ş. Fresh wheat germ was stored in polyethylene pouches at 5˚C.

Three groups of raw wheat germ were used in the study. Raw germs were classified as the following:

- The symbol A was used for the preliminary experiments. Wheat germ supplied was daily produced.
- The symbol B was used for experimental work plan. It was stated by the supplier that wheat germ given was a mixture of fresh and a few days old samples.
- The symbol C was used for reproducibility runs and bed height studies. Fresh wheat germ was used in the runs.

The roasted wheat germ in the column (after cooling) was quickly removed and emptied into a glass jar, allowed to cool to the room temperature. In the storage period both raw and dried wheat germ was placed in paper pouches and stored in an oven at 40˚C.

3.2 EXPERIMENTAL SETUP AND PROCEDURE

3.2.1 EXPERIMENTAL SETUP

A spouted bed drier was constructed using a 250 m^3/h fan, a 3.2 kW electrical heater, a cylindrical glass column with a length of 1.5 m and a diameter of 16 cm. The column had an inverse conical base of 6.2 cm inlet diameter at the cone bottom (Figure 3.1). The conical base piece was made of stainless steel metal sheet and was connected by a flange to the bottom of the glass column. A galvanized pipe was attached under the conical base of the column and a discharge gate was placed on the pipe to remove the wheat germ from the column after the operation. A stainless steel fine wire mesh was used as a support under the column to prevent falling of the particles. The column material was selected as glass in order to make visual observations during the movement of the bed. Three thermocouples were placed on different locations of the column; one under the column (under the sieve) to measure the inlet air temperature, one above the sieve (at the level of discharge gate) and one at the 20^{th} cm of the bed level height to measure the exit temperature of the air in the column. In order to change the direction of the heated air during cooling, a gate valve and a ball valve were put between heater and the column. Cooling line was blocked by a ball valve during heating and operation time periods. (Figure 3.2)

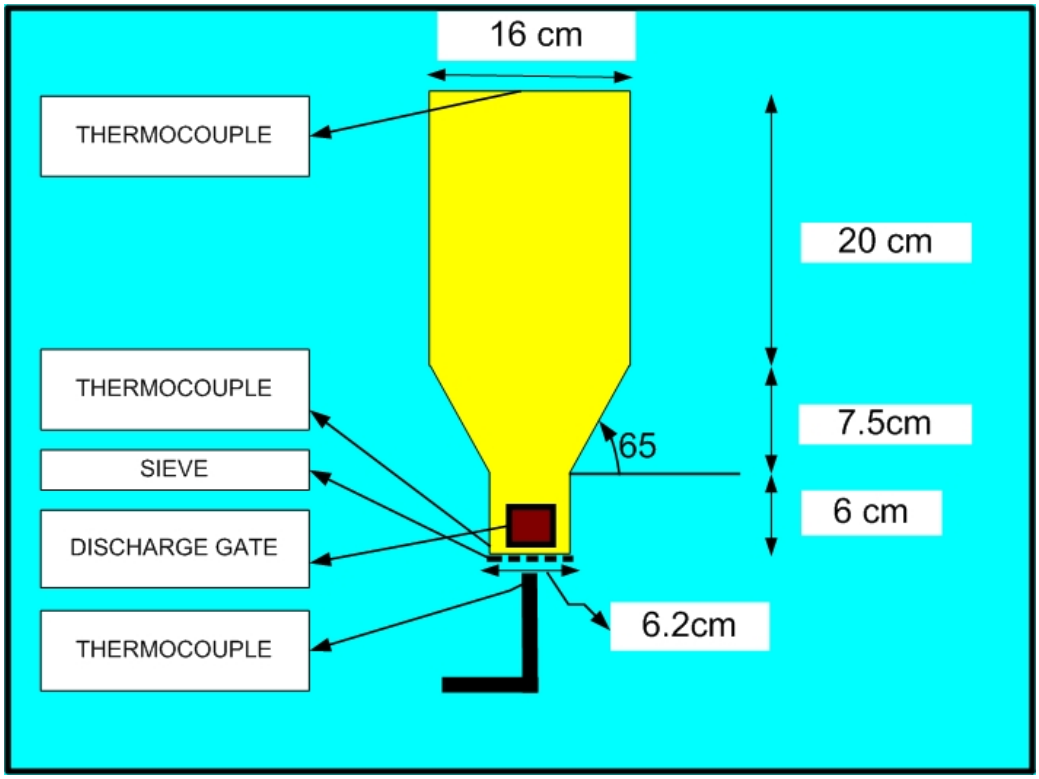

Figure 3.1 Spouted Bed Column

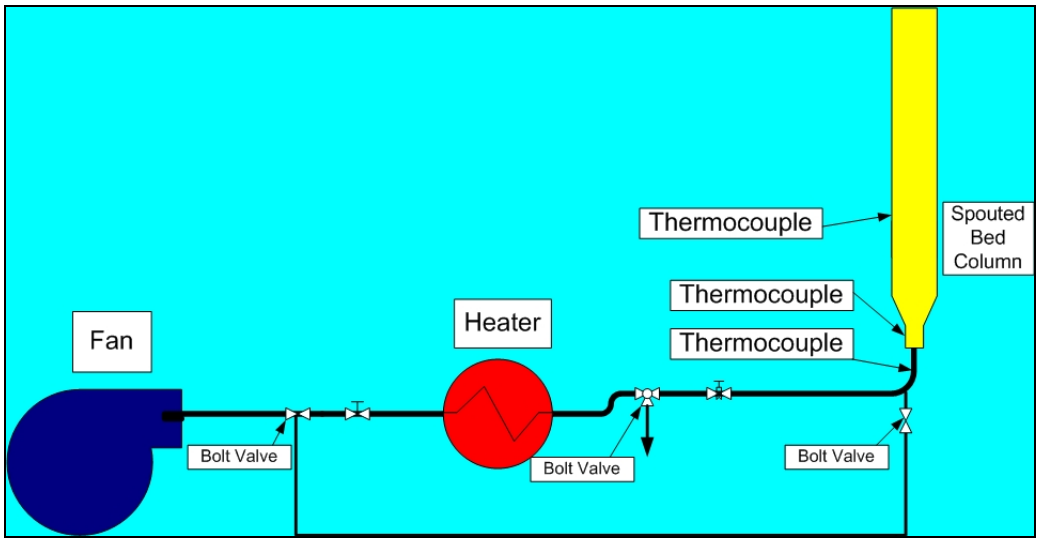

Figure 3.2 Experimental Setup

3.2.2 EXPERIMENTAL PROCEDURE

In a typical run, air flow rate was adjusted with an anemometer and a pre-scaled valve, and air was heated to the desired temperature. When air reached the desired temperature, it was directed out of the process line by using a gate and a ball valve, and wheat germ was fed from the top of the column. Then heated-air was redirected to the main line or to the column, and spouting and roasting process started. Wheat germ was held to a certain temperature-time period. After the process finished, heated-air was again directed outside the process line and ambient air bypassed from the fan exit was fed from under the column, and the roasted wheat germ after cooling was discharged from under the column to a container. Then it was put into a glass jar and hold until it reached the room temperature and the lid of the glass jar was closed. Temperatures were recorded in 10–30 seconds intervals from feeding of the column to the discharge of the wheat germ, during drying and cooling periods.

In the preliminary experiments, 330 g wheat germ was used in each run, which fills the conical part of the column. The air flow rate was changed in the range of 40–70 m^3/h. The experiments were carried out in the temperature range between 185 and 240˚C for 6–20 minutes time intervals. In the experimental work plan acquired from preliminary experiments, the air flow rate, temperature and operation periods changed from 55–65 m^3/h, 201–243˚C and 7–12 minutes, respectively.

In order to stabilize wheat germ Yondem-Makascioglu et al (2005) studied with an existing laboratory type spouted bed unit. The air is drawn in through a mesh filter in the base of the cabinet and blown by the centrifugal fan over a 2kW electrical heater. The cabinet contains the air distribution system and electrical controls. The glass column, which has 9 cm inlet nozzle, 16 cm width and 40 cm height consists of a container with a fine mesh nylon gauze air distributor and stainless steel support gauze. In the constructed setup, the column diameter (16 cm),

the cone angle (65°) remained constant. Air flow rate was a new parameter to adjust. The range of flow rate was found and the flow rate was determined in order to obtain desired product near 200˚C. The operation time seemed to be more than 6 minutes in the new setup. It was due to the wheat germ amount increase, heat loss and decrease in the inlet air diameter. The new conditions were analyzed and an experimental plan was made from the results of preliminary experiments.

3.3 ANALYTICAL DETERMINATION METHODS

Moisture, crude fat, and ash analyses were made in order to determine the chemical composition of wheat germ. Peroxide value analysis was applied during storage period of the raw and processed germ. Sensory evaluation tests and colorimetric measurements were carried out during the study.

3.3.1 MOISTURE ANALYSIS

In order to determine the moisture content of the wheat germ, first the ceramic dish and the lid were dried in an air oven to a constant weight. Then, 1 gram of sample was weighed in this dish and placed into oven at 105˚C. At the end of two hours, the dish was covered with the lid while still in the oven and transferred to a desiccator. After reaching the room temperature, the dish having the sample was weighed. The weight loss was reported as the moisture content of the germ. The experiments were done in triplicate. Arithmetic mean of the results was given. Calculation was done on the wet basis of the raw wheat germ by using the following formula:

$$\text{Moisture content, \%} = \frac{W_W - W_D}{W_W} \times 100 \qquad (3.1)$$

W_W : Wet weight of the sample, g

W_D : Dry weight of the sample, g

3.3.2 CRUDE FAT ANALYSIS

Semi continuous solvent extraction method proposed by AOAC (1995) was used to determine the crude fat content of the raw wheat germ and also to extract the oil from the raw and dried wheat germs for peroxide value analysis using petroleum ether as a solvent. During the experiments soxhlet extraction apparatus was used (Figure 3.3). For semi continuous solvent extraction, the solvent builds up in the extraction chamber for five to ten minutes and completely surrounds the sample, and then siphons back to the boiling flask. This method provides a soaking effect of the sample and does not cause channeling [Nielsen, 1994].

As the raw wheat germ contains more than 10 % moisture, sample was pre-dried in order to obtain easy penetration of the solvent [Nielsen, 1994]. Then the pre-dried sample was put into extraction thimble with porosity permitting a rapid flow of ether. Then the sample in the thimble was covered by cotton wool. After the pre-dried boiling flask has been weighed, about 250 ml of petroleum ether was put into the flask. Then the flask was put on the heater and the soxhlet flask having the sample was placed on it. The condenser is assembled with the soxhlet flask and connected to water supply. Extraction was done at a rate of 5–6 drops per second condensation for about 6 hours by heating the solvent in boiling flask. At the end of the extraction the boiling flask was dried on the heater for about 15 minutes to evaporate the petroleum ether. Then the weight of the flask containing the oil was recorded and the weight of the oil was determined. The experiments were studied triplicate. Calculation was done on the wet basis of the raw wheat germ by using the following formula:

$$\text{Fat, \%} = \frac{Wfat}{W} \times 100 \qquad (3.2)$$

W_{Fat}: Weight of the fat, g

W: Weight of the original sample, g

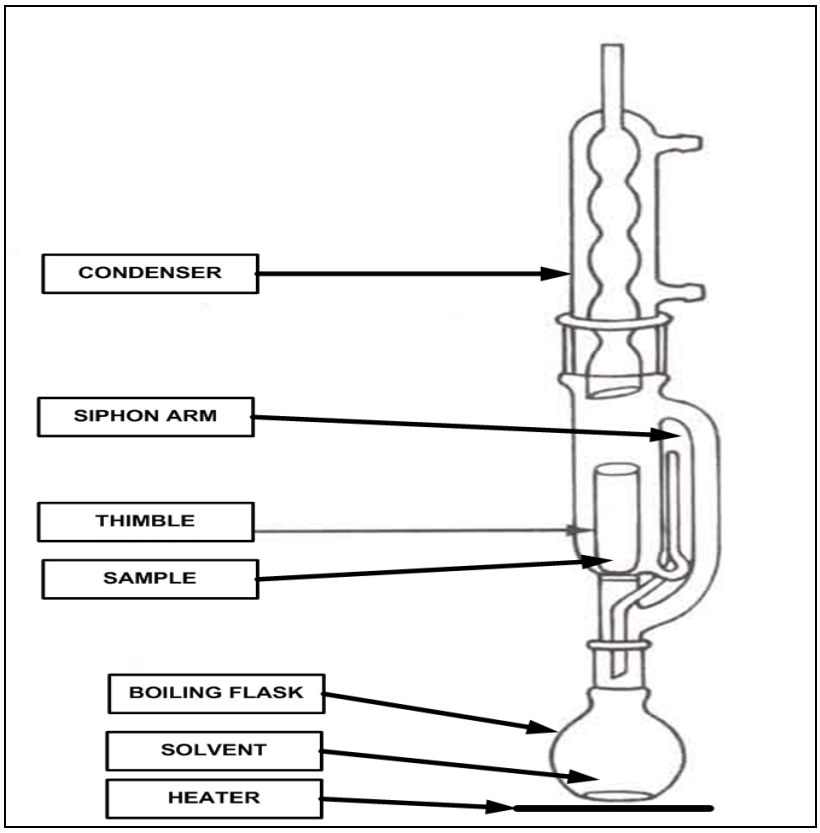

Figure 3.3 Soxhlet extraction apparatus

3.3.3 ASH ANALYSIS

Ash refers to the inorganic residue remaining after either ignition or complete oxidation of organic matter in food stuff. Ash content represents the total mineral content in foods. During the experiments dry ashing procedure was used. Dry ashing refers to the use of a muffle furnace capable of maintaining temperatures of 600-900˚C. At this temperature, water and volatiles are vaporized and organic substances are burned in the presence of oxygen in air to carbon dioxide and oxides of nitrogen.

5.0 g wheat germ was weighed into tared crucible. Then the crucible was placed in cool muffle furnace. After 4 hours of ignition period at about 900˚C, using safety tongs, the crucible was quickly transferred to a desiccator. The crucible was covered; the desiccator was closed and then allowed to cool prior to weighing. The ash content of the sample was calculated by the following equation:

$$\text{Ash, \%} = \frac{W_A}{W_W} \times 100 \qquad (3.3)$$

W_W: Wet weight of the sample, g
W_A: Weight of the ash, g

3.3.4 SENSORY EVALUATION

Sensory evaluation comprises a set of techniques for measurement of human responses to foods and minimizes the potentially biasing effects of brand identity and other information influences on consumer perception. As such, it attempts to isolate the sensory properties of foods themselves and provides important and useful information to product developers, food scientists, and managers about the sensory characteristics of their products [Lawless, 1998].

A sensory evaluation with single person was carried out to discard unacceptable products during preliminary experiments. A second final evaluation panel was applied in order to distinguish similar products obtained. In order to select panelists, a triangle test was applied (Appendix D). A triangle test is a difference test that is used to determine whether there is a sensory difference between two products. After selecting the panelists, a multiple ranking test was applied to select the most favorable product (Appendix D). In multiple ranking test the panelists rank the samples that were given beginning from best to worse. Two products were selected from the results of multiple ranking test. Another triangle test was applied to

distinguish the selected products in the multiple ranking test. Two consecutive triangle tests were applied to panelists in order to distinguish the processed samples in bed level increase studies. Same panelists were used throughout the study.

3.3.5 PEROXIDE VALUE ANALYSIS

The increase in the rancidity of all samples during storage is determined by measuring their peroxide values. For this purpose, the following method was used according to Kirk and Sawyer (1991). Before the analysis the oil was extracted from the sample by using the Soxhlet extractor. For this purpose, wheat germ was taken to extraction. After extraction period, wheat germ oil was placed into a 250 ml stoppered conical flask and its weight was recorded.

The peroxide value is a measure of the peroxides contained in the oil. The peroxide value is usually determined volumetrically. The method depends on the reaction of potassium iodide in acid solution with the bound oxygen followed by titration of the liberated iodine with sodium thiosulphate [Kirk and Sawyer, 1991].

Peroxide values were determined according to method BS684: Section 2.14: 10 ml of chloroform was added to the sample (prepared in part 3.3.2) as a solvent to dissolve the fat. Then 15 ml of glacial acetic acid and 1 ml of fresh saturated aqueous potassium iodide solution was added. The flask was stoppered, mixed for 1 minute and placed for 1 further minute in the dark. After waiting for 1 minute, about 75 ml of water was added into the flask and mixed. The sample was titrated with 0.002 M sodium thiosulphate solution using soluble starch solution (1%) as the indicator. Titration was continued until the solution became colorless. Similarly a blank determination was also carried out. The peroxide value of the samples was calculated according to the following equation. Experiments were running triplicate and the arithmetic mean of the results was given.

$$\text{PV} = \frac{(V - V_O) \times M}{W_{FAT}} \times 1000 \quad (3.4)$$

PV: Peroxide value of the sample, meq of peroxide/kg of oil

V: Volume of sodium thiosulphate solution used for sample, ml

V_0: Volume of sodium thiosulphate solution used for blank, ml

M: Molarity of the sodium thiosulphate solution, 0.002 M

W_{FAT}: Weight of the fat weighed, g

3.3.6 COLOR ANALYSIS

Color is important for the consumer acceptance as well as being the indicator of the brown pigments formed during non-enzymatic browning and caramelization process. Quality control of the heated product can be done by using color analysis.

The wheat germ samples were milled using a laboratory grinder to a particle size smaller than 200 μm to prevent the errors that was caused by heterogeneity of the products. The samples were kept in polyethylene pockets at 5˚C after grinding until they were used.

The percentage of reflectance data was collected over the visible spectrum (from 380 to 780nm) using a fiber optic spectrophotometer (Avaspec-2048). Illuminant D65, and 2° standard observer was chosen. The reflectance readings were converted into L*, a*, and b* values (CIELAB system). The L*, a*, and b* values are the three dimensions of the measured color giving the specific color value of the test material. The L* value represent light- dark spectrum with a range of 0 (black) to 100 (white). The a* and b* are the chromaticity coordinates in the red–green axis and yellow blue axis, respectively. The a* value represents X axis, which is redness (red (+) to (-) green). Similarly, b* represents Y axis, yellow–blueness (yellow (+) to (-) blue). The total color change (ΔE) was calculated using the relationship:

$$\Delta E = \sqrt{(L^* - L^*_{REF})^2 + (a^* - a^*_{REF})^2 + (b^* - b^*_{REF})^2} \quad (3.5)$$

Raw wheat germ was used as a reference to see the effect of roasting on the processed samples. The instrument was calibrated against a standard white color (L * = 100, a * = 0, b * = 0). All measurements were carried out in triplicate and the average value was calculated from the values measured.

CHAPTER 4

RESULTS AND DISCUSSION

Raw wheat germ has a very poor shelf life. In a very short time, the free fatty acids are produced by the action of lipase. These free fatty acids are produced by the action of lipoxygenase. In order to increase the shelf life, the raw wheat germ was thermally treated in a spouted bed to inactivate these enzymes. Wheat germ was cooled in the column for 2 minutes to reduce the wheat germ temperature. Inlet temperature of air, temperature above the sieve and the exit air temperature were recorded during operation period. In temperature – time graphs which were recorded during drying and cooling period (Figure 4.1 – 4.12), inlet temperature of the air almost reached the desired temperature determined at the beginning of the operation. In the temperature profiles of the exit temperature of the air and temperature above the sieve, a sharp increase and if the operation time was long enough, steady state behavior was observed. The exit temperature of the air and the temperature above the sieve were quite close to each other, indicating very good mixing in the bed.

The analyses showed that moisture content of the processed wheat germ decreased from nearly 10 % to less than 1 %. This decrease was considered to cause the initially low air temperatures, which rose slowly and then approached a steady value. It is most likely that roasting of the product occurred at this high temperature level. Identifying the range of roasting temperature of the wheat germ is important for adjusting the degree of roasting. The roasting temperature would be best shown by the exact temperature of the wheat germ. However, it was impractical to measure the temperature of the germ, due to the particle size, the shape of the germ and the conditions of the experimental setup. The data recorded at steady state temperature profile of the exit temperature of the air were averaged to determine the steady state temperature of the exit air.

The processed wheat germ was subjected to sensory evaluation (taste, color, smell, homogeneity of the product) and compared with the average exit temperature of the air. It was concluded that the exit temperature of the air was the best indicator of the wheat germ temperature.

The wheat germ supplied from the supplier was found to contain 8–10 % bran particles because of difficulty of separation in the process. The moisture content of the raw germ changed between 9% and 11% and for the processed germ, the moisture content was below 1%. By using the sieve analysis, the overall geometric mean diameter has been found as 1.19 mm. The fat content of the raw and processed germ was between 10–12%. Mineral content of wheat germ has been found as 4.8 % from the ash analysis.

4.1 DETERMINATION OF THE OPERATING CONDITIONS

In this study, experimental variables are flow-rate, temperature, wheat germ amount, and operation time. Yöndem-Makascıoğlu et al (2005) studied in a lab scale spouted bed unit and determined 200˚C – 6 minutes – 40 m^3/h with 150 g wheat germ (that fills the conical part of the lab equipment) as the best set of parameters from the sensory evaluation tests and lipase and lipoxygenase activities.

The spouted bed constructed in this work required 330 g wheat germ to fill the cylindrical part attached under conical base for discharge gate and the conical base of the column. Preliminary experiments were done in order to determine the best set of parameters. Air flow rate with a range of 40-70 m^3/h was the major limitation for the equipment. Because, for flow rates greater than 70 m^3/h, the temperature was below 190˚C. The temperature range was selected between 185 and 215˚C. Only in one experiment, temperature was 244˚C and it was observed that 244˚C result in unacceptable over-roasted products. Further increase in temperature was impractical, because of the limitation of the heater.

The previous work of Yöndem-Makascıoğlu et al (2005), indicates that the best product can be obtained with 200˚C, so that the air flow rate was increased in further runs in order to compensate the increase in wheat germ amount, still keeping the temperature in the range of 185-210˚C. The operation time was generally in the range of 7–12 minutes. A long operation period of 20 minutes was studied in one run. From the temperature – time graphs, it was observed that temperature profiles reached steady state nearly in 7 minutes time period. To decrease the operation time below 7 minutes means not reaching to a steady state temperature profile in some of runs and not observing the full stages of the operation. It was preferable to decrease the operation time for a studied flow rate – temperature combination where good results obtained. The preliminary runs were tabulated in Appendix A.

4.2 EXPERIMENTAL WORK PLAN

The results of preliminary runs for 330 g wheat germ were shown in Table 4.1. The range of color from white to red represents the degree of roasting. White color represents raw wheat germ. Light blue color represents the products similar to the raw products.

Table 4.1 Flow rate – Inlet air temperature combinations studied in the spouted bed unit during preliminary experiments

T(˚C) / flow rate (m^3/h)	185	190	203	208
40			10 min – 12 min	
50	20 min			
60			9.5 minute	7 minute
70		12 minute		

In the light of the results given in Table 4.1, the plan of final experiments was determined to give exit air temperature in the range of 155 – 160°C by interpolating between the preliminary results. Experiments with different durations were carried out to determine the minimum time required. (Table 4.2)

Table 4.2 Final Experimental Work Plan

Flow Rate (m^3/h)	55	60	65
T (˚C)	216	209	201
Duration (min)	7	7 – 9 – 12	7 – 9

Because of the limited amount of the raw wheat germ supplied from Ankara Un A.Ş., number of the runs was decreased from 9 to 6. The operation was mainly carried out at 60 m^3/h and 65 m^3/h for the 5 runs. The flow rate of 55 m^3/h was intermediate between the good and the insufficient flow rates for the operation in the preliminary runs. Single operation period was preferred for this flow rate and it was found successful. 65 m^3/h – 12 min operation period was eliminated because the temperature profile reached to a two minute steady state at 65 m^3/h – 9 min operation. Further operation time would be unnecessary for the high temperature – short time processing.

For the determination of the best products and best operating conditions, a multiple ranking test was applied to the selected panelists. The selected products and the raw germ were stored at 40˚C in paper bags. Peroxide values were measured periodically. Reproducibility runs were carried out in order to see the reproducibility of the column performance and to compare the change in peroxide values of the products.

Bed level of the column was increased using the flow rate of selected products at maximum temperature. Bed movement was observed and the change in the operation period was studied. Color of the processed samples were analyzed and compared with the raw germ.

Three groups of samples were used in the study; for the preliminary experiments (A), for the runs in experimental work plan (B) and for the reproducibility and bed level studies (C). The runs conducted were given numbers mainly according to the air flow rate and shown with a letter according to raw germ difference.

Table 4.3 Classification of raw wheat germ and studied runs during experimental work plan

Raw germ		B	C	
Operating Conditions	Run number	Experimental Work plan	Reproducibility Study	Bed Level Study
55 m^3/h – 216˚C 7 min – 330 g	1	B1	C1	
60 m^3/h – 209˚C 7 min – 330 g	2	B2		
60 m^3/h – 210˚C 9 min – 330 g	3	B3		
60 m^3/h – 209˚C 12 min – 330 g	4	B4	C4	
65 m^3/h – 201˚C 7 min – 330 g	5	B5		
65 m^3/h – 201˚C 9 min – 330 g	6	B6		
60 m^3/h – 243˚C 0 level – 330 g	7			C7
60 m^3/h – 241˚C 0.8 cm increase – 380g	8			C8
60 m^3/h – 241˚C 1.8 cm increase – 440 g	9			C9
60 m^3/h – 240˚C 2.5 cm increase – 480 g	10			C10

A period of 0.5 minute was recorded as time required for loading the column and starting the operation; a period of 0.3 minute was necessary for changing the valve settings between roasting and cooling; and another 0.5 minute was sufficient for column discharging.

Table 4.4 The notation for temperature profiles

	Loading of the column	Operation time	Valve settings change for cooling period	Cooling period	Time for discharging the column
Time (min)	0.5	7 – 12	0.3	2	0.5

4.3 STUDIES AT 55 m^3/h AIR FLOW RATE

Inlet air temperature was set to 216˚C for a 7 minute operation time period (Figure 4.1). A steady state period was not reached. Exit temperature of the air was 156˚C. A good spouting and bed movement occurred during operation. The experimental data is given in Appendix B. The average exit temperature of air is calculated and tabulated in Table 4.7.

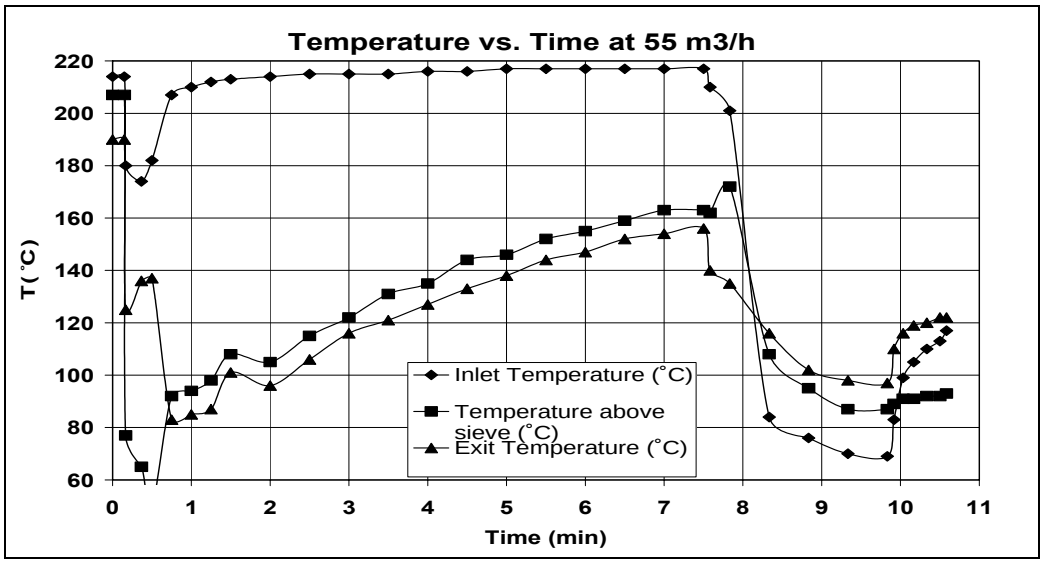

Figure 4.1 Temperature vs. time graph at 55 m^3/h – 216˚C for 7 minute (B1) operation period (330 g wheat germ)

4.4 STUDIES AT 60 m^3/h AIR FLOW RATE

330 g wheat germ was loaded to the column at 209˚C for a 7 minute operation time period (Figure 4.2). For the exit temperatures of air, a steady state in the temperature profiles was not observed. A false increase was observed in the exit temperature of the air and the temperature above sieve because of bad movement of the bed at the beginning of the operation. This could be due to the accumulation of the wheat germ loading on the side of the bed due to the high elevation feeding of the column. The bed recovered itself and a full movement of the particles was established. Exit temperature of the air was around 155˚C.

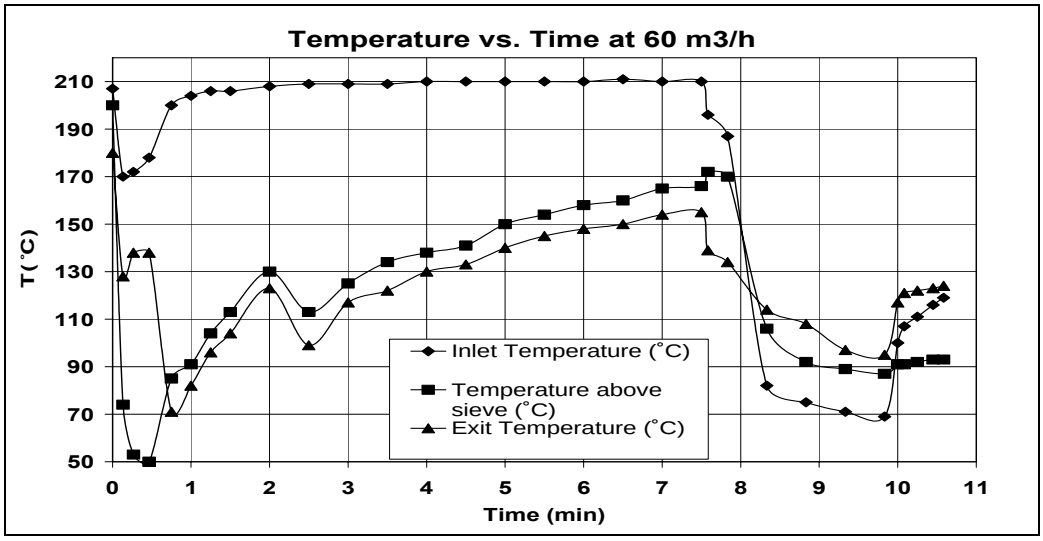

Figure 4.2 Temperature vs. time graph at 60 m^3/h – 209˚C for 7 minute (B2) operation period (330 g wheat germ)

Inlet air temperature was set to 210˚C and 9 minute operation time period was performed (Figure 4.3). A good spouting and bed movement were observed. A steady state was observed in the temperature profiles. Exit temperature of the air was around 160˚C.

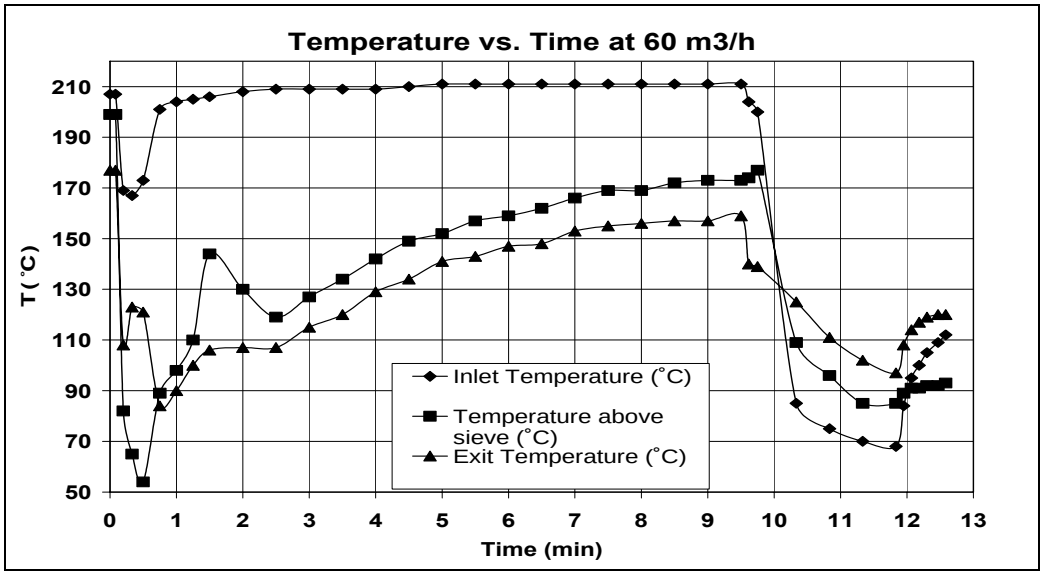

Figure 4.3 Temperature vs. time graph at 60 m^3/h – 210˚C for 9 minute (B3) operation period (330 g wheat germ)

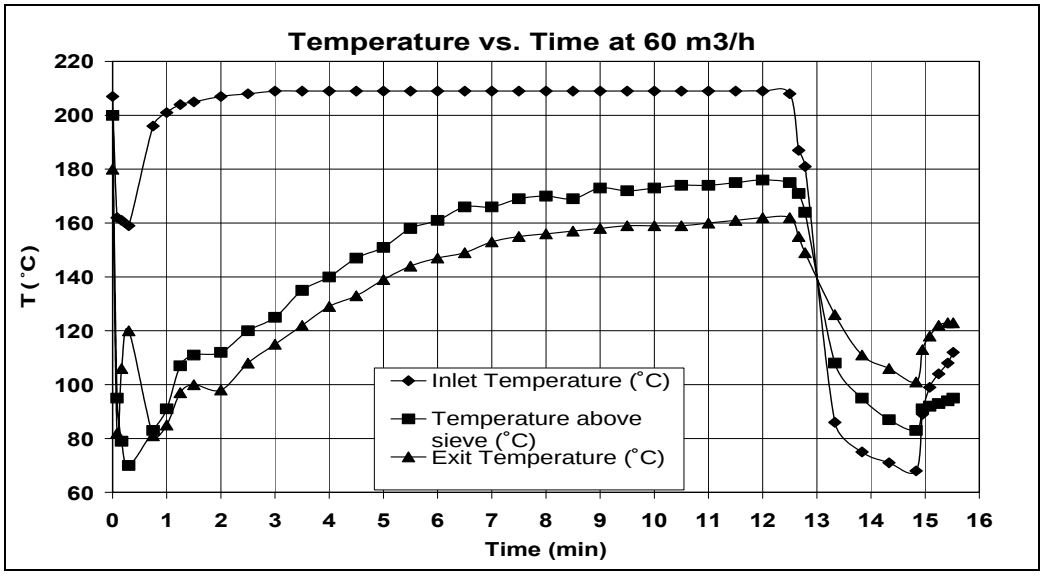

Figure 4.4 Temperature vs. time graph at 60 m^3/h – 209˚C for 12 minute (B4) operation period (330 g wheat germ)

Inlet air temperature was set to 209˚C and 12 minute operation time period was studied (Figure 4.4). A good spouting and bed movement were observed. A steady state was observed in the temperature profiles. Exit temperature of the air was around 160˚C. The results are tabulated in Table 4.7. The experimental data is given in Appendix B.

4.5 STUDIES AT 65 m^3/h AIR FLOW RATE

Inlet air temperature was set to 201˚C and 7 minute operation time period was studied (Figure 4.5). A steady state in the temperature profiles of the exit temperature of the air was not observed. Instead a steady increase was observed. In all of the 7 min operations this behavior was observed. The operation time was not enough to reach to the steady state.

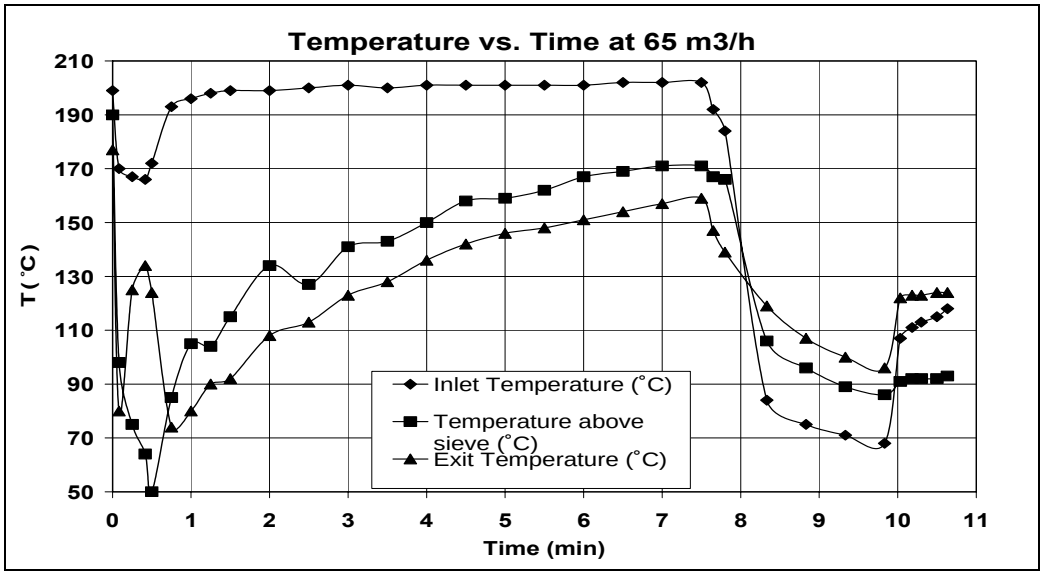

Figure 4.5 Temperature vs. time graph at 65 m^3/h – 201˚C for 7 minute (B5) operation period (330 g wheat germ)

Inlet air temperature was set to 201˚C and 9 minute operation time period was studied (Figure 4.6). A good start up did not occur in this run. This behavior was also observed in the B2 run. It could be due to the initial moisture content of the germ that increased the sticky behavior of the particles. The time between the loading of the bed from the top and beginning of the operation could be important as the waiting time of the wheat germ in the column at the start up increased, the particles stuck each other and they behaved like a heavier pile. The start of the movement in bed was more difficult since the air was fed to the column from a conical base which was not distributed homogenously to the full column like in fluidized beds. The experimental data is given in Appendix B. The results are tabulated in Table 4.7.

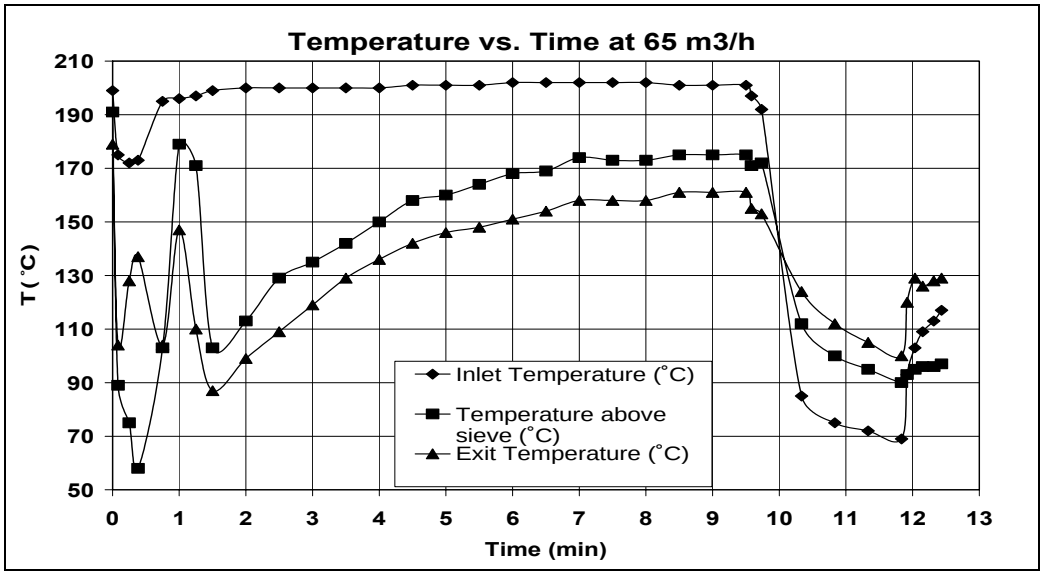

Figure 4.6 Temperature vs. time graph at 65 m^3/h – 201˚C for 9 minute (B6) operation period (330 g wheat germ)

4.6 SENSORY EVALUATION TESTS

A multiple ranking test was carried out for the products dried at the stated temperatures. Before applying the multiple ranking test, a triangle test (Appendix D) was applied in order to select the panelists. Two similar products were given to the panelists in order to see their performance of taste sense. Nine panelists were determined by the triangle test and they were taken to the multiple ranking test. The result of multiple ranking test was tabulated in Table 4.5. A scale of 1 to 6 was used with 1 for the most liked and 6 for the least liked samples. A choice of giving the same number between the similar products was given. In this multiple ranking test five panelists preferred the wheat germ processed at 55 m^3/h – 216˚C for 7 min (B1) as the best one. Three of the panelists chose it as the third and only one panelist as the fourth.

The result showed that wheat germ processed at high temperatures would have better flavor. Out of nine panelists, the product obtained by drying at 60 m^3/h – 209˚C for 12 min (B4) was chosen by two panelists as their best, four as their second, two as their fourth and one as his fifth. In this multiple ranking test the product having the lowest sum was considered to be the best one preferred by the panelists. Two of the products which have similar scores were selected by taking into account the lowest sum. Wheat germs processed at 55 m^3/h – 216˚C for 7 min (B1) and at 60 m^3/h – 209˚C for 12 min (B4) were used throughout this study.

Table 4.5 Multiple ranking test results

Run No	Conditions	Panelists										
		1	2	3	4	5	6	7	8	9	∑	
B1	55 m^3/h – 216˚C – 7 min	1	3	1	3	1	1	1	3	4	18	**1**
B2	60 m^3/h – 209˚C – 7 min	5	1	3	1	6	4	3	4	5	32	
B3	60 m^3/h – 210˚C – 9 min	6	1	5	3	3	5	6	3	3	35	
B4	60 m^3/h – 209˚C – 12min	4	5	2	2	4	2	1	2	1	23	**2**
B5	65 m^3/h – 201˚C – 7 min	1	6	6	6	2	3	4	4	6	38	
B6	65 m^3/h – 201˚C – 9 min	3	3	3	3	4	6	4	1	2	29	

The products which have the lowest scores were subjected to a triangle test to investigate the similarity between them (Table 4.6). Out of eight panelists only one panelist distinguished the products. This result showed that when the exit temperature of the air was in a certain range, the products had a nutty flavor. And it also confirmed the range of the exit air temperature.

Table 4.6 Results of the triangle test performed to distinguish between wheat germs processed at 60 m^3/h – 209˚C for 12 min (B4) and 55 m^3/h – 216˚C for 7 min (B1).

Wheat Germ Used in test	Number of Panelists
B4 and B1	8
Distinguished the Samples	1
Unable to distinguish the samples	7

4.7 REPRODUCIBILITY STUDIES

Reproducibility study was carried out for the conditions that were chosen in the multiple ranking test. The temperature profiles of C1 and C4 were given in Figure 4.7 and Figure 4.8 respectively. They were compared with the temperature profiles of B1 and B4, which have the same conditions, to see the reproducibility in the bed. In both reproducibility runs, a good start up did not occur. However, a significant fit between the general trends of the lines was observed after three minutes. The experimental data is given in Appendix B. The results are tabulated in Table 4.7.

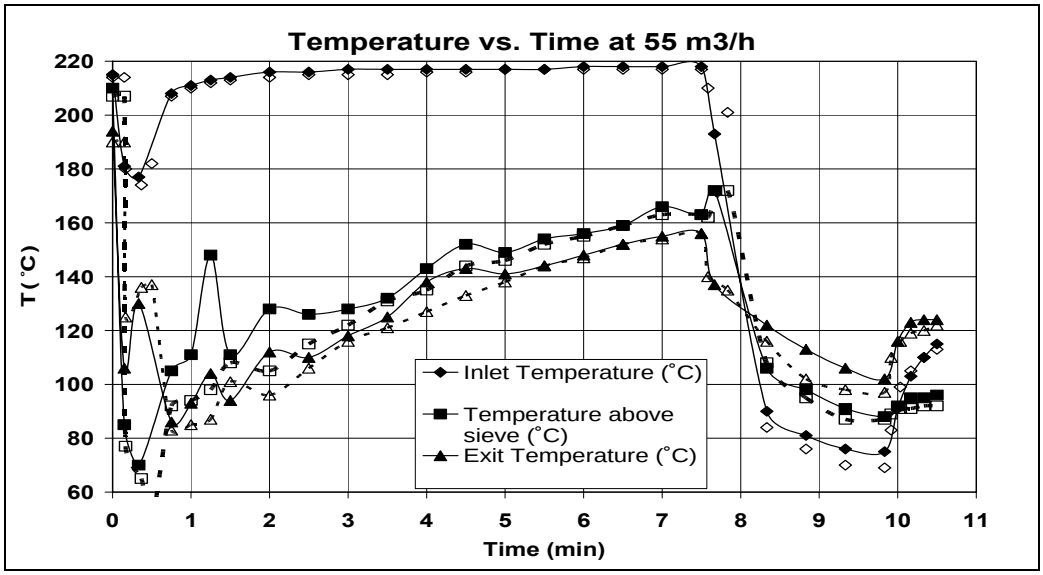

Figure 4.7 Temperature vs. time graph at 55 m^3/h – 217˚C for 7 minute (C1, filled symbols) operation period (330 g wheat germ) along with run B1 (hollow symbols)

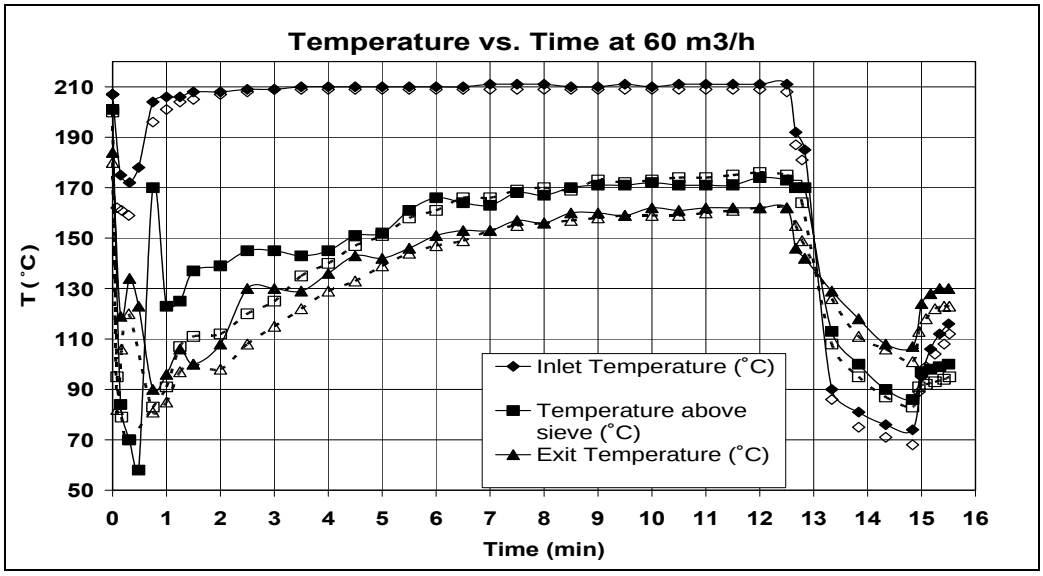

Figure 4.8 Temperature vs. time graph at 60 m^3/h – 210˚C for 12 minute (C4, filled symbols) operation period (330 g wheat germ) along with run B4 (hollow symbols)

The results were listed according to the air flow rate of the runs (Table 4.7). The exit temperature of the air was averaged for the operation time where steady state behavior was observed.

Table 4.7 List of the results obtained during experimental work plan and reproducibility studies (according to the air flow rate of the runs)

Run Number	Flow rate (m^3/h)	T_{inlet} (˚C)	Amount used (g)	Operation time (min)	$T_{avgexit}$ (˚C)
B 1	55	216	330	7	155.0
C 1	55	217	330	7	155.5
B 2	60	209	330	7	154.5
B 3	60	210	330	9	157.3
B 4	60	209	330	12	160.5
C 4	60	210	330	12	160.5
B 5	65	201	330	7	158.0
B 6	65	201	330	9	160.3

4.8 STUDIES ON BED HEIGHT INCREASE

The bed height increase was studied to see the effect on the spouted bed movement. The processed wheat germ capacity was increased from 330g to 480g. The flow rates of 55 m^3/h and 60 m^3/h, which were selected in the multiple ranking tests, were used in the operation. An increase of 2.5 cm in height was tried to reach with the steady movement of the bed. It was observed that 55 m^3/h was not enough for the start up of the bed. It was also observed that 60 m^3/h was appropriate for start up and continuous bed movement when the bed height was increased 2.5 cm. The preliminary run was carried out at 210˚C and the profile of exit air temperature was observed. It was seen that exit air temperature could not reach to the predetermined

range of 155 – 160˚C at this temperature. Therefore the temperature was increased to maximum at this flow rate which was between 240–243˚C. The experiments were done in this temperature range for 0.8 cm which corresponds to 380 g, 1.8 cm (440 g) and 2.5 cm (480 g) increase in bed height. A run with 330 g was also made in order to compare the temperature profiles with the other 330g runs. It was aimed to reach to 160 ˚C and 1 minute operation at this temperature. The processed germ was stored at 40˚C for one week in order to see the effect of higher temperatures on peroxide values.

Inlet air temperature was set to 243˚C and in 5.5 minute operation time period, the exit temperature of the air reached to 160˚C. After 1 minute operation time, the wheat germ was cooled for 2 minutes (Figure 4.9).

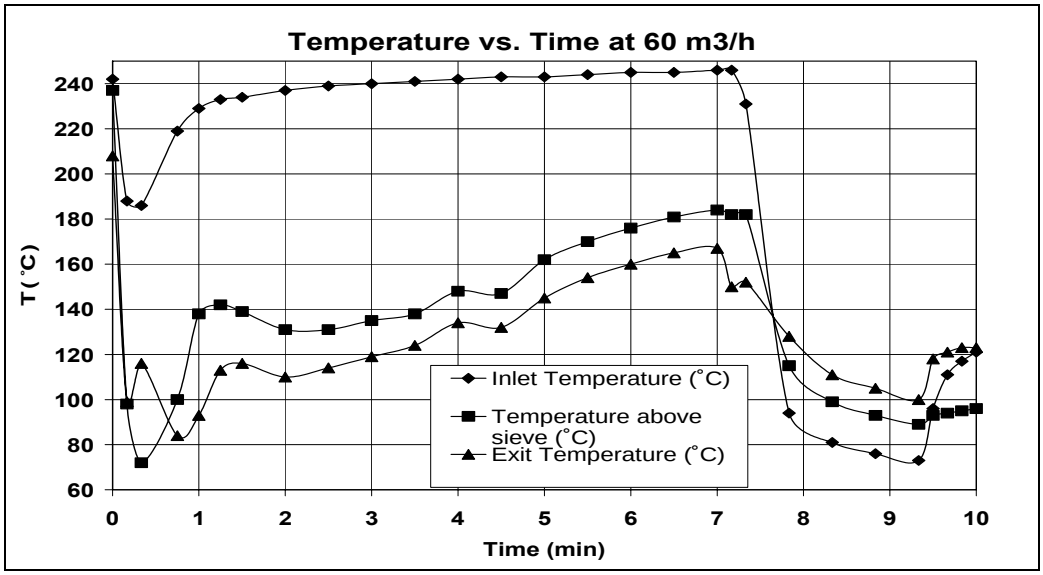

Figure 4.9 Temperature vs. time graph at 60 m^3/h – 243˚C for 6.5 minute (C7) operation period (330 g wheat germ)

Inlet air temperature was set to 241˚C and after 7.5 minute roasting period and 2 minutes cooling period, the operation was finished (Figure 4.10).

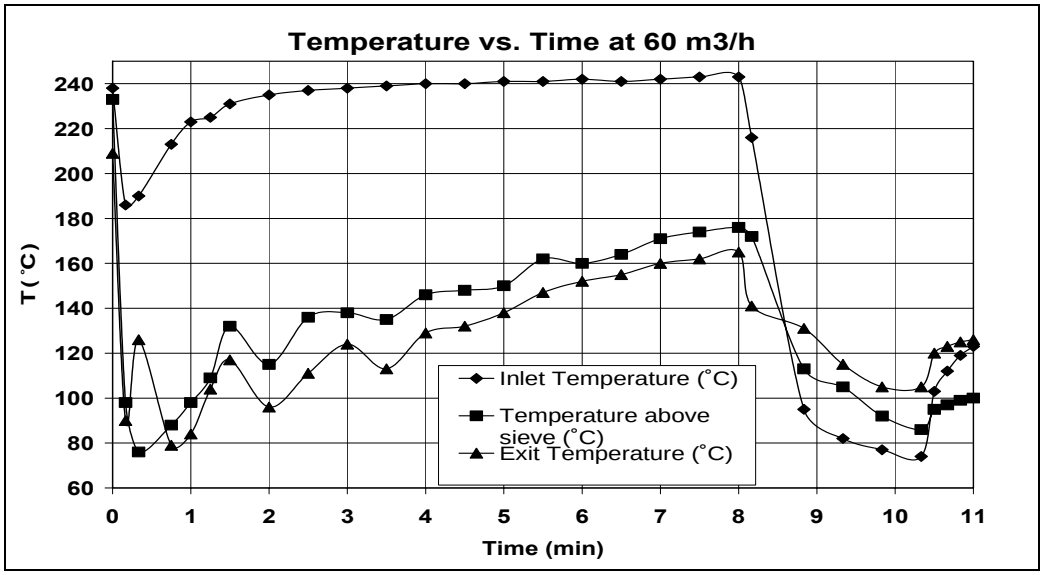

Figure 4.10 Temperature vs. time graph at 60 m^3/h – 241˚C for 7.5 minute (C8) operation period (380 g wheat germ)

Inlet air temperature was set to 241˚C and 8 minute roasting period was enough for satisfying the necessary conditions and to pass to the cooling stage for 440 g loading (Figure 4.11). During operation period, the thermocouple located above the sieve showed fluctuations in the temperature profile. Exit temperature of the air showed a little increase in the direction of the fluctuation.

The height of the bed was increased 2.5 cm; inlet air temperature was set to 241˚C. 10 minute operation time was recorded (Figure 4.12). The exit temperature of the air reached to 160˚C in 8^{th} minute of the operation. The time after reaching to160˚C was two minutes or the operation time was lengthened one minute. The product obtained was over roasted because of the longer operation period after attaining 160˚C. Operation time was held longer because of the noticeable slow circulation rate of the bed compared with the lower height studies. It was apparent that further increase in bed loading required an increase in flow rate of the operation. In the extra one minute, the exit temperature of the air reached to 170˚C. Because of high inlet temperature, the temperature raised rapidly. Since the roasting occurred in

high temperature range, the effect of operation time increased. The experimental data is given in Appendix B.

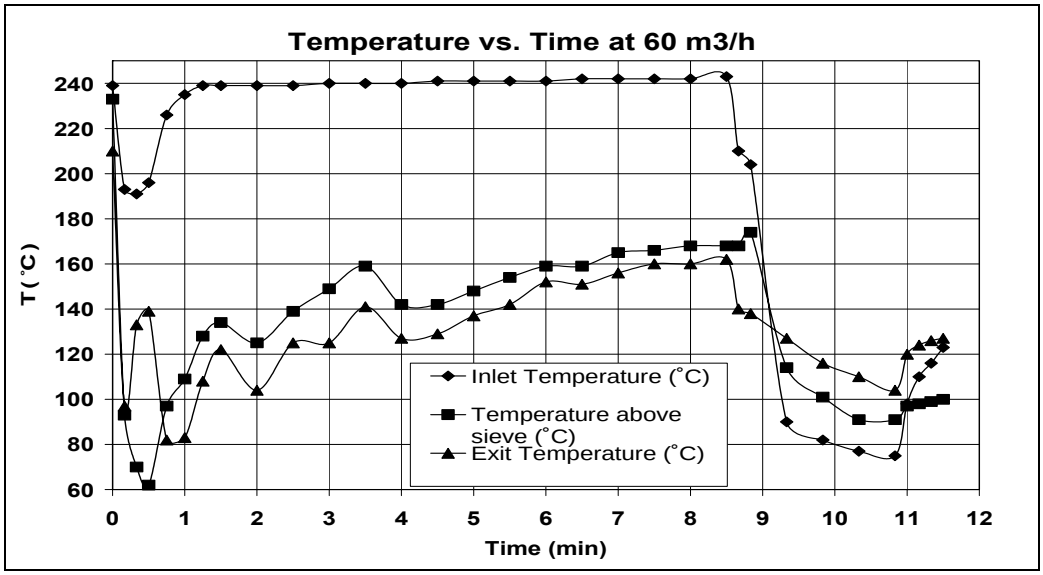

Figure 4.11 Temperature vs. time graph at 60 m^3/h – 241˚C for 8 minute (C9) operation period (440 g wheat germ)

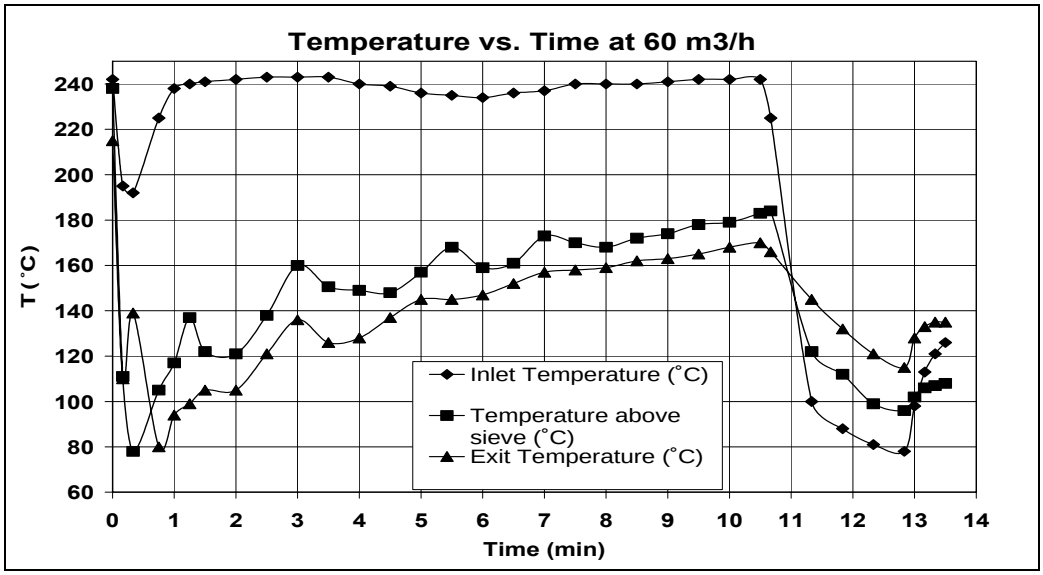

Figure 4.12 Temperature vs. time graph at 60 m^3/h – 240˚C for 10 minute (C10) operation period (480 g wheat germ)

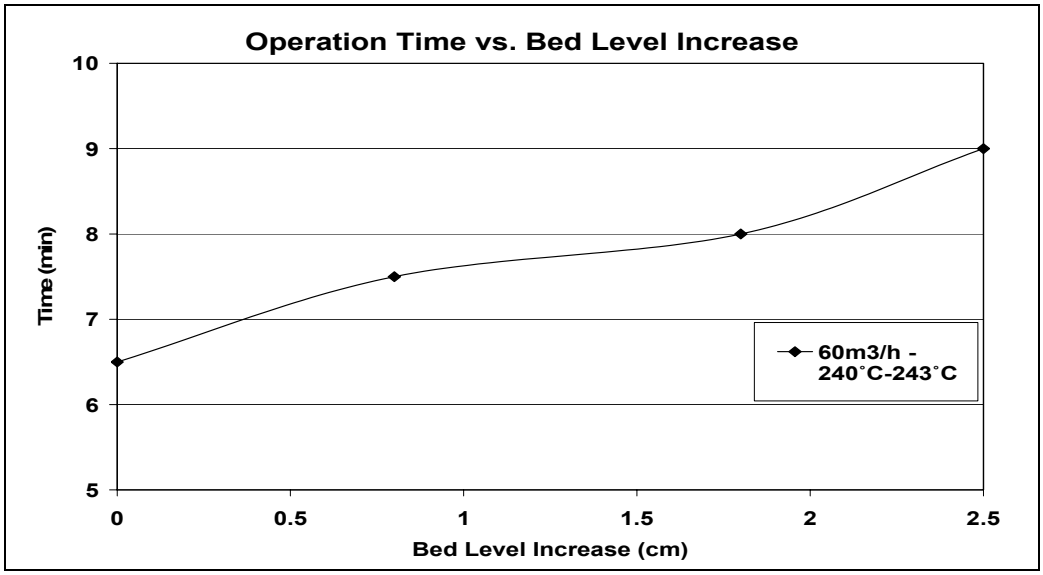

Figure 4.13 Operation time vs. the increase in bed height (wheat germ amount) at 60 m^3/h – 240 to 243˚C

Operation times showed an increase with the increasing bed height as expected. The operation time for C10 run (480g) was shown as 9 minutes since the operation time was lengthened for 1 minute. In C7 run (330 g) operation time was reduced to 6.5 min.

Two consecutive triangle tests were carried out in order to see the differences on wheat germ formed with the increasing bed height and wheat germ increase (Table 4.8). The samples from C8 (380 g) and C9 (440 g) runs were compared with the C7 run (330 g). Since an over roasted product was obtained in C10 run, it was excluded from the sensory evaluation tests. Out of 6 panelists, 1 panelist distinguished the samples correctly. 5 panelists did not distinguish the samples in both tests. The result of the triangle test showed the similarity between the products and an increase in the bed height could be done by checking the exit temperature of the air.

Table 4.8 Results of the two consecutive triangle tests performed to distinguish between wheat germs processed at 60 m^3/h – 240 to 243˚C for 330g (C7) – 380g (C8), and for 330g (C7) – 440g (C9)

Test I (C7 (330 g) – C8 (380 g))	Number of panelists (6)
Distinguished the product	1
Unable to distinguish the product	5
Test II (C7 (330 g) – C9 (440 g))	Number of panelists (6)
Distinguished the product	1
Unable to distinguish the product	5

4.9 COLOR MEASUREMENTS

Wheat germ samples used in the study through experimental work plan, in reproducibility studies, and in the study of bed height were subjected to the color measurement to see the effect of process on the color of the wheat germ. The results are given in Figure 4.14 to 4.19.

The color difference in the graphs shows the difference of raw wheat germ, B and C samples. Comparing L* values of the processed products with the raw wheat germ, an increase in the L* values or lightening of the products was observed except C4, B4 and B3 run (Figure 4.14). A significant decrease in L* value was observed for C4 and B4 runs. The operation time seemed to have an important effect on the L* values of the wheat germ samples. The increase in the lightening of the products was observed by other researchers also in the L* values of the hazelnuts [Özdemir, 2000] and milk [Rhim, Jones, & Swartzel, 1988] during heat processing which were attributed to the heat labile soluble proteins and their subsequent coagulation. However, this initial lightening of the products was not observed in a study on color changes of wheat germ during infrared heating [İbanoğlu, 2002].

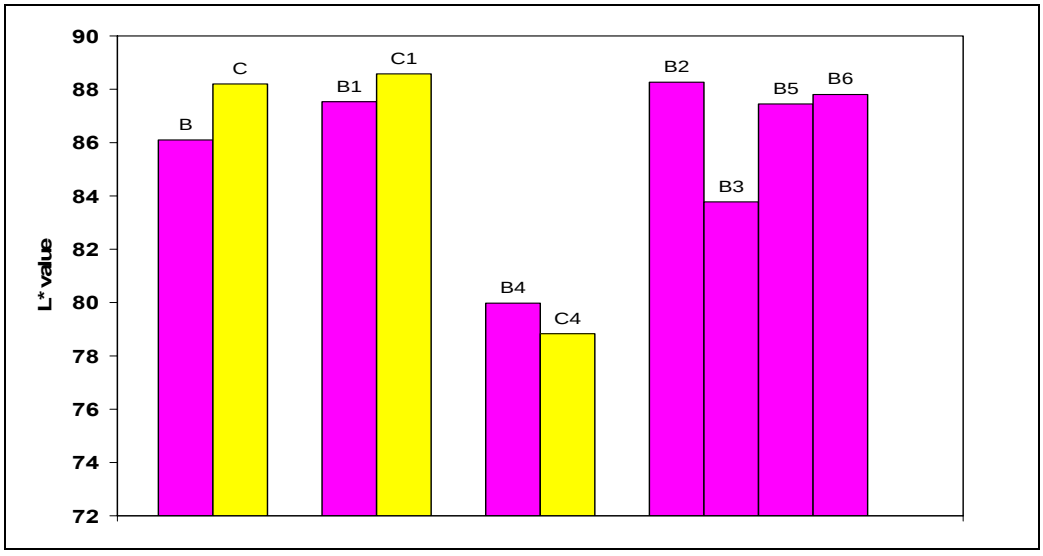

Figure 4.14 Comparison between L* values of raw wheat germ (B, C) and processed wheat germ (B1 – B6, C1, C4).

The initial lightening of the products could be attributed to different method used in drying. All 7 min runs showed initial lightening behavior. The runs with 9 min and 12 min operation periods showed decrease in L* values except B6 run which also had 9 minute operation period. The increase in L* values of B6 run could be attributed to the lower inlet temperature but B6 run showed higher L* value when compared with the B5 run, which also occurred in the same operating conditions with 7 minute operation time. Therefore, the error caused by the heterogeneity because of bran particles in the samples should be considered.

The values of a* were near zero but tended to shift toward the red range (Figure 4.15). The a* values of the wheat germ samples showed an increase tendency compared with the raw germs except B2, B5 and B6 runs. This was an expected result since B2, B5, and B6 runs had higher L* values compared with the raw wheat germ. But the decrease in a* values was not seen in B1 and C1 run which also had higher L* values. A significant increase in the B4 and C4 runs was observed.

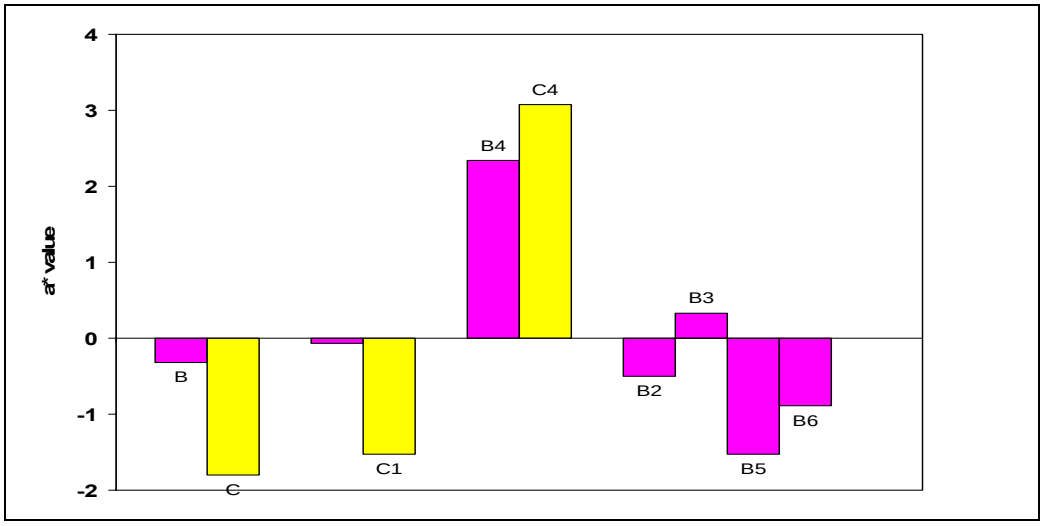

Figure 4.15 Comparison between a* values of raw wheat germ (B, C) and processed wheat germ (B1 – B6, C1, C4).

The values of b* displayed an increase in all runs compared with the raw wheat germs (Figure 4.16). This result indicated that the wheat germ is in the yellowish range and appear more yellowish when roasting occurs. A sharp increase in b* in the 12 min operation indicated that it is related to the length of the operation time.

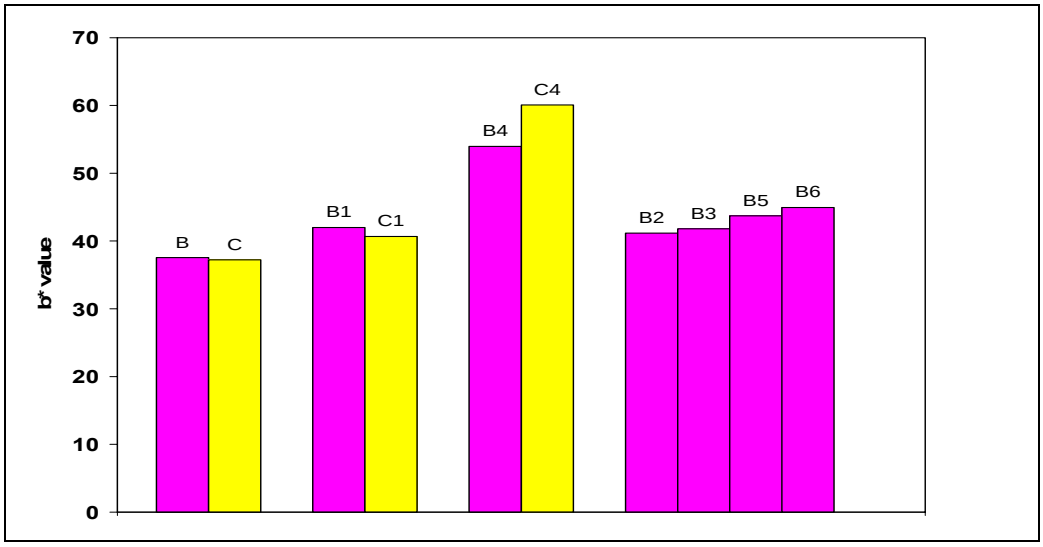

Figure 4.16 Comparison between b* values of raw wheat germ (B, C) and processed wheat germ (B1 – B6, C1, C4).

By taking raw wheat germ as reference total color difference (ΔE*) values were calculated. B4 and C4 runs indicated significant difference compared with the raw wheat germ. Since the biggest change in magnitude among L*, a* and b* values occurred in b* values, similar changes were observed between b* and ΔE* values.

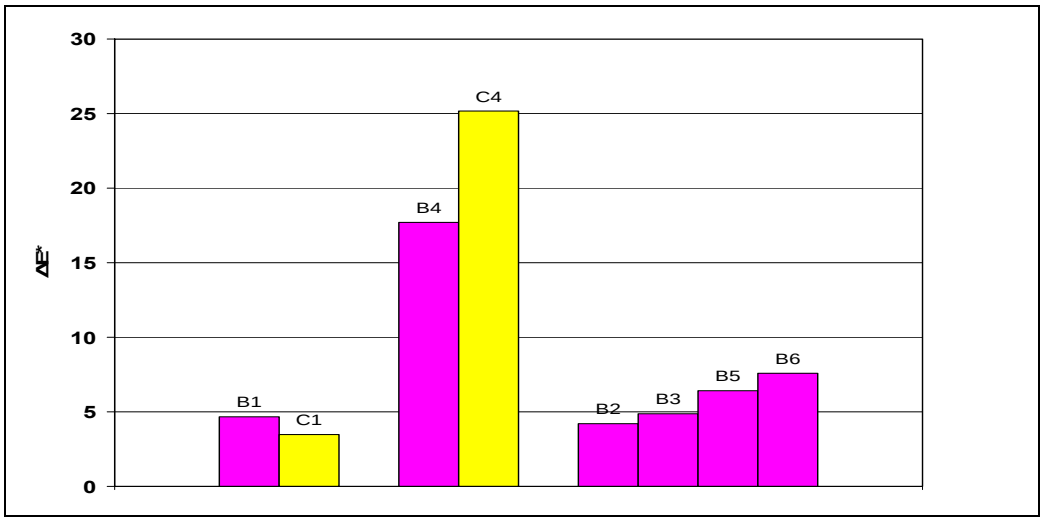

Figure 4.17 ΔE* values of processed wheat germs (B1 – B6, C1, C4), with reference to raw samples

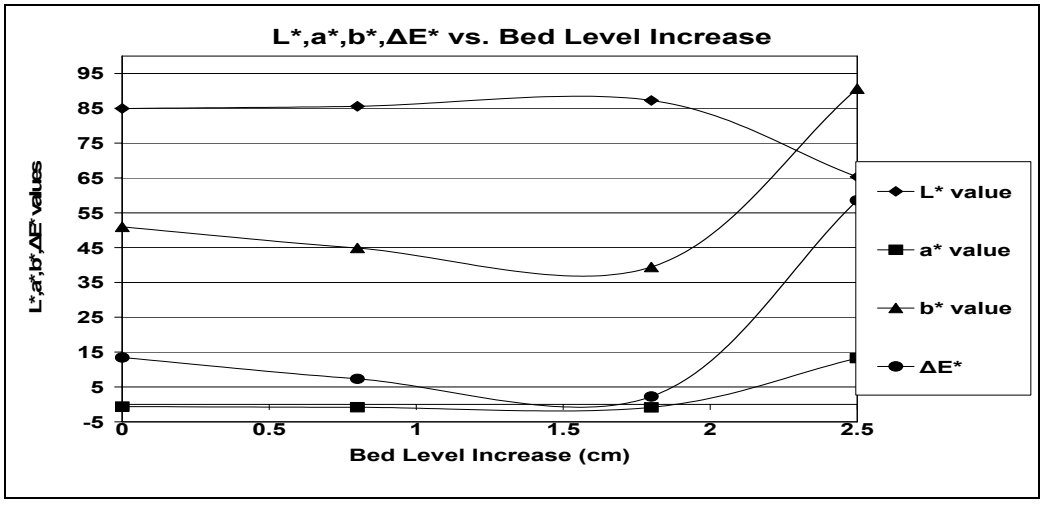

Figure 4.18 Comparison between L*, a*, b* and ΔE* values of C7 (330g), C8 (380g), C9 (440g), C10 (480g) runs.

The L* and a* values of the product was similar in the C7 (330g), C8 (380g), and C9 (440g) runs (Figure 4.18). As a* value represents the redness of the product or roasting degree, the similarity in a* values was more important than L* values. This similarity was in agreement with the result obtained from two consecutive triangle tests. The C10 (480g) run showed a sharp decrease to 65 in L* value, an increase to 14 and 90 in a* and b* values respectively. It was an over processed product, but it indicated that all parameters used in the color measurement has a strong relation with the operation period and the exit temperature of the air since the highest exit air temperature occurred in C10 run (170˚C). The similarity in changes between b* and ΔE* were also occurred in the C7, C8, C9, C10 runs. The experimental data is given in Appendix C.

The variation of b* values with respect to ΔE* values were shown for all runs (Figure 4.19). The runs were arranged according to magnitude of b* values. Almost linear increase with respect to b* was observed for ΔE* values.

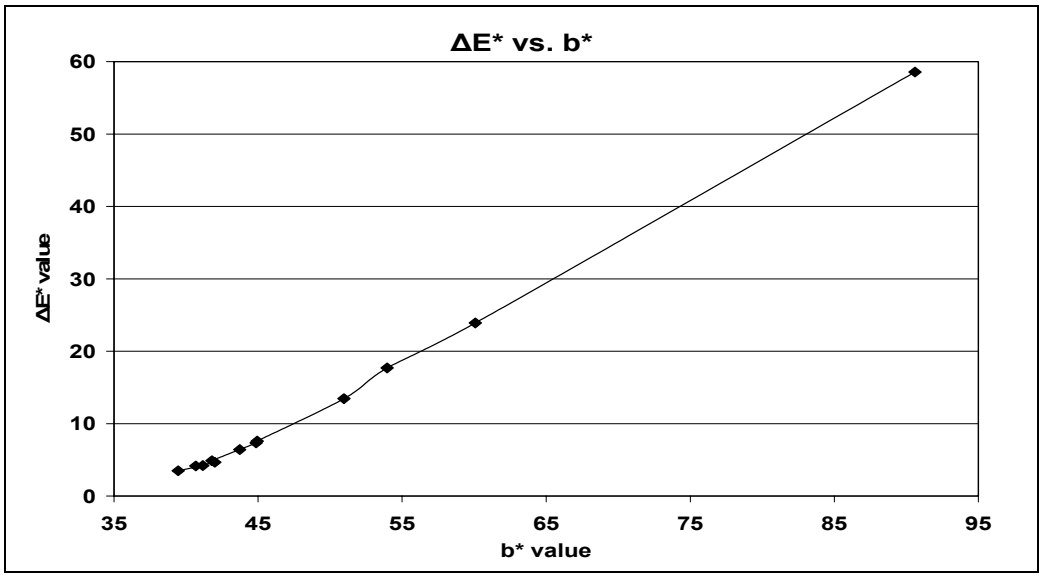

Figure 4.19 The variation of ΔE* values with respect to b* values for all studied runs.

The main change in ΔE* was due to b* value because of the similarities between L* and a* values for all runs. It could be resulted as for the studied conditions, b* values could be used for controlling the processed samples in order to understand the quality of the product.

4.10 STORAGE STUDIES

The raw germ (B) and processed germ in selected conditions (B1 and B4) were stored in paper bags at 40˚C for three weeks. The processed germs in reproducibility study (C1 and C4) were stored for 17 days and the processed samples in bed level study were stored at 40˚C in paper bags for one week. The peroxide values were measured periodically.

The changes in peroxide values of raw wheat germ, and processed wheat germ for the B1, C1, B4 and C4 runs were given in Figure 4.20. The peroxide values of unprocessed germ and processed germ at 200˚C – 40m^3/h – 6min which were packed in paper bags and stored at 40˚C in the previous work of Yöndem-Makascıoğlu et al (2005), are represented to make comparison.

The lipid oxidation in dry foods obeys to zero order kinetics [Labuza, 1982]. Since the peroxide value versus time data were linear for the raw germ, B1, B4, C1 and C4 runs, a zero order rate equation was applied to the experimental data. Because of the same process conditions applied for B1–C1 and B4–C4 runs, the peroxide value results were shown with the same line.

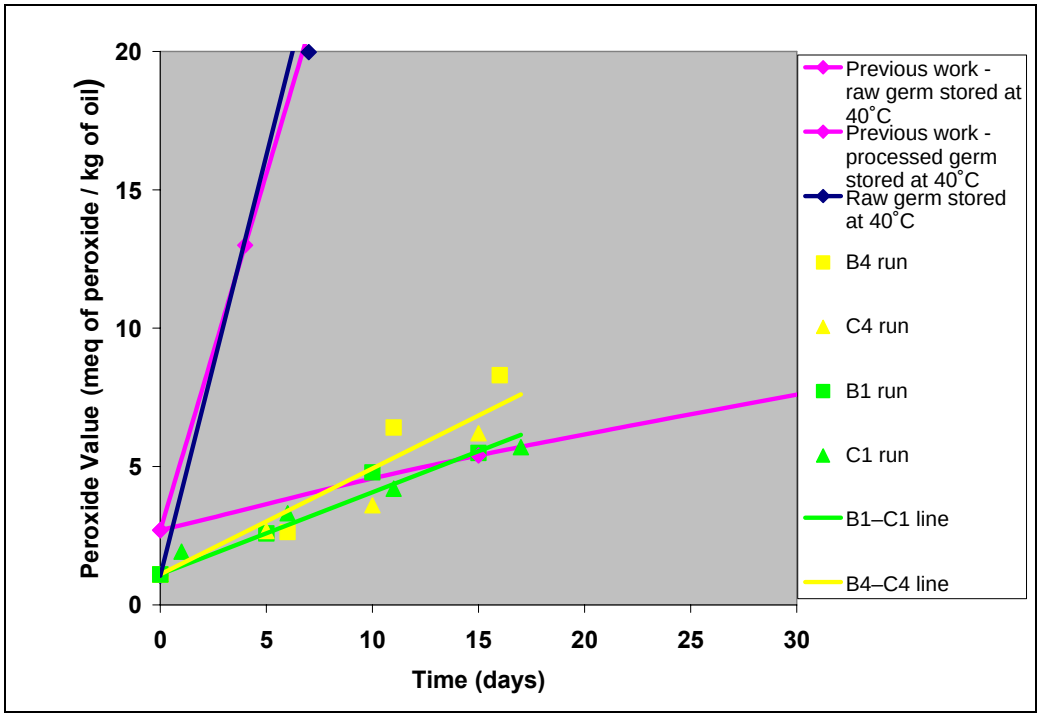

Figure 4.20 Peroxide value vs. time graph for B1, C1, B4, C4, raw germ and processed germ and raw germ stored at 40˚C in the previous study of Yöndem-Makascıoğlu et. al (2005)

The initial peroxide value of the raw wheat germ, B1, C1, B4 and C4 runs was 1.1 meq peroxide / kg oil. The peroxide value of raw germ did not change after the operation. After storage of 22 days, the peroxide value of the raw wheat germ was 75.0 meq peroxide / kg oil. At the end of the 17 days, the peroxide values of the processed germ reached to 7.6 meq peroxide / kg oil for B4–C4 line and 6.14 meq peroxide / kg oil for B1–C1 line. A difference in the reaction rate constants was observed between B4 run and B1, C1, C4 runs. The difference was unexpected because a similarity was observed for the reaction rate constants of C4, C1 and B1 runs. The unexpected change in B4 run could be due to the quality of raw wheat germ supplied by Ankara Un A.Ş. Supplier stated, a mixture of fresh and old samples had been given.

The reaction rate constants for peroxide value production for the germs stored at 40˚C were 3.11, 0.38, and 0.30 for the raw germ, B4–C4 line, and B1–C1 line respectively. The ratio of reaction rate constants indicates the stabilization of the wheat germ. The ratio of reaction rate constants for raw germ to the processed germs were 8.1, and 10.5 for B4–C4 line, and B1–C1 line respectively. In the previous study of Yöndem-Makascıoğlu et. al (2005), the ratio of reaction rate constant of raw germ to the processed germ at 200˚C – 40m^3/h – 6 min was 17.1. The difference between two studies could be attributed to inlet diameter difference (2.8 cm), temperature difference (9–17˚C), wheat germ amount increase (180g). Another difference in the studies was the wheat germs used. In the previous work, Yöndem-Makascıoğlu et al used late spring wheat for the storage and in this work; late winter wheat was used for the storage. A difference in their rancidity development behavior could be expected since their lipid and enzyme contents could vary according to the type of wheat and between seasons.

According to TSE standards, the peroxide value limitation for the edible oils is 10. The raw germ stored at 40˚C exceeded the limit value in 3 days; the behavior of processed samples indicated that the limit value would be exceeded in 24 and 31 days for B4–C4 line, and B1–C1 line respectively.

In the study of Yöndem-Makascıoğlu et. al (2005), the raw wheat germ and processed germ was stored at 40˚C, 25˚C and 5˚C and the activation energies for paper, polyethylene and vacuum-packed polyethylene pouches were estimated by using k values at 40˚C, room temperature and 5˚C by using the Arrhenius equation. The activation energies for paper bags were 9.1 kcal / mol for the raw wheat germ and 9.5 kcal / mol for the processed germ. To estimate the storage stability of raw wheat germ and processed germ stored at room temperature and 5 ˚C, the activation energies for paper bags were used from the study of Yöndem-Makascıoğlu et al (2005). It was estimated that the raw germ stored at 22˚C and 5 ˚C will exceed peroxide value of 10 in 8 and 20 days respectively; the processed wheat germs stored

at 22˚C and 5 ˚C exceed peroxide value of 10 in 8.5 and 23 weeks for B4–C4 line, and in 11 and 29.5 weeks for B1–C1 line respectively.

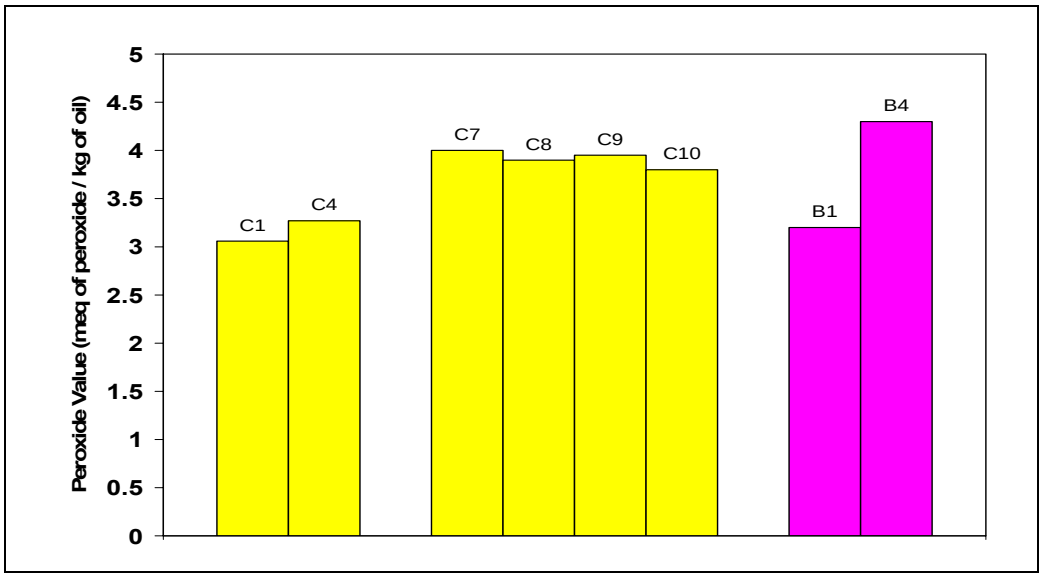

Figure 4.21 Comparison of the peroxide values of the processed wheat germs of B1, C1, B4, C4 runs with the processed wheat germ used in C7, C8, C9, C10 runs in the 7th day of the storage period at 40˚C.

The wheat germ used in bed height increase study was stored at 40˚C for one week. A comparison was made between the peroxide values of the processed wheat germ of C1, C4, B1 and B4 runs (Figure 4.21). A comparison with C1 and C4 was more convenient because the raw germ was taken from the supplier on the same day. Because of the similarity between C1, C4 and B1 runs, it was also compared with the B1 and B4 runs. It was aimed to see the effect of bed height increase and higher inlet temperature (240–243 ˚C). For this reason, the seventh day peroxide values of the processed wheat germ were calculated for B1, B4, C1 and C4 runs. There is a difference between the peroxide values of B1, C1, and C4 runs. However, the results were around B4 run. It can be claimed that a good stabilization was not achieved but

all of those samples seem to have almost been stabilized as the sample treated with B4 run. The high peroxide values of bed height increase studies could be attributed to the high temperature inlet of the air. The single data points obtained for bed height runs may not reflect the trend of peroxide formation correctly.

CONCLUSIONS

In this thesis, a spouted bed unit was constructed for drying, roasting and cooling of wheat germ. The drying temperatures ranged between 201 and 243˚C, operation times between 7 and 12 minutes, and air flow rate between 55 and 65 m^3/h.

Experimental results showed that exit temperature of the air was the best variable describing the roasting degree of the product. The steady state temperature period of the exit temperature of the air was averaged. The preliminary results indicated that exit air temperature between 155 and 160˚C will be appropriate.

Sensory evaluation tests were carried out. The germs processed at 60 m^3/h – 209˚C for 12 min and 55 m^3/h – 216˚C for 7 min were selected as the sample for storage studies, on the basis of the results of sensory evaluation tests. The products were found highly acceptable by panelists. Sensory evaluation results showed that similar products were obtained in taste in the selected exit air temperature range.

The reproducibility runs were carried out for the selected conditions and achieved in the general trends of temperature profiles. The problems at the start up could be reduced with vibration equipment attached to the column by decreasing the bed recovery time.

The bed height increase study was carried out at 60 m^3/h – 240 to 243˚C. The capacity was increased from 330 g to 480g. The results of sensory evaluation tests showed that similar products were obtained for 330g, 380 g and 440 g load. Circulation rate was observed to decrease for 480g as the bed height increased. For further increase in bed height, the flow rate must be increased.

Operation time could be reduced with higher temperatures (240 to 243˚C) as the exit air temperature increases rapidly to the exit air temperature range.

Color difference of the products was studied by comparing the processed products with the raw wheat germ. ΔE* values were found to be highly correlated with b* values. Operation time made significant changes on the color parameters. Since very similar products obtained for the same operation period but different temperature – flow rate conditions, using the device for the quality control of the products, L*, a* and especially b* value should be modeled for temperature, time and air flow rate changes to explain the small variations seen in the similar products.

The wheat germ stabilization was achieved. The initial peroxide values of raw germ, processed samples were found similar to each other. The roasting process did not cause peroxide formation. The rate of increase of total peroxide value was reduced by 8–10 folds compared to raw germ.

According to TSE standards, the peroxide value limitation for edible oils is 10. During storage in paper bags, the raw germ stored at 40˚C exceeded this value in 3 days while the extrapolated values of the processed samples exceed this value in 24 to 31 days. It was estimated that the raw germ stored at 22˚C and 5 ˚C will exceed the limit value in 8 to 20 days respectively, the processed wheat germs stored at 22˚C and 5 ˚C are expected to reach the limit value in 8.5–11 weeks at 22˚C and 23–29.5 weeks at 5˚C. In addition, storage in O_2 impermeable material under vacuum should probably lead to longer storage periods of processed wheat germ compared to paper bags.

REFERENCES

Anon., in Ullman's Encyclopedia of Industrial Chemistry, Vol: A10, Fats and Fatty Oils, pp:179 – 181, VCH Verlagsgesellschaft mbH, D – 69451 Weinheim, Germany. (1993)

AOAC., Official Methods of Analysis, Association of Official Chemists, St. Paul, Minnesota. (1995)

Belitz H.D., Grosch W., Food Chemistry, Springer and Verlag, Berlin. (1987)

Çakmaklı Ü., Köse E., Kemahlıoğlu K., "Effects of Addition of Crude Wheat Germ together with a Mixture of Improvers on Dough and Bread Characteristics", Gıda 20, (4), pp:243 – 248. (1995)

Cara L., Armand M., Borel P., Senft M., Portugal H., Pauli A., Lafont H., Lairon D., "Long-Term Wheat Germ Intake Beneficially Affects Plasma Lipids and Lipoproteins in HyperCholesterolemic Human Subjects", Human and Clinical Nutrition, (3166), pp :317 – 326. (1992)

Food And Agriculture Organization of the United Nations (FAO) (www.fao.org) http://www.fao.org/ag/AGP/AGPC/doc/field/Wheat/asia/turkey.htm at 2005-12-26

Gnanasambandam R., Zayas J.F., "Functionality of Wheat Germ Protein in Comminuted Meat Products as Compared with Corn Germ and Soy Proteins", Journal of Food Science Vol: 57 No:4, pp:829 – 833. (1992)

Hoseney R.C., Principles of Cereal Science and Technology, American Association of Cereal Chemists, St. Paul, Minnesota. (1990)
Huges, H. D., Henson, E.R, Crop Production, the Macmillan Company. (1957)

İbanoğlu E, "Kinetic Study on Color Changes in Wheat Germ due to Heat", Journal of Food Engineering, 51, pp: 209 – 213. (2002)

Inglett G.E., Wheat: Production and Utilization, The Avi Publ. Co. Inc. (1974)

Jurkovic N., Colic I, "Effect of Thermal Processing on the Nutritive Value of Wheat Germ Protein", Die Nahrung, 37 (6), pp: 538 – 543. (1993)

Kent N.L., Evers A.D., Technology of Cereals, Pergamon, Oxford. (1994)

Kim Y. S., Flores, Chung O. K., "Physical, Chemical, and Thermal Characterization of Wheat Flour Milling Coproducts", Journal of Food Process Engineering, 26, pp: 469 – 488. (2003)

Kirk R.S., Sawyer R., Analysis of Foods, Longman Scientific and Technical Wiley, New York. (1991)

Labuza T. P., Shelf Life Dating of Foods, Food and Nutrition Press, Westport, Connecticut. (1982)

Lawless H. T., Heymann H., Sensory Evaluation of Food, Chapman & Hall, New York. (1998)

Mathur K. B., Epstein N., Spouted Beds, Academic Press, New York. (1974)

Nagaraju V. D., Murthy C. T., Ramalakshimi K., Rao P. N., "Studies on Roasting of Coffee Beans in a Spouted Bed", Journal of Food Engineering, 31, pp: 263-270. (1997)

Nagaraju V.D., Ramalakshmi K., "Roasting of Coffee Beans in a Spouted Bed Coffee Roaster", Journal of Food Science, vol. 39, No.5, pp: 530 – 533. (2002)

Nicoli M.C., Anese M., Manzocco L., Lerici C. R., "Antioxidant Properties of Coffee Brews in Relation to the Roasting Degree", Lebensmittel Wissenschaft und Technologie, 30, pp: 292 – 297. (1997)

Nielsen S.S., Introduction to the Chemical Analysis of Foods, Chapman and Hall, New York. (1994)

Özdemir M., Devres O., "Kinetics of Color Changes of Hazelnuts during Roasting", Journal of Food Engineering, pp: 44, 31 – 38. (2000)

Passos M. L., Mujumdar A.S., Raghavan V.G.S., "Spouted Beds for Drying: Principles and Design Considerations", Advances in Drying, 4, pp: 359 – 397. (1987)

Pomeranz, Y., Wheat Chemistry and Technology, American Association of Cereal Chemists, St. Paul, Minnesota. (1978)

Pomeranz Y., Modern Cereal Science and Technology, VCH Publishers, Inc., New York. (1987)

Rao P. H., Kumar G. V., Rao G. C. P., Shurpalekar S. R.,"Studies on Stabilization of Wheat Germ", Lebensmittel Wissenschaft und Technologie, 13, 302 – 307. (1980)

Rhim J. W., Jones V. A., Swartzel K. R.,"Kinetic Studies in the Color Changes of Skim Milk", Lebensmittel Wissenschaft und Technologie, 24, 334-338. (1988)

Robbins P. T., Fryer P.J., "The Spouted-bed Roasting of Barley: Development of a Predictive Model for Moisture and Temperature", Journal of Food Engineering, 59, 199 – 208. (2003)
Tolonen M., Vitamins and Minerals in Health Nutrition, Ellis Horwood, New York. (1990)

Vani B., Zayas J. F., "Wheat Germ Protein Flour Solubility and Water Retention", Journal of Food Science, 60, (4), pp: 845 – 848. (1995)

Vetrimani R., Jyothirmayi N., Rao P. H., Ramadoss C. S., "Inactivation of Lipase and Lipoxygenase in Cereal Bran, Germ and Soybean by Microwave Treatment", Lebensmittel Wissenschaft und Technologie, 25, pp:532 – 535. (1992)

Virtalaine Tuomas, Kallio H., "Development of Rancidity Analyzed by Headspace Gas Chromatography and Sensory Analysis", J. Agric. Food Chem., 48, pp: 3522 – 3527. (2000)

Wilson H. K., Grain Crops, Mcgraw-Hill Book Company, Inc. (1955)

WORC, Western Organization of Resource Councils, World Wheat Facts, Fact Sheet November 2002.

Yöndem-Makascıoğlu F., Gürün B., Dik T, Kıncal N.S., "Use of a Spouted Bed to Improve the Storage Stability of Wheat Germ Followed in Paper and Polyethylene Packages", Journal of the Science of Food and Agriculture, 85 (8), pp: 1329 – 1336. (2005)

APPENDIX A

PRELIMINARY EXPERIMENTAL DATA

A1 STUDIES AT 40 m^3/hr AIR FLOW RATE

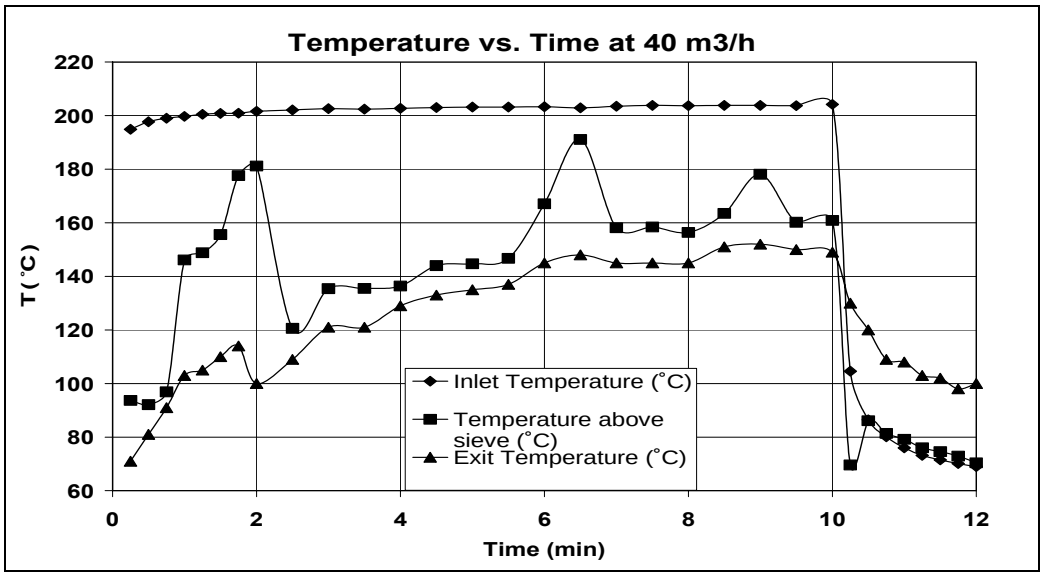

Figure A.1 Temperature vs. time graph at 203˚C – 40 m^3/h for 10 minute operation period (330 g wheat germ)

Table A.1 Temperature vs. time graph at 203˚C – 40 m^3/h for 10 minute operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.25	194.9	93.7	71
0.5	197.7	92.1	81
0.75	199	96.9	91
1	199.7	146.1	103
1.25	200.5	148.8	105
1.5	200.8	155.6	110
1.75	200.9	177.6	114
2	201.6	181.2	100
2.5	202.1	120.6	109
3	202.6	135.4	121
3.5	202.4	135.5	121
4	202.7	136.4	129
4.5	203	144	133
5	203.2	144.7	135
5.5	203.2	146.7	137
6	203.3	167.1	145
6.5	202.9	191.1	148
7	203.5	158.1	145
7.5	203.8	158.4	145
8	203.7	156.4	145
8.5	203.8	163.5	151
9	203.8	178.1	152
9.5	203.7	160.2	150
10	204.2	160.9	149
10.25	104.6	69.6	130
10.5	86.5	86.1	120
10.75	80.1	81.4	109
11	76	79.2	108
11.25	73.2	76	103
11.5	71.5	74.6	102
11.75	70.1	72.9	98
12	69	70.4	100

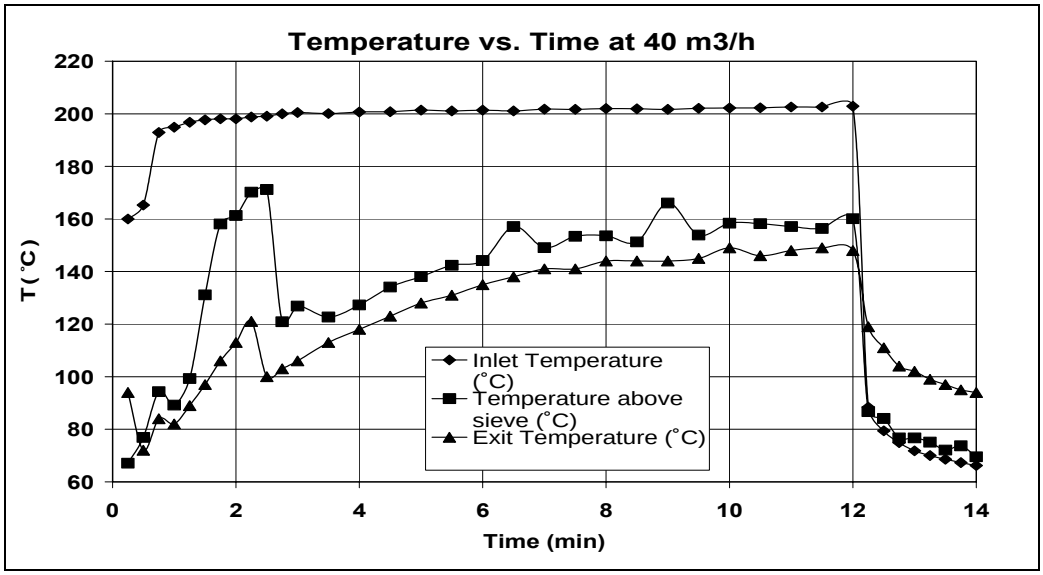

Figure A.2 Temperature vs. time graph at 200˚C - 40 m^3/h for 12 minute operation period (330 g wheat germ)

Table A.2 Temperature vs. time graph at 200˚C – 40 m^3/h for 12 minute operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.25	160	67.1	94
0.5	165.3	76.9	72
0.75	192.9	94.3	84
1	194.9	89.2	82
1.25	196.8	99.3	89
1.5	197.7	131.1	97
1.75	198.1	158.1	106
2	198.1	161.3	113
2.25	198.8	170.2	121
2.5	199.1	171.2	100
2.75	200	120.9	103
3	200.5	126.9	106
3.5	200.1	122.7	113
4	200.7	127.3	118

Table A.2 (Continued) Temperature vs time graph at 200˚C – 40 m^3/h for 12 minute operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
4.5	200.8	134.1	123
5	201.4	138.1	128
5.5	201.1	142.4	131
6	201.4	144.2	135
6.5	201.1	157.1	138
7	201.8	149.1	141
7.5	201.7	153.4	141
8	202	153.6	144
8.5	201.9	151.3	144
9	201.7	166.1	144
9.5	202.1	153.9	145
10	202.2	158.4	149
10.5	202.3	158.2	146
11	202.6	157.1	148
11.5	202.6	156.4	149
12	202.9	160.1	148
12.25	88.4	86.7	119
12.5	79.4	84.1	111
12.75	74.9	76.7	104
13	71.8	76.7	102
13.25	70	75.1	99
13.5	68.6	72.1	97
13.75	67.3	73.7	95
14	66.2	69.5	94

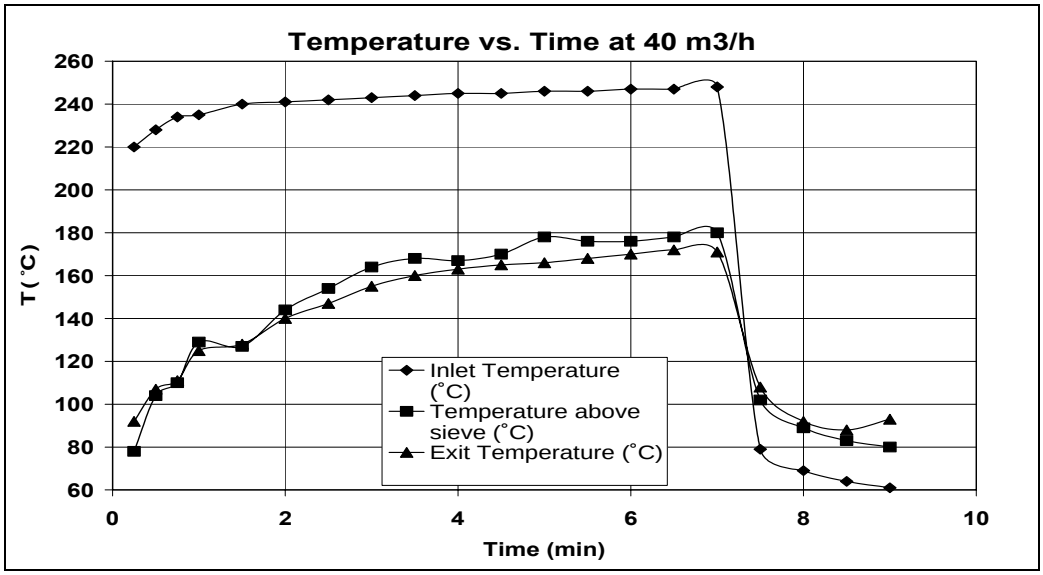

Figure A.3 Temperature vs. time graph at 244˚C - 40 m^3/h for 7 minute operation period (150 g wheat germ)

Table A.3 Temperature vs. time graph at 244˚C – 40 m^3/h for 7 minute operation period (150 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.25	220	78	92
0.5	228	104	107
0.75	234	110	111
1	235	129	125
1.5	240	127	128
2	241	144	140
2.5	242	154	147
3	243	164	155
3.5	244	168	160
4	245	167	163
4.5	245	170	165
5	246	178	166
5.5	246	176	168
6	247	176	170
6.5	247	178	172

Table A.3 (Continued) Temperature vs. time graph at 244˚C – 40 m^3/h for 7 minute operation period (150 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
7	248	180	171
7.5	79	102	108
8	69	89	92
8.5	64	83	88
9	61	80	93

A2 STUDIES WITH 50 m^3/hr AIR FLOW RATE

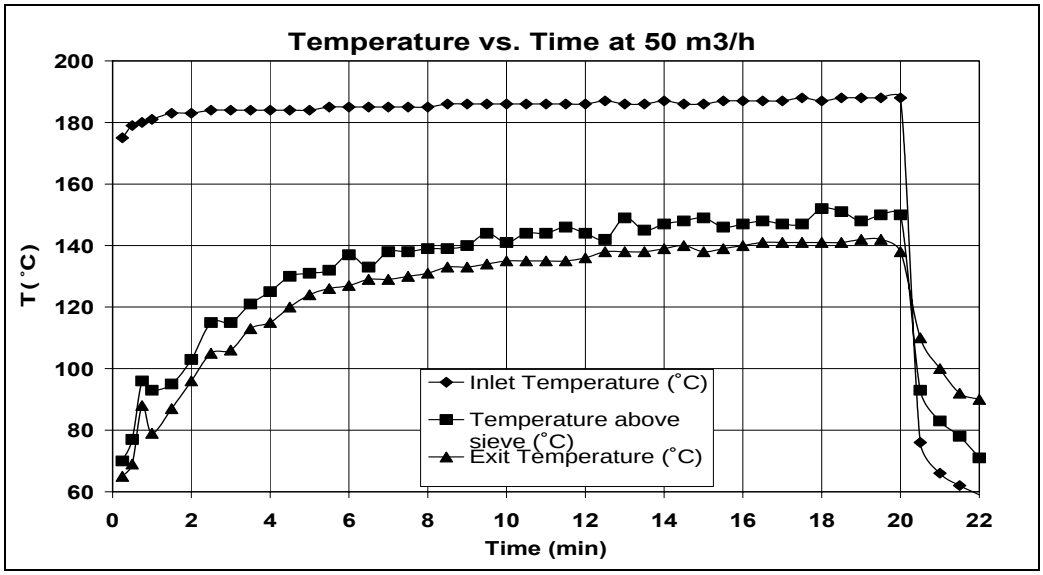

Figure A.4 Temperature vs. time graph at 186˚C - 50 m^3/h for 20 minute operation period (330 g wheat germ)

Table A.4 Temperature vs. time graph at 186˚C – 50 m^3/h for 20 minute operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.25	175	70	65
0.5	179	77	69
0.75	180	96	88
1	181	93	79
1.5	183	95	87
2	183	103	96
2.5	184	115	105
3	184	115	106
3.5	184	121	113
4	184	125	115
4.5	184	130	120
5	184	131	124
5.5	185	132	126
6	185	137	127
6.5	185	133	129
7	185	138	129
7.5	185	138	130
8	185	139	131
8.5	186	139	133
9	186	140	133
9.5	186	144	134
10	186	141	135
10.5	186	144	135
11	186	144	135
11.5	186	146	135
12	186	144	136
12.5	187	142	138
13	186	149	138
13.5	186	145	138
14	187	147	139
14.5	186	148	140
15	186	149	138
15.5	187	146	139

Table A.4 (continued) Temperature vs. time graph at 186˚C – 50 m^3/h for 20 minute operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
16	187	147	140
16.5	187	148	141
17	187	147	141
17.5	188	147	141
18	187	152	141
18.5	188	151	141
19	188	148	142
19.5	188	150	142
20	188	150	138
20.5	76	93	110
21	66	83	100
21.5	62	78	92
22	59	71	90

A3 STUDIES WITH 60 m^3/hr AIR FLOW RATE

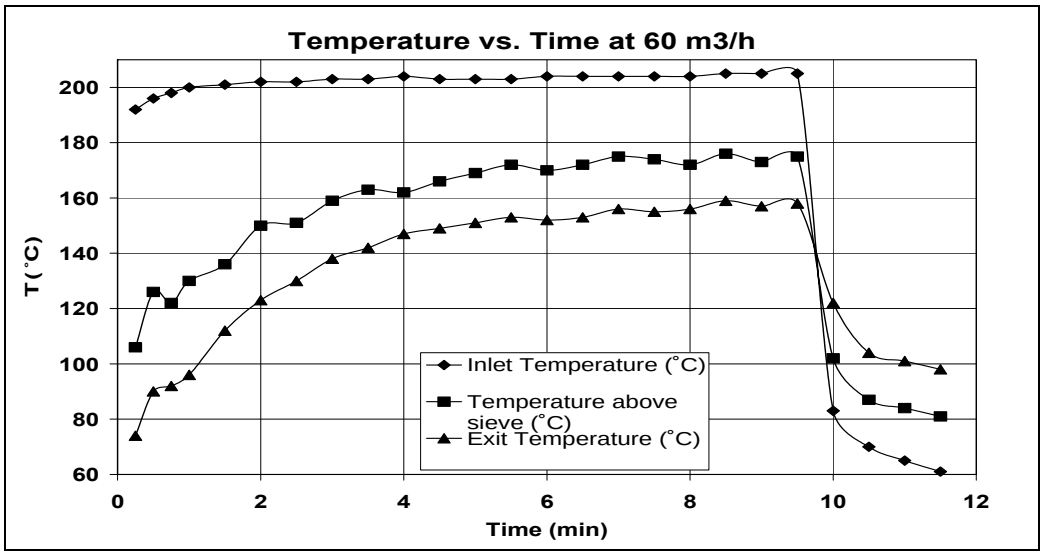

Figure A.5 Temperature vs. time graph at 203˚C - 60 m^3/h for 9.5 minute operation period (330 g wheat germ)

Table A.5 Temperature vs. time graph at 203˚C – 60 m^3/h for 9.5 minute operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.25	192	106	74
0.5	196	126	90
0.75	198	122	92
1	200	130	96
1.5	201	136	112
2	202	150	123
2.5	202	151	130
3	203	159	138
3.5	203	163	142
4	204	162	147
4.5	203	166	149
5	203	169	151
5.5	203	172	153
6	204	170	152
6.5	204	172	153
7	204	175	156
7.5	204	174	155
8	204	172	156
8.5	205	176	159
9	205	173	157
9.5	205	175	158
10	83	102	122
10.5	70	87	104
11	65	84	101
11.5	61	81	98

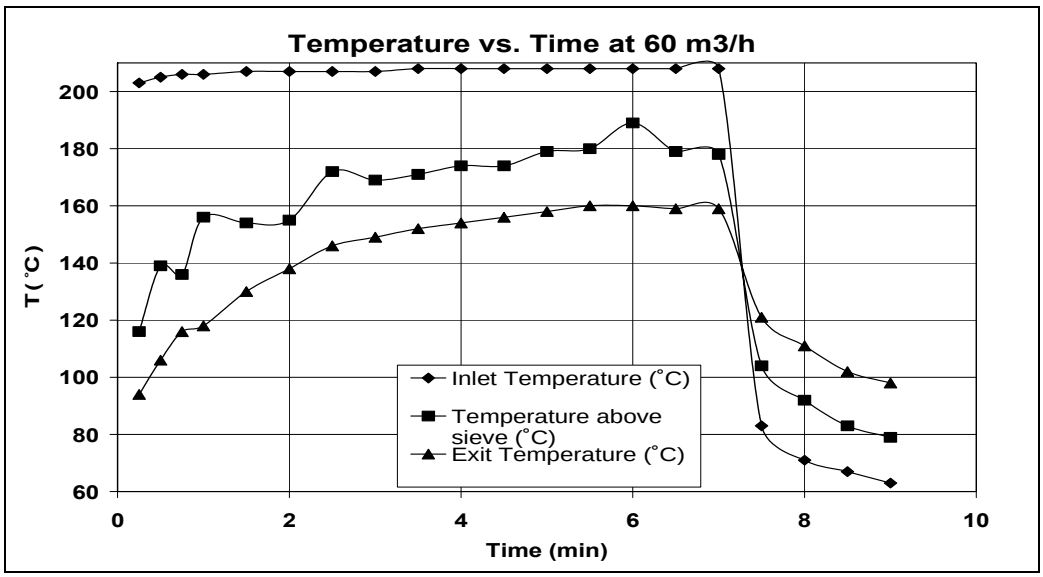

Figure A.6 Temperature vs. time graph at 208˚C - 60 m^3/h for 7 minute operation period (330 g wheat germ)

Table A.6 Temperature vs. time graph at 208˚C – 60 m^3/h for 7 minute operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.25	203	116	94
0.5	205	139	106
0.75	206	136	116
1	206	156	118
1.5	207	154	130
2	207	155	138
2.5	207	172	146
3	207	169	149
3.5	208	171	152
4	208	174	154
4.5	208	174	156
5	208	179	158
5.5	208	180	160

Table A.6 (Continued) Temperature vs. time graph at 208˚C – 60 m^3/h for 7 minute operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
6	208	189	160
6.5	208	179	159
7	208	178	159
7.5	83	104	121
8	71	92	111
8.5	67	83	102
9	63	79	98

A4 STUDIES WITH 70 m^3/hr AIR FLOW RATE

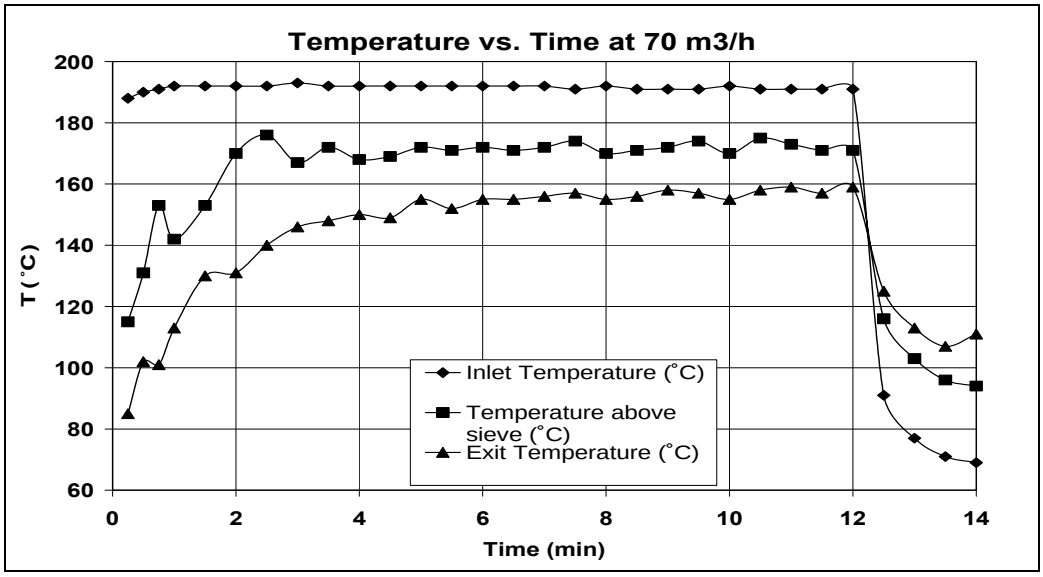

Figure A.7 Temperature vs. time graph at 192˚C - 70 m^3/h for 12 minute operation period (330 g wheat germ)

Table A.7 Temperature vs. time graph at 192˚C – 70 m^3/h for 12 minute operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.25	188	115	85
0.5	190	131	102
0.75	191	153	101
1	192	142	113
1.5	192	153	130
2	192	170	131
2.5	192	176	140
3	193	167	146
3.5	192	172	148
4	192	168	150
4.5	192	169	149
5	192	172	155
5.5	192	171	152
6	192	172	155
6.5	192	171	155
7	192	172	156
7.5	191	174	157
8	192	170	155
8.5	191	171	156
9	191	172	158
9.5	191	174	157
10	192	170	155
10.5	191	175	158
11	191	173	159
11.5	191	171	157
12	191	171	159
12.5	91	116	125
13	77	103	113
13.5	71	96	107
14	69	94	111

APPENDIX B

EXPERIMENTAL DATA

B1 STUDIES AT 55 m^3/hr AIR FLOW RATE

Table B.1 Temperature vs. time graph at 216˚C – 55 m^3/h for 7 minute (B1) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	214	207	190
0.15	214	207	190
0.17	180	77	125
0.37	174	65	136
0.50	182	50	137
0.75	207	92	83
1.00	210	94	85
1.25	212	98	87
1.50	213	108	101
2.00	214	105	96
2.50	215	115	106
3.00	215	122	116
3.50	215	131	121
4.00	216	135	127
4.50	216	144	133
5.00	217	146	138
5.50	217	152	144
6.00	217	155	147
6.50	217	159	152

Table B.1 (Continued) Temperature vs. time graph at 216˚C – 55 m^3/h for 7 minute (B1) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
7.00	217	163	154
7.50	217	163	156
7.58	210	162	140
7.83	201	172	135
8.33	84	108	116
8.83	76	95	102
9.33	70	87	98
9.83	69	87	97
9.92	83	89	110
10.03	99	91	116
10.17	105	91	119
10.33	110	92	120
10.50	113	92	122
10.58	117	93	122

B2 STUDIES AT 60 m^3/hr AIR FLOW RATE

Table B.2 Temperature vs. time graph at 209˚C – 60 m^3/h for 7 minute (B2) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	207	200	180
0.13	170	74	128
0.27	172	53	138
0.47	178	50	138
0.75	200	85	71
1.00	204	91	82
1.25	206	104	96
1.50	206	113	104
2.00	208	130	123
2.50	209	113	99
3.00	209	125	117
3.50	209	134	122
4.00	210	138	130
4.50	210	141	133
5.00	210	150	140
5.50	210	154	145
6.00	210	158	148
6.50	211	160	150
7.00	210	165	154
7.50	210	166	155
7.58	196	172	139
7.83	187	170	134
8.33	82	106	114
8.83	75	92	108
9.33	71	89	97
9.83	69	87	95
10.00	100	91	117
10.08	107	91	121
10.25	111	92	122
10.45	116	93	123
10.58	119	93	124

Table B.3 Temperature vs. time graph at 210˚C – 60 m^3/h for 9 minute (B3) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	207	199	177
0.08	207	199	177
0.20	169	82	108
0.33	167	65	123
0.50	173	54	121
0.75	201	89	84
1.00	204	98	90
1.25	205	110	100
1.50	206	144	106
2.00	208	130	107
2.50	209	119	107
3.00	209	127	115
3.50	209	134	120
4.00	209	142	129
4.50	210	149	134
5.00	211	152	141
5.50	211	157	143
6.00	211	159	147
6.50	211	162	148
7.00	211	166	153
7.50	211	169	155
8.00	211	169	156
8.50	211	172	157
9.00	211	173	157
9.50	211	173	159
9.62	204	174	140
9.75	200	177	139
10.33	85	109	125
10.83	75	96	111
11.33	70	85	102
11.83	68	85	97
11.95	84	89	108
12.07	95	91	114
12.18	100	91	117
12.30	105	92	119
12.47	109	92	120
12.58	112	93	120

Table B.4 Temperature vs. time graph at 209˚C – 60 m^3/h for 12 minute (B4) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	207	200	180
0.08	162	95	82
0.17	161	79	106
0.30	159	70	120
0.75	196	83	81
1.00	201	91	85
1.25	204	107	97
1.50	205	111	100
2.00	207	112	98
2.50	208	120	108
3.00	209	125	115
3.50	209	135	122
4.00	209	140	129
4.50	209	147	133
5.00	209	151	139
5.50	209	158	144
6.00	209	161	147
6.50	209	166	149
7.00	209	166	153
7.50	209	169	155
8.00	209	170	156
8.50	209	169	157
9.00	209	173	158
9.50	209	172	159
10.00	209	173	159
10.50	209	174	159
11.00	209	174	160
11.50	209	175	161
12.00	209	176	162
12.50	208	175	162
12.67	187	171	155

Table B.4 (Continued) Temperature vs time graph at 209˚C – 60 m^3/h for 12 minute (B4) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
12.78	181	164	149
13.33	86	108	126
13.83	75	95	111
14.33	71	87	106
14.83	68	83	101
14.95	89	91	113
15.08	99	92	118
15.25	104	93	122
15.42	108	94	123
15.52	112	95	123

B3 STUDIES AT 65 m^3/hr AIR FLOW RATE

Table B.5 Temperature vs. time graph at 201˚C – 65 m^3/h for 7 minute (B5) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	199	190	177
0.08	170	98	80
0.25	167	75	125
0.42	166	64	134
0.50	172	50	124
0.75	193	85	74
1.00	196	105	80
1.25	198	104	90
1.50	199	115	92
2.00	199	134	108
2.50	200	127	113
3.00	201	141	123
3.50	200	143	128
4.00	201	150	136
4.50	201	158	142
5.00	201	159	146
5.50	201	162	148
6.00	201	167	151
6.50	202	169	154
7.00	202	171	157
7.50	202	171	159
7.65	192	167	147
7.80	184	166	139
8.33	84	106	119
8.83	75	96	107
9.33	71	89	100
9.83	68	86	96
10.03	107	91	122
10.18	111	92	123
10.30	113	92	123
10.50	115	92	124
10.63	118	93	124

Table B.6 Temperature vs time graph at 201˚C – 65 m^3/h for 9 minute (B6) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	199	191	179
0.08	175	89	104
0.25	172	75	128
0.38	173	58	137
0.75	195	103	104
1.00	196	179	147
1.25	197	171	110
1.50	199	103	87
2.00	200	113	99
2.50	200	129	109
3.00	200	135	119
3.50	200	142	129
4.00	200	150	136
4.50	201	158	142
5.00	201	160	146
5.50	201	164	148
6.00	202	168	151
6.50	202	169	154
7.00	202	174	158
7.50	202	173	158
8.00	202	173	158
8.50	201	175	161
9.00	201	175	161
9.50	201	175	161
9.58	197	171	155
9.73	192	172	153
10.33	85	112	124
10.83	75	100	112
11.33	72	95	105
11.83	69	90	100
11.92	93	93	120
12.03	103	95	129
12.15	109	96	126
12.32	113	96	128
12.43	117	97	129

B4 REPRODUCIBILITY STUDIES

Table B.7 Temperature vs. time graph at 217˚C – 55 m^3/h for 7 minute (C1) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	215	210	194
0.15	181	85	106
0.33	177	70	130
0.75	208	105	86
1.00	211	111	93
1.25	213	148	104
1.50	214	111	94
2.00	216	128	112
2.50	216	126	110
3.00	217	128	118
3.50	217	132	125
4.00	217	143	138
4.50	217	152	143
5.00	217	149	141
5.50	217	154	144
6.00	218	156	148
6.50	218	159	152
7.00	218	166	155
7.50	218	163	156
7.67	193	172	137
8.33	90	106	122
8.83	81	98	113
9.33	76	91	106
9.83	75	88	102
10.00	91	92	116
10.17	103	95	123
10.33	110	95	124
10.50	115	96	124

Table B.8 Temperature vs. time graph at 210˚C – 60 m^3/h for 12 minute (C4) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	207	201	184
0.15	175	84	119
0.32	172	70	134
0.48	178	58	123
0.75	204	170	90
1.00	206	123	96
1.25	206	125	106
1.50	208	137	100
2.00	208	139	108
2.50	209	145	130
3.00	209	145	130
3.50	210	143	129
4.00	210	145	136
4.50	210	151	143
5.00	210	152	142
5.50	210	161	146
6.00	210	166	151
6.50	210	164	153
7.00	211	163	153
7.50	211	168	157
8.00	211	167	156
8.50	210	170	160
9.00	210	171	160
9.50	211	171	159
10.00	210	172	162
10.50	211	171	161
11.00	211	171	162
11.50	211	171	162
12.00	211	174	162
12.50	211	173	162
12.67	192	170	146

Table B.8 (Continued) Temperature vs time graph at 210˚C – 60 m^3/h for 12 minute (C4) operation period (330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
12.83	185	170	142
13.33	90	113	129
13.83	81	100	118
14.33	76	90	108
14.83	74	86	107
15.00	95	97	124
15.17	106	98	128
15.33	112	99	130
15.50	116	100	130

B5 BED HEIGHT STUDIES

Table B.9 Temperature vs. time graph at 243˚C – 60 m^3/h for 6.5 minute (C7) operation period (0 cm level - 330 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	242	237	208
0.17	188	98	99
0.33	186	72	116
0.75	219	100	84
1.00	229	138	93
1.25	233	142	113
1.50	234	139	116
2.00	237	131	110
2.50	239	131	114
3.00	240	135	119
3.50	241	138	124
4.00	242	148	134
4.50	243	147	132
5.00	243	162	145
5.50	244	170	154
6.00	245	176	160
6.50	245	180.9	165
7.00	246	184	167
7.17	246	182	150
7.33	231	182	152
7.83	94	115	128
8.33	81	99	111
8.83	76	93	105
9.33	73	89	100
9.50	96	93	118
9.67	111	94	121
9.83	117	95	123
10.00	121	96	123

Table B.10 Temperature vs. time graph at 241˚C – 60 m^3/h for 7.5 minute (C8) operation period (0.83 cm increase - 380 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	238	233	209
0.17	186	98	90
0.33	190	76	126
0.75	213	88	79
1.00	223	98	84
1.25	225	109	104
1.50	231	132	117
2.00	235	115	96
2.50	237	136	111
3.00	238	138	124
3.50	239	135	113
4.00	240	146	129
4.50	240	148	132
5.00	241	150	138
5.50	241	162	147
6.00	242	160	152
6.50	241	164	155
7.00	242	171	160
7.50	243	174	162
8.00	243	176	165
8.17	216	172	141
8.83	95	113	131
9.33	82	105	115
9.83	77	92	105
10.33	74	86	105
10.50	103	95	120
10.67	112	97	123
10.83	119	99	125
11.00	123	100	126

Table B.11 Temperature vs. time graph at 241˚C – 60 m^3/h for 8 minute (C9) operation period (1.83 cm increase - 440 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	239	233	210
0.17	193	93	97
0.33	191	70	133
0.50	196	62	139
0.75	226	97	82
1.00	235	109	83
1.25	239	128	108
1.50	239	134	122
2.00	239	125	104
2.50	239	139	125
3.00	240	149	125
3.50	240	159	141
4.00	240	142	127
4.50	241	142	129
5.00	241	148	137
5.50	241	154	142
6.00	241	159	152
6.50	242	159	151
7.00	242	165	156
7.50	242	166	160
8.00	242	168	160
8.50	243	168	162
8.67	210	168	140
8.83	204	174	138
9.33	90	114	127
9.83	82	101	116
10.33	77	91	110
10.83	75	91	104
11.00	98	97	120
11.17	110	98	124
11.33	116	99	126
11.50	123	100	127

Table B.12 Temperature vs time graph at 240˚C – 60 m^3/h for 10 minute (C10) operation period (2.5 cm increase - 480 g wheat germ)

Time (min)	Inlet Temperature (˚C)	Temperature above sieve (˚C)	Exit Temperature (˚C)
0.00	242	238	215
0.17	195	111	110
0.33	192	78	139
0.75	225	105	80
1.00	238	117	94
1.25	240	137	99
1.50	241	122	105
2.00	242	121	105
2.50	243	138	121
3.00	243	160	136
3.50	243	151	126
4.00	240	149	128
4.50	239	148	137
5.00	236	157	145
5.50	235	168	145
6.00	234	159	147
6.50	236	161	152
7.00	237	173	157
7.50	240	170	158
8.00	240	168	159
8.50	240	172	162
9.00	241	174	163
9.50	242	178	165
10.00	242	179	168
10.50	242	183	170
10.67	225	184	166
11.33	100	122	145
11.83	88	112	132
12.33	81	99	121
12.83	78	96	115
13.00	98	102	128
13.17	113	106	133
13.33	121	107	135

APPENDIX C

EXPERIMENTAL DATA FOR COLOR ANALYSIS

Table C.1 Color Analysis results (L*, a*, b* values)

Run Number	Conditions	L*	a*	b*
B	Raw germ	86.1	-0.3	37.6
B1	55m^3/h – 216˚C – 7min	87.5	-0.1	42.0
B2	60m^3/h – 209˚C – 7min	88.3	-0.5	41.2
B3	60m^3/h – 210˚C – 9min	83.8	0.3	41.8
B4	60m^3/h – 209˚C – 12min	80.0	2.3	54.0
B5	65m^3/h – 201˚C – 7min	87.5	-1.5	43.7
B6	65m^3/h – 201˚C – 9min	87.8	-0.9	44.9
C	Raw germ	88.2	-1.8	37.2
C1	55m^3/h – 217˚C – 7min	88.6	-1.5	40.7
C4	60m^3/h – 210˚C – 12min	78.8	3.1	60.1
C7	60m^3/h – 243˚C – 6.5min – 0 cm (330g)	84.9	-0.6	51.0
C8	60m^3/h – 241˚C – 7.5min – 0.83cm (380g)	85.6	-0.8	44.9
C9	60m^3/h – 241˚C – 8 min – 1.83cm (440g)	87.3	-0.8	39.5
C10	60m^3/h – 240˚C – 10 min – 2.5 cm (480g)	65.3	13.3	90.6

APPENDIX D

SENSORY EVALUATION TESTS

Figure D.1 Triangle Test

Name: Date:

There are three samples below and two of them are the same.

Please Circle the similar samples after tasting them from left to right.

@ ® €

Figure D.2 Multiple Ranking Test

Name: Date:

There are six different samples below. Please order these samples according to their taste. (e.g. show the best one with 1 – the second one with 2). You may give the same number to the samples which are hard to distinguish. (e.g. 1, 2, 3, 3, 5, 6)

	Order	Sample Code
The Best	1	
	2	
	3	
	4	
	5	
	6	