EFFECTS OF DIFFERENT OVENS AND ENZYMES ON QUALITY PARAMETERS OF BREAD

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ABSTRACT

EFFECTS OF DIFFERENT OVENS AND ENZYMES ON QUALITY PARAMETERS OF BREAD

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The main objective of the study was to determine the effects of enzymes on quality of breads baked in halogen lamp-microwave combination, microwave and conventional oven. It was also aimed to determine the optimum processing conditions in these ovens.

In the first part of the study, as independent variables, baking time, baking temperature for conventional oven; microwave power for microwave oven and microwave power and halogen power for combination oven was used. Weight loss, specific volume, firmness and color of the breads were measured during the study. The optimum baking conditions were determined as 13 min at 200°C in conventional oven, 0.75 min at 100% power in microwave oven, 10 min at 60% power in halogen

lamp oven, and 3 min at 30% microwave power and 70% halogen lamp power in halogen lamp-microwave combination oven. In the case of combination oven, specific volume and color values of breads were comparable with the conventionally baked breads but weight loss and firmness of them were still higher.

The effects of different enzymes (α-amylase, xylanase, lipase & protease) were studied to reduce the quality problems of breads baked in microwave and halogen lamp-microwave combination oven. The optimum baking conditions determined for each type of oven in the first part of the study were used in the investigation of the functions of enzymes on bread quality during baking and staling. As a control, no enzyme added breads baked at 200°C for 13 min in conventional oven were used.

All the enzymes were found to be effective in reducing initial firmness and increasing specific volume of breads baked in microwave and halogen lamp-microwave combination ovens. However, in conventional baking, the effects of enzymes on crumb firmness were seen mostly during storage.

The usage of enzyme protease in the bread formulation resulted in breads with higher volume and darker color in all of the ovens. All of the enzymes were found to be effective to retard the staling of breads baked in conventional, microwave and halogen lamp-microwave combination ovens.

Keywords: Baking, Bread, Enzymes, Halogen lamp, Microwaves, Near-infrared, Staling.

ÖZ

FARKLI FIRIN VE ENZİMLERİN EKMEĞİN KALİTE PARAMETRELERİ ÜZERİNDEKİ ETKİLERİ

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Çalışmanın ana amacı, enzimlerin halojen lamba-mikrodalga kombinasyonlu, mikrodalga ve konvansiyonel fırınlarda pişirilen ekmeklerin kalitesi üzerindeki etkilerinin araştırılmasıdır. Aynı zamanda bu fırınlardaki optimum işlem koşullarının belirlenmesi de amaçlanmıştır.

Çalışmanın ilk bölümünde, bağımsız değişken olarak; konvansiyonel fırın için pişirme zamanı, pişirme sıcaklığı; mikrodalga fırın için mikrodalga gücü ve kombinasyon fırın için mikrodalga ve halogen lamba gücü kullanılmıştır. Çalışma sırasında ekmeklerin ağırlık kaybı, özgül hacim, iç sertlik ve renkleri ölçülmüştür. Optimum pişirme koşulları, konvansiyonel fırında, 200°C'de 13 dakika, mikrodalga fırında, %100 fırın gücü ile 0,75 dakika, halogen lamba fırında %60 fırın gücü ile 10

dakika ve halojen lamba-mikrodalga kombinasyonlu fırında, %30 mikrodalga gücü ve %70 halogen lamba gücü ile 3 dakika olarak belirlenmiştir.

Kombinasyon fırında pişirilen ekmeklerin, özgül hacim ve renk değerleri konvansiyonel fırında pişirilen ekmekler ile karşılaştırılabilir kalitede olmuştur ancak bu ekmeklerin ağırlık kaybı ve iç sertlik değerleri hala yüksektir.

Mikrodalga ve halojen lamba-mikrodalga kombinasyonlu fırında pişirilen ekmeklerin kalite problemlerini azaltmak için değişik enzimlerin (α-amilaz, ksilanaz, lipaz ve proteaz) etkileri incelenmiştir. Çalışmanın birinci bölümünde her tip fırın için belirlenen optimum pişirme koşulları, enzimlerin pişirme ve bayatlama sırasında ekmeklerin kalitesi üzerindeki fonksiyonlarının araştırılmasında kullanılmıştır. Kontrol olarak, konvansiyonel fırında 200°C'de 13 dakika pişirilen, enzim ilave edilmemiş ekmekler kullanılmıştır.

Bütün enzimler mikrodalga ve halojen lamba-mikrodalga kombinasyonlu fırınlarda pişirilen ekmeklerin ilk sertliklerinin azaltılmasında ve özgül hacimlerinin artırılmasında etkili bulunmuştur. Buna rağmen, konvansiyonel pişirme'de, enzimlerin iç sertlik üzerindeki etkileri, daha çok saklama sırasında görülmüştür.

Proteaz enziminin ekmek formülasyonunda kullanılması, bütün fırınlarda, daha yüksek hacim ve daha koyu renge sahip ekmek elde edilmesine sebep olmuştur. Bütün enzimler, konvansiyonel, mikrodalga ve halojen lamba-mikrodalga kombinasyonlu fırınlarda pişirilen ekmeklerin bayatlamalarının geciktirilmesinde etkili bulunmuştur.

Anahtar sözcükler: Bayatlama, Ekmek, Enzimler, Halojen lamba, Mikrodalga, Pişirme, Yakın-kızılötesi.

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TABLE OF CONTENTS

ABSTRACT iii
ÖZ v
ACKNOWLEDGMENTS vii
TABLE OF CONTENTS viii
LIST OF TABLES xi
LIST OF FIGURES xiv

CHAPTER

1. INRODUCTION 1
   1.1 Halogen lamp-Microwave Combination Heating of Foods 1
      1.1.1 Microwave Heating Mechanisms 1
      1.1.2 Halogen lamp Heating Mechanisms 3
      1.1.3 Halogen lamp-Microwave Combination Heating Mechanisms 4
   1.2 Bread Baking 5
   1.3 Problems in Microwave Baking 8
   1.4 Enzymes in the Baking Industry 11
      1.4.1 α-Amylase 12
      1.4.2 Xylanase 13
      1.4.3 Lipase 15
      1.4.4 Protease 16
   1.5 Staling 17
      1.5.1 Bread Staling 18
      1.5.2 Retardation of Staling of Breads 19

1.6 Objectives of the Study 20

2. MATERIALS AND METHODS 22
2.1 Materials 22
2.2 Preparation of Bread Dough 22
2.3 Determination of Power of Microwave Oven 23
2.4 Determination of Optimum Baking Conditions in Different Ovens 24
2.4.1 Conventional Oven 24
2.4.2 Microwave Oven 24
2.4.3 Halogen Lamp Oven 25
2.4.4 Halogen Lamp-Microwave Combination Oven..... 25
2.5 Effects of Enzymes on Quality of Breads Baked in Different Ovens 26
2.6 Effects of Enzymes on Staling of Breads Baked in Different Ovens 26
2.7 Quality Measurements 26
2.7.1 Weight Loss 27
2.7.2 Specific volume 27
2.7.3 Crumb Firmness 28
2.7.4 Color 28
2.8 Statistical Analysis 28

3. RESULTS AND DISCUSSION 30
3.1 Determination of Optimum Baking Conditions in Different Ovens 30
3.1.1 Conventional Oven 30
3.1.2 Microwave Oven 35
3.1.3 Halogen Lamp Oven 40
3.1.4 Halogen Lamp-Microwave Combination Oven..... 44
3.2 Effects of Enzymes on Quality of Breads Baked in Different Ovens 51

3.2.1 Conventional Oven 52
3.2.2 Microwave Oven 56
3.2.3 Halogen Lamp-Microwave Combination Oven 62
3.3 Effects of Enzymes on Staling of Breads Baked in Different Ovens 65
3.3.1 Conventional Oven 65
3.3.2 Microwave Oven 67
3.3.3 Halogen Lamp-Microwave Combination Oven 70
3.4 Comparison of Quality of Breads Baked in Different Ovens 71

4. CONCLUSION AND RECOMMENDATIONS 78
REFERENCES 80
APPENDICES
A. MODAL CONSTANTS 93
B. CORRELATION COEFFICIENTS 96
C. ANOVA AND DUNCAN TABLES 98
D. REGRESSION ANALYSES TABLES 116

LIST OF TABLES

TABLE

3.1 Percentage of reduction in firmness of breads baked in different ovens 76

A.1 Modal constants for weight loss of breads baked in conventional oven 93

A.2 Modal constants for ΔE value of breads baked in conventional oven 93

A.3 Modal constants for weight loss of breads baked in microwave oven ... 94

A.4 Modal constants for weight loss of breads baked in halogen lamp oven 94

A.5 Modal constants for ΔE value of breads baked in halogen lamp oven ... 94

A.6 Modal constants for weight loss of breads baked in halogen lamp-microwave combination oven 95

A.7 Modal constants for ΔE value of breads baked in halogen lamp-microwave combination oven 95

B.1 Correlation coefficients of specific volume and crumb firmness of conventionally baked breads at different temperatures 96

B.2 Correlation coefficients of weight loss and crumb firmness of microwave baked breads at different oven powers 96

B.3 Correlation coefficients of specific volume and crumb firmness of halogen lamp baked breads at different oven powers 97

C.1 ANOVA and Duncan's Multiple Range Test Table for moisture content of conventionally baked breads formulated with different enzyme types just after baking 98

C.2 ANOVA and Duncan's Multiple Range Test Table for specific volume of conventionally baked breads formulated with different enzyme types just after baking 99

C.3 ANOVA and Duncan's Multiple Range Test Table for firmness of conventionally baked breads formulated with different enzyme types just after baking 100
C.4 ANOVA and Duncan's Multiple Range Test Table for ΔE value of conventionally baked breads formulated with different enzyme types just after baking 101
C.5 ANOVA and Duncan's Multiple Range Test Table for moisture content of microwave baked breads formulated with different enzyme types just after baking 102
C.6 ANOVA and Duncan's Multiple Range Test Table for specific volume of microwave baked breads formulated with different enzyme types just after baking 103
C.7 ANOVA and Duncan's Multiple Range Test Table for firmness of microwave baked breads formulated with different enzyme types just after baking 104
C.8 ANOVA and Duncan's Multiple Range Test Table for ΔE value of microwave baked breads formulated with different enzyme types just after baking 105
C.9 ANOVA and Duncan's Multiple Range Test Table for moisture content of halogen lamp-microwave combination baked breads formulated with different enzyme types just after baking 106
C.10 ANOVA and Duncan's Multiple Range Test Table for specific volume of halogen lamp-microwave combination baked breads formulated with different enzyme types just after baking 107
C.11 ANOVA and Duncan's Multiple Range Test Table for firmness of halogen lamp-microwave combination baked breads formulated with different enzyme types just after baking 108
C.12 ANOVA and Duncan's Multiple Range Test Table for ΔE value of halogen lamp-microwave combination baked breads formulated with different enzyme types just after baking 109

C.13 ANOVA and Duncan's Multiple Range Test Table for moisture content of conventionally baked breads formulated with different enzyme types after 2 days storage 110
C.14 ANOVA and Duncan's Multiple Range Test Table for firmness of conventionally baked breads formulated with different enzyme types after 2 days storage 111
C.15 ANOVA and Duncan's Multiple Range Test Table for moisture content of microwave baked breads formulated with different enzyme types after 2 days storage 112
C.16 ANOVA and Duncan's Multiple Range Test Table for firmness of microwave baked breads formulated with different enzyme types after 2 days storage 113
C.17 ANOVA and Duncan's Multiple Range Test Table for moisture content of halogen lamp-microwave combination baked breads formulated with different enzyme types after 2 days storage 114
C.18 ANOVA and Duncan's Multiple Range Test Table for firmness of halogen lamp-microwave combination baked breads formulated with different enzyme types after 2 days storage 115
D.1 Regression table for weight loss of breads baked in halogen lamp-microwave combination oven 116
D.2 Regression table for specific volume of breads baked in halogen lamp-microwave combination oven 117
D.3 Regression table for ΔE value of breads baked in halogen lamp-microwave combination oven 118

LIST OF FIGURES

FIGURE

2.1 The figure of halogen lamp-microwave combination oven 25

3.1 Variation of weight loss of breads during conventional baking at different temperatures 31

3.2 Variation of specific volume of breads during conventional baking at different temperatures 32

3.3 Variation of firmness of breads during conventional baking at different temperatures 33

3.4 Variation of ΔE value of breads during conventional baking at different temperatures 34

3.5 Variation of weight loss of breads during microwave baking at different oven powers 36

3.6 Variation of specific volume of breads during microwave baking at different oven powers 37

3.7 Variation of firmness of breads during microwave baking at different oven powers 38

3.8 Variation of ΔE value of breads during microwave baking at different oven powers 39

3.9 Variation of weight loss of breads during halogen lamp baking at different oven powers 40

3.10 Variation of specific volume of breads during halogen lamp baking at different oven powers 41

3.11 Variation of firmness of breads during halogen lamp baking at different oven powers 42

3.12 Variation of ΔE value of breads during halogen lamp baking at different oven powers 43
3.13 Variation of weight loss of breads during halogen lamp-microwave combination baking at different oven powers 45
3.14 Variation of specific volume of breads during halogen lamp-microwave combination baking at different oven powers 46
3.15 Variation of firmness of breads during halogen lamp-microwave combination baking at different oven powers 47
3.16 Variation of ΔE value of breads during halogen lamp-microwave combination baking at different oven powers 48
3.17 Effects of halogen power and baking time on weight loss of breads baked in halogen lamp-microwave combination oven 50
3.18 Effects of halogen power and baking time on specific volume of breads baked in halogen lamp-microwave combination oven 50
3.19 Effects of halogen power and baking time on ΔE value of breads baked in halogen lamp-microwave combination oven 51
3.20 Effects of enzymes on moisture content of breads baked in conventional oven just after baking 53
3.21 Effects of enzymes on specific volume of breads baked in conventional oven just after baking 54
3.22 Effects of enzymes on firmness of breads baked in conventional oven just after baking 55
3.23 Effects of enzymes on ΔE value of breads baked in conventional oven just after baking 56
3.24 Effects of enzymes on moisture content of breads baked in microwave oven just after baking 57
3.25 Effects of enzymes on specific volume of breads baked in microwave oven just after baking 58
3.26 Effects of enzymes on firmness of breads baked in microwave oven just after baking 60
3.27 Effects of enzymes on ΔE value of breads baked in microwave oven just after baking 61

3.28 Effects of enzymes on moisture content of breads baked in halogen lamp-microwave combination oven just after baking 62
3.29 Effects of enzymes on specific volume of breads baked in halogen lamp-microwave combination oven just after baking 63
3.30 Effects of enzymes on firmness of breads baked in halogen lamp-microwave combination oven just after baking 64
3.31 Effects of enzymes on ΔE value of breads baked in halogen lamp-microwave combination oven just after baking 65
3.32 Effects of enzymes on moisture content of breads baked in conventional oven after 2 days storage 66
3.33 Effects of enzymes on firmness of breads baked in conventional oven after 2 days storage 67
3.34 Effects of enzymes on moisture content of breads baked in microwave oven after 2 days storage 68
3.35 Effects of enzymes on firmness of breads baked in microwave oven after 2 days storage 69
3.36 Effects of enzymes on moisture content of breads baked in halogen lamp-microwave combination oven after 2 days storage 70
3.37 Effects of enzymes on firmness of breads baked in halogen lamp-microwave combination oven after 2 days storage 71
3.38 Effects of different baking methods on weight loss of breads 72
3.39 Effects of different baking methods on specific volume of breads 73
3.40 Effects of different baking methods on firmness of breads 74
3.41 Effects of different baking methods on ΔE value of breads 75

CHAPTER 1

INTRODUCTION

1.1 Halogen Lamp-Microwave Combination Heating of Foods

Halogen lamp-microwave combination heating is a new technology that combines the time saving advantage of microwave heating with the browning and crisping advantages of halogen lamp heating. Since there is no information about the halogen lamp-microwave combination heating in literature, in understanding its mechanism, it is important to review the mechanisms of microwave and halogen lamp heating separately.

1.1.1 Microwave Heating Mechanisms

Microwaves are electromagnetic waves of radiant energy having wavelength between radio and infrared waves on the electromagnetic spectrum (Giese, 1992). Microwaves are usually generated by an electromagnetic device called a "magnetron".

The major mechanisms of microwave heating of foods involve orientation polarization and interfacial (space charge) distribution. Some dielectric materials contain permanent dipoles that tend to reorient under the influence of alternating fields, thus causing orientation polarization (Metaxas and Meredith, 1983). Heat is generated because of the inability of rotating molecules to keep pace with the alternating field. Water, the major constituent of most food products, is the main source of interactions of microwave with food materials because of its dipolar nature. Interfacial distribution arises owing to the charge build up in the interfaces of

components in heterogeneous systems (Metaxas and Meredith, 1983). In interfacial distribution, any charged particles in foods will experience a force alternating at the rate of microwave frequency. The net force will accelerate the particle in one direction and then in the opposite. The accelerated particle collides with adjacent particles and heat is generated by this collision (Buffler, 1993). For microwave heating the energy equation includes a heat generation term:

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T + \frac{Q}{\rho C_p} \tag{1.1}$$

where T is temperature, t is time, α is thermal diffusivity, ρ is density, C_p is specific heat of the material and Q is the rate of heat generated per unit volume of material.

The heat generated per unit volume of material per unit time (Q) represents the conversion of electromagnetic energy. Its relationship to the electric field intensity (E) at that location can be derived from Maxwell's equation of electromagnetic waves as shown by Metaxas and Meredith (1983):

$$Q = 2\pi\varepsilon_0\varepsilon'' f E^2 \tag{1.2}$$

where the magnetic loses of the food material have been ignored, ε_0 is the dielectric constant of free space, ε'' is the dielectric loss factor of the food, f is the frequency of oven and E is the electric field intensity.

The driving forces for heat and mass transfer when a food is heated by microwave differ from conventional methods. In foods heated by microwave, time-temperature profiles within the product are caused by internal heat generation owing to the absorption of electrical energy from the microwave field and heat transfer by conduction, convection and evaporation (Mudgett, 1982). The surface temperature of a food heated by microwave energy is cooler than the interior because of the lack of ambient heat and the cooling effects of evaporation (Decareau, 1992). A porous media was found to be hotter in the inside when heated by microwaves and hotter on the outside when heated by convection (Wei et al., 1985a, 1985b). Compared to

conventional heating, moisture flows, owing to concentration and pressure gradients, are uniquely and significantly altered during microwave heating. The extend to which each of these is affected in a particular situation is difficult to extract from the literature. Relatively large amounts of internal heating seem to result in increased moisture vapor generation inside a solid food material, which creates significant internal pressure and concentration gradients (Datta, 1990).

Microwave heating have some advantages compared to conventional heating, such as less start-up time, faster heating, energy efficiency, space savings, precise process control, selective heating and final product formation with higher nutritive value (Decareau and Peterson, 1986).

1.1.2 Halogen Lamp Heating Mechanisms

Infrared (IR) radiation is the part of the sun's electromagnetic spectrum that is predominantly responsible for the heating effect of the sun (Ranjan et al., 2002). Infrared radiation is found between the visible light and radiowaves (Sepulveda and Barbosa-Canovas, 2003) and can be divided into three different categories, namely, near-infrared radiation (NIR), mid-infrared radiation (MIR) and far-infrared (FIR) radiation (Ranjan et al., 2002).

Halogen lamp heating provides near-infrared radiation and its region in the electromagnetic spectrum is near the visible light with higher frequency and lower penetration depth than the other infrared radiation categories.

Often the infrared source has a high temperature (500-3000°C), and heat transfer by convection is also taking place and can not be ignored. As penetration of this kind of radiation is poor, the heating effect of infrared radiation has an impact only on the surface of the body and heat transfer through the body proceeds by conduction or convection (Sepulveda and Barbosa-Canovas, 2003). The penetration depth of infrared radiation has a strong influence on how much the surface temperature increases or the level of surface moisture that builds up over time.

Infrared radiation penetration depths can vary significantly for various food materials. Datta and Ni (2002) showed that as the infrared radiation penetration depth decreases, i.e., as infrared energy is absorbed closer to the surface, the surface temperature increases.

Use of different types of electromagnetic waves, for heating food and in food preservation have also been reported by various researchers. Heating of foods by microwave heating has been studied in detail but infrared heating has not been explored. Infrared heating of foods have been studied by some of the researchers such as Gintzburg (1969); Il'yasov and Krasnikov (1991); Ratti and Mujumdar (1995); Sakai and Hanzawa (1994) and Sandu (1986). Ginzburg (1969) treated the infrared power deposition as an exponential decay from the surface into the material and predicted temperature profiles for infrared heating. Il'yasov and Krasnikov (1991) provided detailed discussions of infrared energy absorption in foods but did not focus on energy or mass transport. Sandu (1986) provided qualitative descriptions of temperature and moisture profiles in foods during infrared heating.

Some of the advantages of infrared radiation as compared to conventional heating are reduced heating time, equipment compactness, rapid processing, decreased chance of flavor loss, preservation of vitamins in food products, and absence of solute migration from inner to outer regions (Ranjan et al., 2002).

1.1.3 Halogen Lamp-Microwave Combination Heating Mechanisms

Halogen lamp-microwave combination heating implies two different heating mechanisms together.

There is no study on halogen lamp (near-infrared radiation)-microwave combination heating in the literature, but some combination heating methods were studied to be an alternative to conventional heating, such as infrared and hot air assisted microwave heating (Datta and Ni, 2002), microwave-hot air combination heating (Kudra et al., 1990; Riva et al., 1991; Lu et al., 1998; Ren and Chen, 1998),

and microwave-impingement combination heating (Smith, 1979, 1983, 1986; Walker and Li, 1993). Several patents have been developed for producing surface browning and crispness by adding to microwaves either hot air circulation (August, 1987; Eke, 1987; Maiellano and Sklenak, 1991; Thorneywork and Jelly, 1994) or infrared heat (Eck and Buck, 1980; Fujii and Tsuda, 1987; Jung and Lee, 1992). These patent documents do not report the engineering fundamentals of the combined heating processes. Datta and Ni (2002) have mentioned that there is still a lack of understanding on the fundamentals of heat and moisture transport in foods when adding infrared or hot air to microwaves. Microwave heating modifies the transport processes due to internal pressures developed from evaporation. Such pressure-driven flow depends on the structure and properties of the food material, microwave power level, etc. When infrared is added to microwave heating, the already complex transport processes can be modified significantly. It is expected that the power level and penetration of infrared energy would be significant parameters in such a process, but the effects of these parameters have not been identified in quantitative engineering terms (Datta and Ni, 2002).

1.2 Bread Baking

The process of bread manufacture can be divided into three major parts, each of which is of equal significance in producing an acceptable end product: dough making, fermentation, and baking (Pomeranz and Shellenberger, 1971).

In yeast leavened products, mixing a dough fulfills two functions: homogeneous distribution of components, and development of the gluten into elongated fibers, so that it can form a structure capable of retaining dispersed gas to give a light loaf of bread (Matz, 1960).

The products of microbial metabolism modify the dough and are essential for production of light, well aerated, and appetizing bread. The two main changes occur during fermentation are fermentation of carbohydrates into carbon dioxide, alcohol, and small amounts of other compounds that act as flavor precursors and modification

of the proteinaceous matrix for optimum dough development and gas retention during the baking stage. As fermentation continues, more gas is produced and the gas cells in the dough become larger and larger. 60% of total gas produced is lost during fermentation, punching, molding and proofing of the dough. Yeast cells do not have mobility in dough so punching brings the yeast cells and fermentables together. After punching, the dough is molded by sheeting followed curling and rolling. The dough must be sheeted in different directions to have strong dough in all directions (Hoseney, 1986).

The final stage in bread making, baking, is a key step in which the raw dough piece is transformed into a light, porous, readily digestible and flavorful product, under the influence of heat. With the requisite quality attributes, the bread production presumes a carefully controlled baking process. The vital influence on final product quality includes the rate and amount of heat application, the humidity level in the baking chamber and baking time (Therdthai et al., 2002).

The reactions that take place during baking are the physical changes and the chemical / biochemical changes. These reactions must take place in order, at the specified temperature, in the correct time and in the proper atmosphere. These reactions are as follows: Film formation, gas expansion, gas solubility reduction, alcohol evaporation, yeast action, carbon dioxide formation, starch gelatinization, gluten denaturation, sugar caramelization and browning reactions (Matz, 1960).

Although the presence of a film encasing the dough piece can be noticed during the steam proofing process, this film becomes much more apparent when the dough piece is first placed in the oven. The comparatively hot oven atmosphere causes the film to thicken and become more elastic. The elasticity of the film is a direct function of the moisture content of the oven atmosphere. Another physical phenomenon that begins as soon as the dough is placed in the oven is the reduction in the solubility of the entrapped gases. This is an important factor contributing to the product's oven spring. The gas most active in this reaction is carbon dioxide. In addition to being present in the dough as a free gas encased by the gluten structure,

much of the carbon dioxide is dissolved in the dough liquid or bound by weak forces to other dough constituents. As the internal loaf temperature rises to around 49°C, the dissolved and bound carbon dioxide is released. The hot oven atmosphere also immediately causes the gases contained within this elastic film and held by the gluten structure to expand. Last of the physical changes is the evaporation of liquids. The most important of these liquids are water and alcohol. The water enters the process as a liquid and leaves as liquid and water vapor. The ethyl alcohol is produced during the fermentation process by the action of the yeast on some of the sugars in dough. When the internal dough temperature reaches 80°C, the alcohol begins to evaporate, increasing the internal vapor pressure and further contributing to the oven spring (Matz, 1960).

The yeast action is a continuing one that begins in the fermentation room. It ends in the oven when the internal loaf temperature reaches around 63°C. The principal products of yeast action are carbon dioxide and ethyl alcohol. The production of the carbon dioxide is accelerated as the loaf temperature increases to the 63°C. This also must be considered as another factor contributing to oven spring (Matz, 1960).

When starch and cold water are mixed, the starch will absorb about 30% of its weight in water. Although the granules swell slightly, the water can be removed and the starch dried to its original state without any permanent change. As the mixture is heated to 54°C, an irreversible change takes place. The starch granules begin to absorb water very rapidly and swell until they become several times their original size. This reaction is known as gelatinization (Zallie, 1988).

The proteins making up the gluten of the dough are subject to an irreversible denaturation when they are brought to high temperatures. This denaturation is characterized by decreased solubility and extensibility of the protein fibers. As a result, the vehicle walls become more or less fixed, and expansion virtually ceases. This reaction begins at 74°C (Matz, 1960).

When sugars such as fructose, maltose and dextrose are heated to around 171°C, the molecules combine to form colored substances called caramels. This reaction, known as caramelization, can only take place in the crust because the internal loaf (crumb) temperature never exceeds 100°C. The browning reaction starts at around 160°C. It is the result of heating reducing sugars with proteins or other nitrogen-containing substances to form compounds called melanoidins. Melanoidins look like caramels, and at the lower temperature taste similar to caramels (Matz, 1960).

1.3 Problems in Microwave Baking

Baking is a complex process that brings about a series of physical, chemical, and biochemical changes in food such as gelatinization of starch, denaturation of protein, liberation of carbon dioxide from leavening agents, volume expansion, evaporation of water, crust formation and browning reactions. It can be described as a simultaneous heat and mass transfer within the product with the environment inside the oven (Sumnu, 2001).

Quality problems associated with microwave baking include dense or gummy texture, crumb hardness and an undesirable moisture gradient along a vertical axis in the final baked product (Bell and Steinke, 1991). One of the reasons for these problems is that physicochemical changes and interactions of major ingredients, which would normally occur over a lengthy baking period in a conventional system, can not always be completed during the short baking period of a microwave system (Hegenbert, 1992). Other reasons are specific interactions of each component in the formulation with microwave energy (Goebel et al., 1984).

The biggest difference between convection ovens and microwave ovens is the inability of the microwave ovens to induce browning. The cool ambient temperature inside a microwave oven causes surface cooling of microwave-baked products and low surface temperature prevents Maillard browning reactions to occur, which are responsible for the production of many flavored and colored compounds (Decareau,

1992; Hegenbert, 1992). Brown surfaces, produced by the Maillard reaction and caramelization of sugars, are a result of high temperatures accompanied by dehydration (Burea et al., 1987). When the samples are heated in microwave oven for a longer period, they become dry and brittle but never brown. In order to eliminate the crust color problem, Lorenz et al. (1973) emphasized the importance of bread formulation by using relatively dark doughs (rye, whole-wheat). Hybrid or multimedia ovens combining impingement with microwaves have been introduced so as to overcome the problem related to crustless or unacceptable color of products baked using microwaves (Smith, 1986; Walker and Li, 1993). Susceptors which consist of a metallized plastic film laminated to paperboard on top of which, or within which, the sample is placed and have the property of absorbing microwave energy and converting it to heat, which is transferred to the sample by conduction or radiation can also be used to achieve effective browning and crispness (Zuckerman and Miltz, 1992; Zincirkiran et al., 2002).

The short microwave baking time may also influence flavor development, as the flavor compounds may not have the opportunity to develop as they would under conventional baking. Microwave energy causes different flavor components to become completely volatilized at different rates and in different proportions than occurs during conventional heating. It was also found that different chemical reactions take place during microwave cooking as opposed to conventional cooking; in this way different flavors are produced (Sumnu, 2001).

Compared to conventional heating, moisture flows due to concentration and pressure gradients are significantly altered during microwave heating. Relatively larger amounts of interior heating result in increased moisture vapor generation inside the food material, which creates significant interior pressure and concentration gradients. This result in higher rate of moisture losses during microwave heating, creating an outward flux of rapidly escaping vapor (Datta, 1990). Breads and cakes baked in microwave oven were shown to lose more moisture as compared to conventionally baked ones (Sumnu et al., 1999; Zincirkiran et al., 2002).

Conventional formulations of bread or bread-like doughs develop unacceptable textures when baked in the microwave oven (Lorenz et al., 1973; Ovadia and Walker, 1996). The exterior parts are rubbery and tough and the interior parts are firm and difficult to chew (Shukla, 1993). Firmness and toughness are two separate properties. Firmness can be defined as the force required to compress a given area by 25% of its thickness. Toughness can be defined as the exertion required to pull a slice of bread apart (Ovadia and Walker, 1996). Toughness is related to gluten while firmness is related to starch granules. The firmness problem of bread interiors is associated with the large diameter, preswollen starch granules. Addition of fat and emulsifiers were shown to reduce the firmness of microwave baked breads (Ozmutlu et al., 2001a,b). More amylose was shown to leach out during microwave baking of breads and cakes as compared to conventional baking (Higo and Naguchi, 1987; Seyhun, 2002). This also explains why the initial texture of microwave baked breads are firmer. The interaction of gluten with microwaves has an adverse effect on firmness and toughness of microwave baked breads (Yin and Walker, 1995). Microwave baked breads containing low gluten were shown to be softer than the ones containing high gluten (Ozmutlu et al., 2001b). Solutions to the problem of toughening on the exterior involve depolymerizing the gluten protein i.e. reducing the size of the gluten proteins by breaking the peptide bonds. Designing a low moisture dough in which water activity is further reduced by salts and dextrose addition of texturizing agents helps to obtain a more uniform texture in microwave baked breads (Shukla, 1993).

Breads baked in microwave oven stale faster compared to the ones baked in conventional ovens. This behavior is known as “Higo Effect” (Higo et al., 1983). The Higo effect is, the hypothesis that more amylose is leached out of starch granules when bread is heated by microwaves. This amylose was found to be more disoriented and contained less bound water than in conventionally heated bread. Upon cooling, the surrounding amylose molecules align and contribute to crumb firmness. With microwave-heated bread, amylose is better able to realign into a more crystalline structure than conventionally heated bread and become harder very rapidly (Ovadia, 1994).

Additional product development will be necessary in order to form microwave-baked products that will have the same volume, texture and eating quality as those associated with conventionally prepared ones. Conventional formulations can be improved or a new formulation can be designed by using some additives to solve the problem of toughness or firmness in microwave baked breads. Processing conditions and mechanisms can also be adjusted to decrease the firmness in microwave-baked breads. Combination heating may be a solution to improve the quality of microwave baked products.

1.4 Enzymes in the Baking Industry

Enzymes are widely used as technological aids in several food processes. Rapid advances in biotechnology have made new enzymes available for the baking industry (Maarel et al., 2002). In recent years, the baking industry has focused its attention on the replacement of several chemical compounds by enzymes, since they are clean label compounds (Haros et al., 2002). Since the main task of the baking industry is to provide a wide range of high-quality products for the consumer and enzymes are one of the additives used for this aim, their use is continuously increasing (Poutanen, 1997).

Different enzymes are currently added to the bread making process for improving dough handling, fresh bread quality and the shelf life (Haros et al., 2002). Additionally, several enzymes have been suggested to act dough and/or bread improvers, by modifying one of the major dough components (Maarel et al., 2002). Enzymes have not been targeted specifically to produce browning reactions, although this might be a desirable property, especially in microwavable products. In some applications, specific exogenous enzymes are added primarily to improve the aroma. (Poutanen, 1997).

Microbial enzymes are being increasingly used to facilitate processing and to achieve improved and uniform product quality. Although enzymes act at a molecular

level, they are able to induce remarkable changes in both the microstructure and the functional properties of cereal foods.

1.4.1 α-Amylase

The main application of amylases in baking is bread making. Literature data show that amylases can be used to improve or control dough-handling properties and product qualities (i.e. volume, color, shelf life). Volume and anti-firming are the keys to the success of amylases (Hamer, 1995).

The level of fermentable monosaccharides and disaccharides in wheat flour is low. This level of fermentable sugars is not sufficient for bread production of an appropriate volume and desired sensory properties. Bread volume, bread crumb structure and bread crust color depend significantly on the quantity and type of the amylolytic enzymes present in flour, these enzymes are responsible for hydrolysis of starch to sugars. β-amylase is prevalent in wheat flour, however the amount of α-amylase is negligible and it is necessary to supplement the flour with a certain amount of α-amylase. α-Amylases from cereals, fungal and bacterial sources have been investigated for their use as additives in bread baking. Although all three types attack gelatinized starch they differ in two important features: heat stability and distribution of the resultant oligosaccharides in baked bread (Zobel and Kulp, 1996). On account of its thermoinstability, fungal α-amylase has certain advantages such as the risk of an overdose is smaller and the activity of enzymes is permanent and standardized (Curic et al., 2002). On the contrary, bacterial α-amylases are thermostable and, and if not carefully dosed, may result in the overproduction of dextrins during baking. This would cause a sticky bread crumb (Zobel and Kulp, 1996; Poutanen, 1997).

Fungal α-amylases have a long history of use as flour improvers. Amylases from fungal sources act on damaged starch reducing its ability to immobilize water, thus increasing dough mobility and resulting in improved dough handling (Martinez and Jimenez, 1997). The enhanced production of fermentable sugars increases yeast

growth and thus the power to produce carbon dioxide (Martinez and Jimenez, 1997; Maarel et al., 2002). The enzyme-induced changes in dough rheology are also an important reason for the increased bread volume. α-Amylase may prolong the period of dough expansion in the oven, increasing the maximum dough-piece height and loaf volume (Cauvain and Chamberlain, 1988). This effect of fungal α-amylase has been reported by some researchers (Maninder and Jorgensen, 1983; Kuracina et al., 1987).

The mechanism of bread firming is still unknown, but the importance of starch recrystallization, is obvious. One suggested explanation of the positive effects of α-amylase in reducing staling is that the enzyme produces low molecular weight branched-chain starch polymers as hydrolysis products, which interfere with amylopectin recrystallization. As α-amylases are starch hydrolysing enzymes, they could disrupt the starch network and thereby decrease the amount of available starch for retrogradation and cause reduction in firmness (Duran et al., 2001). It has also been suggested that the dextrins interfere with the interactions between the swollen starch granules and the continuous protein network in the bread and retard staling (Martin and Hoseney, 1991; Akers and Hoseney, 1994).

1.4.2 Xylanase

One of the other groups of enzymes in breadmaking hydrolyses non-starch polysaccharides. Modification of initial structures of wheat non-starch polysaccharides through enzyme addition usually affects the dough and bread characteristics. Pentosanase activity was reported to improve gluten elasticity and final bread quality (Haros et al., 2002).

The improving effect of pentosanases on bread volume has been associated with a better gas retention during proofing, probably due to the action of enzyme in reducing the viscosity of the gelling starch and allowing greater and longer expansion in the oven before enzyme inhibition and protein denaturation (Martinez and Jimenez, 1997). Similarly, Rouau et al. (1994) reported that pentosanase

containing enzyme preparation produced improved and more uniform bread quality and Krishnarau and Hoseney (1994) showed that pentosanase preparation increased the loaf volume of wheat bread enriched with insoluble pentosans.

According to Maat et al. (1992), the positive effect of xylanase on bread volume was due to the redistribution of water from the pentosan phase to the gluten phase. The increase in the volume of the gluten fraction increases its extensibility, which will result in better ovenspring.

Haros et al. (2002) reported that the presence of all carbohydrases (cellulase, xylanase, β-glucanase) tested led to breads with higher specific volume and lower firmness compared to the control.

Hamer (1995) suggested that pentosanases could have a specific action on the rate of gluten formation and the quality of the gluten. This may explain the reported beneficial effect of pentosanases on crumb structure.

Xylanases are known to have an anti-staling action during bread storage but their action is not clear. The improving action of xylanase might be primarily attributed to the hydrolysis of the cell wall polysaccharides of the wheat grain. The monosaccharides and oligosaccharides resulting from the enzyme action could affect the water balance and may interfere with protein-starch interaction during bread storage, in the same way as specific dextrins have been described to interfere in the amylopectin retrogradation (Haros et al., 2002). On the other hand, Kim and D'Appolonia (1977) observed that pentosans decreased the staling rate with the water-insoluble pentosans exerting a more pronounced effect than the water-soluble pentosans. This is in conflict with claims that pentosanases retard staling.

The synergistic combination of xylanases with amylase has proven to be beneficial and is used in many improver formulations (Haseborg and Himmelstein, 1988; Rouau et al., 1994; Hammond, 1994; Hamer, 1995).

1.4.3 Lipase

Lipases can produce mono and diglycerides from lipids, which improve crumb softness of bread. Addition of specific lipases in combination with triglycerides also improves loaf volume, crumb softness and staling rate (Gil et al., 1999). Microbial lipases are used in shelf-life prolongation (Vulfson, 1994) and for flavor improvement (Kazlauskas and Bornscheuer, 1998) in industrial applications of bakery products.

Hamer (1995) reported that no effects of lipase were observed on color, taste or crumb texture of breads, but freshness was significantly increased.

It has been stated that monoglycerides basically control the rate of moisture transfer during bread storage and, that during baking, emulsifiers increase the retention of moisture in the heat-coagulated gluten, giving greater initial crumb softness (Waldt, 1968).

The generally accepted theory about the mechanism of antistaling action of monoglycerides is based on the ability of monoglycerides to form complexes with amylose and amylopectin. Additionally, the antifirming effect of emulsifiers was attributed to mainly the weakened cohesion between the swollen starch granules, which are rich in amylopectin (Zobel and Kulp, 1996). Similarly, Lagendijk and Pennings (1970) reported that the antistaling function of an emulsifier was due to their interaction with amylopectin that prevented amylopectin crystallization.

According to Stampfli and Nersten (1995), the mechanism of monoglycerides in retarding the firming process is based on the ability of monoglycerides to form complexes with amylose. This amylose monoglyceride inclusion complex is insoluble in water. Therefore, the part of the amylose, which is complexed by the monoglycerides, does not participate in the gel formation, which normally occurs with the starch in the dough during baking. Therefore, upon cooling, the complexed

amylose will not recrystallize and will not contribute to staling of the bread crumb (Thamstorf, 1983).

Pisesookbuntern and D' Appolonia (1983) reported that monoglycerides retarded the rate of bread firming rather than decreasing the initial bread firmness. However, Schoch (1965) showed that monoglycerides were effective on the initial bread firmness but not on the bread firming rate. In another study, it was shown that monoglycerides both decreased the initial bread crumb firmness and retarded the rate of bread firming (Valjakka et al., 1994).

1.4.4 Protease

Proteases help to break down the gluten protein so that the dough is softer and more extensible. The actions of proteases on bread processing are:

1. Reduced mixing time since there is less resistance to mixing,
2. Improved flow characteristics of the dough,
3. Improved machining properties, protease treatment substantially lessens the machining difficulties experienced with very tight doughs,
4. Improved gas retention, the increased extensibility and pliability of the gluten film help it to retain the gas that evolves in the system better during processing (Mathewson, 2000).

Similarly, Singh et al. (1978) noted that the presence of proteases increased tolerance to mixing but lowered the resistance of the doughs. Dough handling was much easier, and fermentation was accelerated. Moreover, proteases have been shown to reduce the viscosity of dough with the cleavage of peptide bonds by releasing free water caused by the high water binding capacity of gluten (Haseborg, 1981).

Proteases can be used to assure bread dough uniformity and help controlling of bread texture and improve flavor (El-Dash and Johnson, 1967; Hamer, 1995).

The effects of gluten protein on the firmness of bread have been explained by several researchers. Martin et al. (1991) suggested that bread firming could be caused by interactions of starch and protein. Similarly, Inagaki and Seib (1992) showed that during baking or aging of bread, interactions between swollen starch granules and the gluten matrix somehow occur. During aging of the bread, amylopectin recrystallizes resulting in increased rigidity of the starch granule and decreased flexibility of the gluten matrix. All these changes seem to contribute to crumb firming (Valjakka et al., 1994; Zobel and Kulp, 1996). As proteases modify gluten protein, these interactions are weakened and firming is decreased.

Since proteases cause the cleavage of peptide bonds, they have ability to give new amino groups such as substrate to Maillard reactions; which contribute to development of crust color and product flavor (Mathewson, 2000). Similarly, El-Dash and Johnson (1967); Ruttloff and Drechsel (1975) have suggested that proteases affected the organoleptic properties of products as well as texture and their main effect was to cut the peptide chains and free the amino acids, resulting in enhanced color and flavor.

Hamer (1995) suggested that by the usage of proteases, fermentation time was shortened and the amount of carbon dioxide produced increased. The color of the crust, aroma of the products, and texture, density, softness, and tenderness of the crumb were improved.

1.5 Staling

All undesirable changes that occur upon storage together are called staling. Although different approaches have been brought up to clarify the staling mechanism and to prevent it, the phenomenon of staling is still not completely understood (Stampfli and Nersten, 1995). When it was contemplated from the economical point of view, staling has considerable economic importance for the baking industry since it limits the shelf life of baked products (Maarel et al., 2002).

1.5.1 Bread Staling

Bread staling refers to all changes that occur in bread after baking. Changes occur in both crumb and crust of the bread (D'Appolonia and Morad, 1981). Staling of bread is affected by various components in wheat flour (Kim and D'Appolonia, 1977). Staling is a phenomenon, which describes the deterioration of bread quality during storage (Stampfli and Nersten, 1995). They have showed that consumers associate staling with some typical sensorial changes in the bread such as loss of flavor, loss of crispness in the crust, increased crumbliness and crumb firmness.

Bread crumb firming is probably the change most widely associated with staling. Investigations in the causes of bread staling have shown that changes in starch structure, namely, gelatinization and retrogradation of starch contribute to texture from soft to firm (Bloksma and Bushuk, 1988).

Schoch (1965) suggested that bread staling was due to the gradual association of amylopectin within the swollen granules, as differentiated from the leached out amylose, which had formed a gel structure between the granules immediately after baking, whereas according to Ghiasi et al. (1984), firming was not solely a result of amylopectin retrogradation. Factors other than amylopectin retrogradation have been considered as possible contributors to bread staling. Similarly, it was suggested that bread staling could be caused by progressive cross binding between protein and swollen residues of starch granules, mediated by amylose molecules leached out during baking (Martin, 1989; Martin et al., 1991; Martin and Hoseney, 1991). Inagaki and Seib (1992) found that firming occurred even when the starch contained no amylose and they instead proposed that interaction between swollen starch granules and the gluten matrix might occur during aging of the bread.

Staling mechanism of breads baked in microwave oven is required to be well understood to have an idea about staling mechanism of breads baked in halogen lamp-microwave combination oven. The changes of bread with microwave heating are complex and many changes such as microwave induced gluten changes and a decrease in moisture content occur simultaneously. It has been difficult to clarify the

phenomenon of rapid staling of microwave heated bread by simply comparing changes in the physical properties of microwave treated and non-microwave treated bread, because they are different in degree of gelatinization and moisture content. The rapid hardening and the decrease in the desired crispy texture of bread heated by microwaves are common for microwave baking. The reason of rapid hardening of microwave-heated bread is mainly leaching out of more amylose during microwave baking as compared to conventional baking. Moreover, microwave heating increases the staling rate of bread and this is caused primarily by a decrease in moisture content of the bread as a result of high moisture loss during microwave treatment (Yamauchi et al., 1993).

Higo et al. (1983), explains the rapid staling of microwave-baked breads with respect to conventionally baked bread with the "Higo Effect". The Higo Effect is the hypothesis that more amylose is leached out of starch granules when bread is heated by microwaves. This amylose has been found to be more disoriented and contained less bound water than in conventionally heated bread. Upon cooling, the surrounding amylose molecules align and contribute to crumb firmness. With microwave-heated bread, amylose is better able to realign into a more crystalline structure than conventionally heated bread. Microwave-heated bread therefore becomes much harder very rapidly (Ovadia, 1994).

1.5.2 Retardation of Staling of Breads

In commercial bread production, strategies can be employed to extend bread freshness. Practical measures such as formulation modifications, variation of production parameters and use of various production methods, should be taken into consideration (Zobel and Kulp, 1996). The mostly used strategy in retarding the staling of breads is modification of formulation. There are various studies on this phenomenon.

Ingredients have different effects on bread staling, such as emulsifiers, sugars, shortening and enzymes. But since bread is a complex medium and all the ingredients interact with each other, it is difficult to estimate their specific effects on

bread texture. Maleki et al. (1981) investigated the effects of emulsifiers, sugar and shortening levels on the staling of bread. Many researchers have shown that monoglycerides of higher fatty acids are effective softening agents for bread (Bechtel, 1955).

Different enzymes are currently added to the bread making process for improving dough handling, fresh bread quality and also the shelf life (Haros et al., 2002). α-Amylases have been found to be effective in reducing staling by many researchers (Martin and Hoseney, 1991; Akers and Hoseney, 1994). Xylanases were found to have an anti-staling action during bread storage (Haros et al., 2002). It has been observed that addition of specific lipases in combination with triglycerides also improves loaf volume, crumb softness and staling rate (Gil et al., 1999).

Starches, either native or modified, have been applied to improve food texture and to retard firming after storage (Moore et al., 1984). The effects of starches on retarding the firming of breads have been investigated by several researchers (Johnson and Miller, 1959; Jankowski and Jankiewiez, 1961; Herz, 1965; Moore et al., 1984; Snyder, 1984).

Hamer (1995) demonstrated that hydrocolloids like xanthan and guar gums retarded firming.

The baking temperature of breads has been shown to affect bread staling (Giovanelli et al., 1997). The staling rate was lowered by decreasing the baking temperature both in terms of crumb hardening and starch retrogradation.

1.6 Objectives of the Study

The main objective of the study was to investigate the effects of different enzymes on the quality and staling of breads baked in different ovens (halogen lamp-microwave combination, microwave and conventional). Although, there are various studies about the investigation of the effects of enzymes on quality of breads baked in conventional oven there is not any information in the literature about the effects of

enzymes on quality of breads baked in either microwave or halogen lamp-microwave combination ovens.

In the first part of the study, it was aimed to compare the quality of breads baked in different ovens (conventional, microwave, halogen lamp and halogen lamp-microwave combination oven). The optimum baking conditions of breads baked in microwave, halogen lamp and halogen lamp-microwave combination ovens were determined to obtain breads having comparable quality with that of conventionally baked ones. In the second part of the study, the effects of enzymes on the quality of breads baked in conventional, microwave and halogen lamp-microwave combination ovens were investigated.

Microwave heating is known to cause quality problems in baked products. The most obvious defects are the absence of brown crust formation, firm texture and rapid staling. Therefore it was aimed to improve the quality, especially the color of microwave baked products by using halogen lamp-microwave combination oven. Moreover, enzymes were used to reduce the firmness and rapid staling problems of microwave and halogen lamp-microwave combination baked products.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

Bread flour was supplied from Ankara Un, Turkey. Flour contains 32% wet gluten, 13.1% moisture and 0.55% ash. All the other ingredients were supplied from a local market.

Four different types of enzymes were used to compare their effects on quality of breads baked in different ovens. These enzymes were fungal α-amylase (ORBAMIL ES 10X), xylanase (ORBAZIM HC 1000), lipase (ORBAZIM HC 120Y) and protease (ORBAPROTEASE P) and obtained from ORBA^{TM} Biokimya Sanayi ve Ticaret A.Ş., Turkey.

2.2 Preparation of bread dough

The composition of the dough containing no enzyme was on flour basis; 100% flour, 8% sugar, 6% milk powder, 2% salt, 3% yeast, 8% margarine, 55% water.

Dough was prepared by using straight dough method. This method is the simpler one, which is a single step process. All the ingredients are mixed together in a single batch. After mixing, there is fermentation step. During fermentation step dough is taken out of the incubator and punched, then fermentation continues. The

fermented dough is then divided and shaped. After this step, proofing takes place, which is defined as last fermentation. Then, the samples are ready for baking.

Before preparing the dough, the surrounding temperature of the laboratory was adjusted to 26 ± 2 ^{o}C by using a heater. First of all, the dry ingredients were mixed. Yeast was dissolved in water at 30 ^{o}C. Margarine was melted and added to the dry ingredients in liquid phase together with dissolved yeast. Water at 30 ^{o}C was added to the mixture. All the ingredients were mixed by a mixer (Kitchen Aid, 5K45SS, USA). Final dough temperature and pH were measured as 27 ± 1 ^{o}C and 5.57 ±. 0.01, respectively.

After complete mixing of the dough, it was placed into the incubator (Nüve EN 400, Turkey) for fermentation. The total duration of the fermentation was 105 minutes. After the first 70 minutes, the dough was taken out of the incubator, punched and placed into the incubator again. A second punch took place at the end of the fermentation. The incubation conditions, temperature and relative humidity in the incubator were 30 ^{o}C and 85%, respectively. Relative humidity was adjusted by using saturated potassium chloride solution placed on the bottom of the incubator. The humidity was controlled by a hygrometer (Nel RH 1300, Turkey).

After punching the fermented dough for the second time, the dough was divided into 50 g pieces in greased glass baking pans (8.5cm in diameter) lined with wax paper. Each piece was shaped and placed into the incubator for the last time for 20 minutes under the same incubation conditions. Then, the dough samples were ready for baking.

2.3 Determination of Power of Microwave Oven

IMPI 2-liter test was used. The oven was operated on the highest power with a load of 2000±5g of water placed in two 1L Pyrex beakers. Initial water temperature should be 20±2 °C. The beakers were placed in the center of the oven, side by side in the width dimensions of the cavity. The oven was turned on for 2 min and 2 s. Final

temperatures were measured immediately after the oven was turned off. The power measurement was replicated three times. The power was calculated by using Equation 2.1.

$$P(W) = \frac{70(\Delta T_1 + \Delta T_2)}{2} \quad (2.1)$$

where ΔT_1 and ΔT_2 are the temperature rises of the water in the two beakers calculated by subtracting the initial water temperature from the final temperature (Buffler, 1993).

2.4 Determination of Optimum Baking Conditions in Different Ovens

Full factorial design was performed and the reported data were the average of three replications. As independent variables, different baking times and temperature for conventional oven, microwave power for microwave oven, halogen power for halogen lamp oven and microwave power and halogen power for combination oven were used. The optimum baking conditions were determined for different types of ovens. In these experiments no enzyme was added to the dough.

2.4.1 Conventional Oven

Conventional baking was performed in a commercial electrical oven (Arçelik ARMF 4 Plus, Turkey). The prepared dough samples were baked at 175 ^{o}C, 200 ^{o}C and 225 ^{o}C for 12, 13 and 14 minutes. The oven was preheated before placing the dough samples into it. Four breads were baked at a time. Breads baked at the optimum condition were used as control.

2.4.2 Microwave Oven

The halogen lamp-microwave combination oven (Advantium oven^{TM}, General Electrics, USA) was used by only operating the microwave power (Figure 2.1). The power of microwave oven has been determined as 706 W by using IMPI 2-

liter test (Buffler, 1993). The efficiency of the oven was 74%. The independent variables were microwave power and baking time. Dough samples were baked at 50% power for 0.5, 0.75, 1.0, 1.5 and 2.0 minutes; and at 100% power for 0.5, 0.75 and 1.0 minutes. Only one bread was baked at a time.

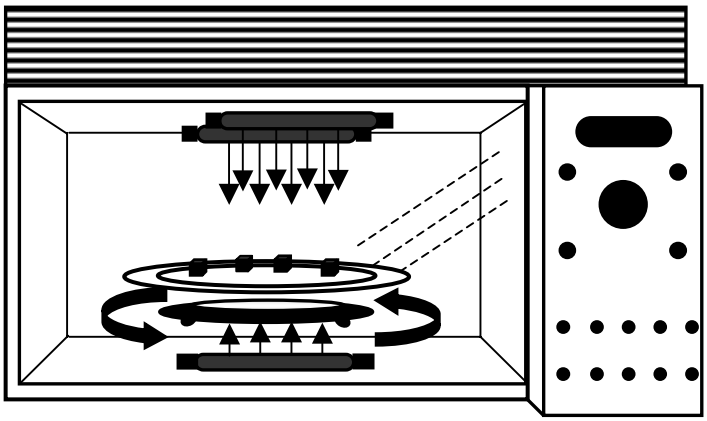

Figure 2.1 The figure of halogen lamp-microwave combination oven

2.4.3 Halogen Lamp Oven

Halogen lamp-microwave combination oven (Advantium oven^{TM}, General Electrics, USA) was used by only operating the halogen lamps. The oven consists of two 1500W halogen lamps above and one 1500W halogen lamp below. Halogen lamps at the top and bottom were operated at the same power during halogen lamp baking. Dough samples were baked at 50% power for 10, 11, 12, and 13 minutes, at 60% power for 7, 8, 9, and 10 minutes and at 70% power for 6, 7, 8 and 9 minutes. Only one bread was baked at a time.

2.4.4 Halogen Lamp-Microwave Combination Oven

Halogen lamp-microwave combination oven (Advantium oven^{TM}, General Electrics, USA) combines microwave and halogen lamp heating in the oven. The prepared dough samples were baked at 60% halogen power–50% microwave power for 1.5, 2.0, 2.5 and 3.0 minutes; at 70% halogen power–30% microwave power for

2.5, 3.0, 3.5 and 4.0 minutes; at 60% halogen power–30% microwave power for 3.0, 3.5, 4.0 and 4.5 minutes; at 50% halogen power–30% microwave power for 3.5, 4.0, 4.5 and 5.0 minutes; at 40% halogen power–30% microwave power for 3.5, 4.0, 4.5 and 5.0 minutes. Only one bread was baked at a time.

2.5 Effects of Enzymes on Quality of Breads Baked in Different Ovens

Full factorial design was performed and the reported data were the average of three replications. Independent variables were enzyme type (α-amylase, xylanase, lipase and protease) and baking method (conventional, microwave and halogen lamp-microwave combination baking). In investigating the effects of enzymes on quality of breads, the optimum baking conditions determined for different ovens at the previous parts of the study were used.

Enzymes were added to the flour and flour was kept at room temperature, 20 ± 2 ^{o}C for 5 hours. α-Amylase was added to the flour, as 5g / 100kg flour, xylanase, as 7.5g / 100kg flour, lipase, as 0.6g / 100kg flour and protease, as 60g / 100kg flour as recommended by the company supplying these enzymes.

2.6 Effects of Enzymes on Staling of Breads Baked in Different Ovens

After baking at the optimum baking conditions for different types of ovens, the breads were cooled at room temperature (20 ± 2 ^{o}C) for 1 hour. After cooling, the breads were wrapped with stretch film and stored at 20 ± 2 ^{o}C for 2 days.

2.7 Quality Measurements

In determining the optimum baking conditions for different types of ovens and investigating the effects of enzymes on quality of breads baked in these ovens, the quality parameters measured were weight loss, specific volume, crumb firmness and crust color of breads. For fresh samples, all the measurements except weight loss were done after cooling of breads at room temperature (20 ± 2 ^{o}C) for 1 hour.

2.7.1 Weight Loss

Weight loss measurements were done just after baking and calculated by using the following equation:

$$\text{Weight loss (\%)} = \frac{W_i - W_f}{W_f} \times 100 \qquad (2.2)$$

where W_i was the weight of the dough before it was placed into the oven and W_f was the weight of the baked bread immediately after it was removed from the oven.

In the investigation of the effects of enzymes after baking and during storage, moisture content in wet basis was used.

2.7.2 Specific Volume

Bread specific volume was determined by the rape seed displacement method (AACC, 1988). First, bulk density of rape seeds was determined by filling a glass container, whose volume is known, uniformly with rape seeds through tapping and smoothing the surface with a ruler. All measurements were done until the constant weight was reached between three consecutive measurements. Bulk density of rape seeds was found to be 667 kg/m^3. Then, breads and rape seeds were placed into the container. The container was tapped and the surface was smoothed with a ruler. Tapping and smoothing were continued until constant weight was reached between three consecutive measurements. Equation 2.3 is used to calculate the volume of breads.

$$W_{seeds} = W_{total} - W_{bread} - W_{container}$$
$$V_{seeds} = W_{seeds} / \rho_{seeds}$$
$$V_{bread} = V_{container} - V_{seeds} \qquad (2.3)$$

Specific volume of breads was calculated by using equation 2.4.

$$SV_{bread} = V_{bread} / W_{bread} \quad (2.4)$$

where W(kg) is weight, V(m^3) is volume, ρ(kg/m^3) is density and SV(m^3/kg) is the specific volume.

2.7.3 Crumb Firmness

Firmness of breads was measured using a universal testing machine (Lloyd Instruments LR 30K, UK). Breads were compressed for 25% at a speed of 55 mm/min. Bread samples were prepared according to the method of AACC (AACC, 1988). Firmness measurements were done on fresh (after cooling of breads for 1 hour) and stale (after 2 days storage) bread samples.

2.7.4 Color

Crust color of the bread samples was measured using a Minolta color reader (CR-10, Japan) using the Hunter L^*, a^*, and b^* color scale. Triplicate readings were carried out at room temperature from different positions of bread crust, and mean value was recorded. The L^* value represents 'lightness', from zero (black) to 100 (white). The a^* value represents, 'redness' or 'greenness' ranging from +60 to –60 while b^* value represents 'yellowness' or 'blueness' ranging from +60 to –60. Total color change (ΔE) was calculated from the following equation in which dough was used as the reference point, whose L^*, a^*, b^* value was denoted by L_0, a_0 and b_0.

$$\Delta E = [(L^* - L_0)^2+(a^* - a_0)^2+(b^* - b_0)^2]^{1/2} \quad (2.5)$$

2.8 Statistical Analysis

Analyses of variance (ANOVA) were performed to determine significant differences between different enzyme types ($p \leq 0.05$). Variable means were compared by Duncan' s Multiple Range test. At least three replications were done for each experimental condition. Data obtained from halogen lamp-microwave

combination oven were analyzed by multiple regressions to fit the second order equations to all dependent variables (SAS, 1988). Models were used to plot contour plots by using SAS.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Determination of Optimum Baking Conditions in Different Ovens

Breads were baked in conventional, microwave, halogen lamp and halogen lamp-microwave combination ovens to determine the optimum baking conditions in each one. Independent variables were baking time and baking temperature for conventional oven, oven power for the other ovens. The quality parameters that were used for the determination of optimum baking conditions were weight loss, crumb firmness, specific volume and color of breads.

3.1.1 Conventional Oven

Weight loss of the breads baked in conventional oven increased linearly with baking time (Figure 3.1). The coefficients of determination (r^2) for weight loss of breads baked in conventional oven for different baking temperatures were very high, ranging between 0.98 and 0.99 (Table A.1). It was previously shown by other researchers that breads (Zincirkiran et al., 2002) and cakes (Sumnu et al., 1999) baked in conventional oven lost weight linearly with baking time. The increase in temperature increased the weight loss of breads since samples were heated more at high temperatures, which increased the moisture loss. Similarly, Giovanelli et al. (1997) showed that higher moisture loss occurred during baking at higher oven temperature.

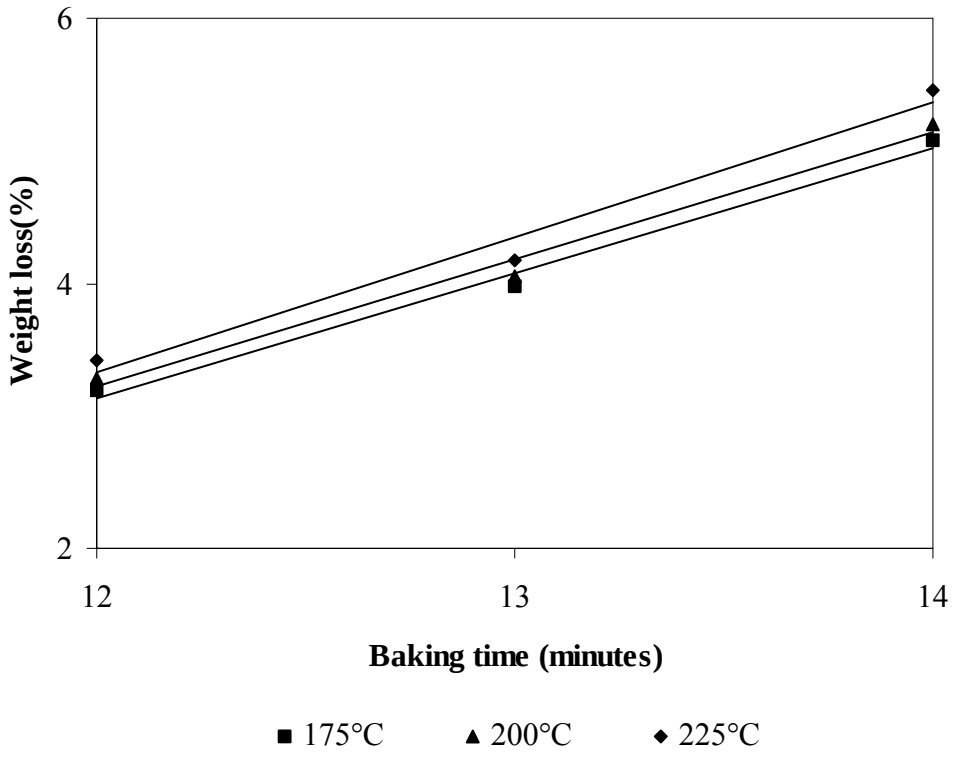

Figure 3.1 Variation of weight loss of breads during conventional baking at different temperatures

Variation of specific volumes of breads with baking time during conventional baking at different baking temperatures was shown in Figure 3.2. As baking time increased volume of the breads increased and then decreased by making a peak. This trend was also observed by other researchers (He and Hoseney, 1992). Modification of the proteinaceous matrix is required for optimum dough development and gas retention and this matrix requires sufficient crumb temperature and baking time for the occurrence of complex reactions, which causes the formation of this matrix (Pomeranz and Shellenberger, 1971). The lower specific volumes at shorter baking times might be due to the insufficient and low strength starch-gluten matrix formation, which can not retain the gases inside the dough. On the other hand, at the top of the peak, the matrix mentioned above might have sufficient strength to retain the gas inside which led to high expansion and breads with high specific volume. The starch-gluten matrix formation is due to starch gelatinization, gluten coagulation and other complex interactions among medium constituents (DeStefanis et al., 1977).

After a certain baking time specific volume of breads decreased because of drying and shrinking.

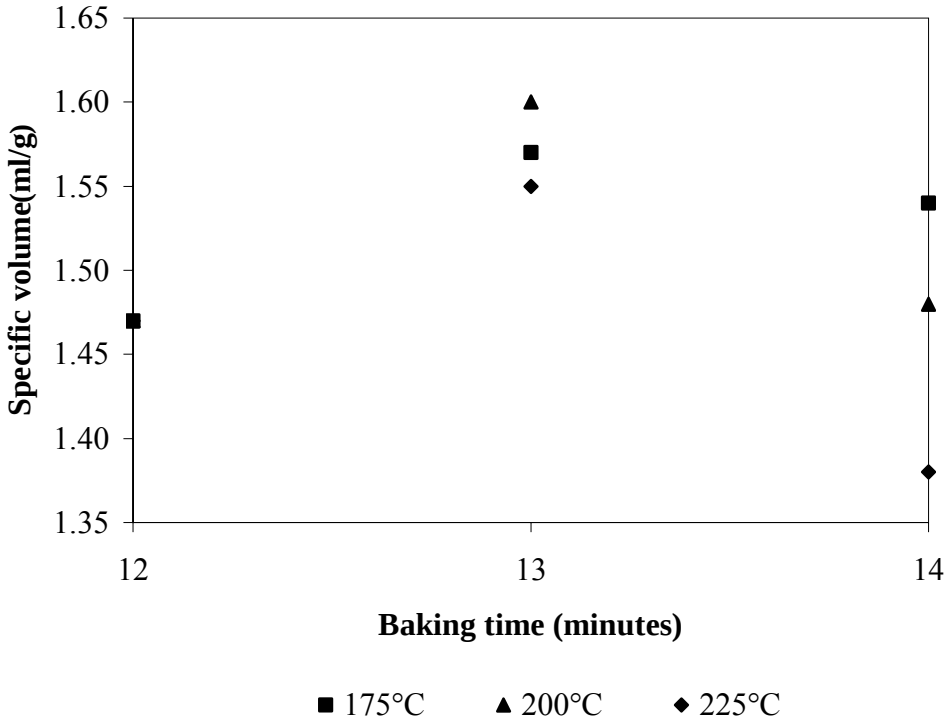

Figure 3.2 Variation of specific volume of breads during conventional baking at different temperatures

Figure 3.3. shows the variation of crumb firmness with baking time at different temperatures. As specific volume increased, crumb firmness decreased. Firmness was found to be negatively correlated with specific volume. The correlation coefficients between specific volume and crumb firmness were - 1.0, - 0.99, -0.94 for different baking temperatures, 175^{o}C, 200^{o}C, 225^{o}C respectively (Table B.1).

It was previously mentioned that in evaluating firmness measurements, specific loaf volume was an important variable. Axford et al. (1968) showed that firmness of breads decreased linearly with increasing specific volume.

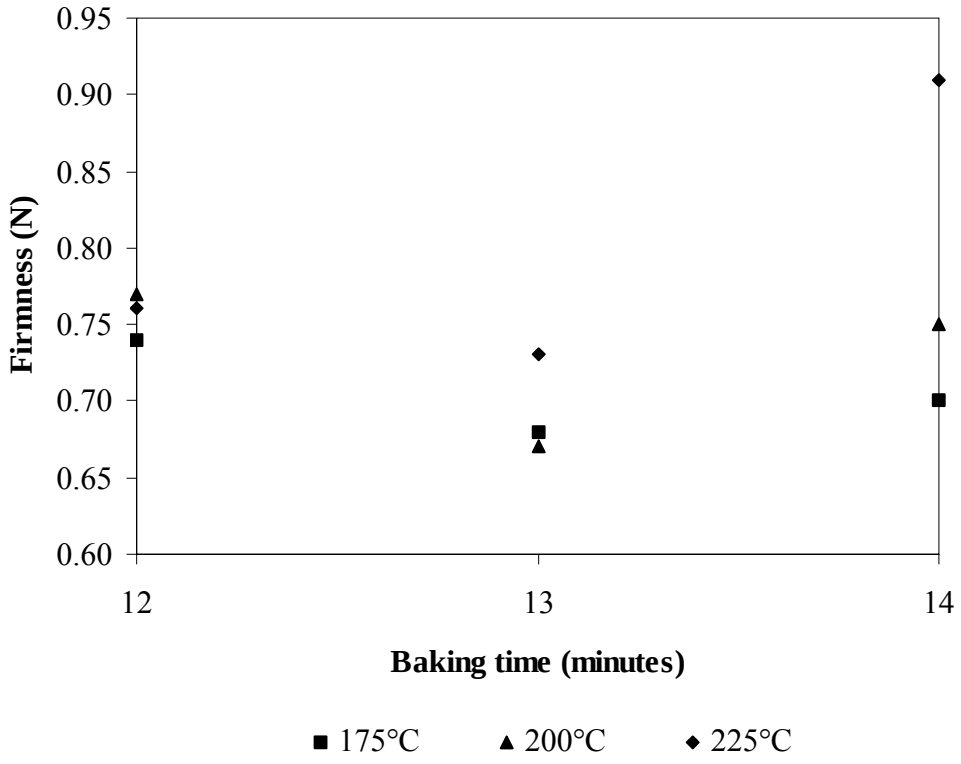

Figure 3.3 Variation of firmness of breads during conventional baking at different temperatures

The effects of baking time and temperature on ΔE value of breads which indicates how much the color of bread samples differ from that of the dough is shown in Figure 3.4. For the samples having similar colors with dough, ΔE value approaches to zero. When the color of samples are different from that of dough, ΔE values are expected to be higher.

ΔE value of the breads baked in conventional oven increased linearly with baking time (Figure 3.4). The coefficients of determination (r^2) for ΔE value of breads baked in conventional oven for different baking temperatures, 175^{o}C, 200^{o}C, 225^{o}C, were calculated as 0.92, 0.98 and 0.94 respectively. (Table A.2). As browning reactions of maillard reactions and caramelization require high temperatures and long processing times, the higher the baking time and temperature, the higher the ΔE value could be observed.

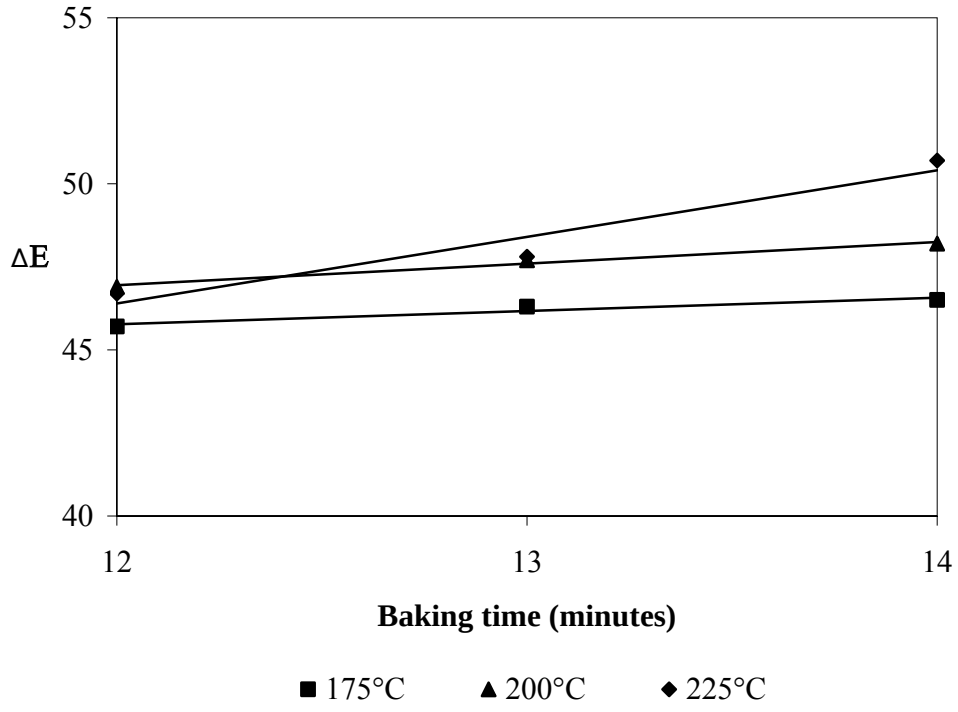

Figure 3.4 Variation of ΔE value of breads during conventional baking at different temperatures

Samples exposed to baking temperature of 225 ^{o}C showed a sharp increase in ΔE value. The rates of variation of ΔE values with respect to time for each baking temperature were given in Table A.2. It is known that as heat is transferred from outer to the inner side of the food sample in conventional ovens, the surface is the hottest part, so the surface temperature can reach the required values for browning. Higher baking temperatures provide the achievement of browning at the surface of breads in a shorter time.

The optimum baking conditions for conventional oven were determined by using specific volume and crumb firmness results and the acceptability of crust color of samples were also taken into account. It was previously demonstrated that firmness was one of the most important criteria since there was a strong correlation between crumb firmness and consumer perception of the freshness of white pan bread (Axford, et al., 1968). The condition giving the least firm and the most

voluminous breads was 13 min of baking at 200^{o}C and therefore, it was selected as the optimum condition for conventional oven.

3.1.2 Microwave Oven

Weight loss of the breads baked in microwave oven increased linearly with baking time (Figure 3.5). The r^2 values were 0.99 and 1.0 for 50% and 100% oven power treatments, respectively (Table A.3). It was previously shown by other researchers that breads (Zincirkiran et al., 2002) and cakes (Sumnu et al., 1999) baked in microwave oven lost weight linearly with baking time. Breads baked at 100% power had higher weight loss as compared to 50% power because as power was increased more microwaves were sent onto the bread samples during the same baking time resulting in more heating.

The rates of weight loss of microwave baked breads treated with different microwave powers were much higher than conventionally baked breads (Table A.1 and A.3). Relatively large amounts of interior heating create significant internal pressure and concentration gradients which increase the flow of liquid through the food to the boundary. Therefore, foods heated in the microwave oven lose more moisture than conventional heating (Datta,1990).

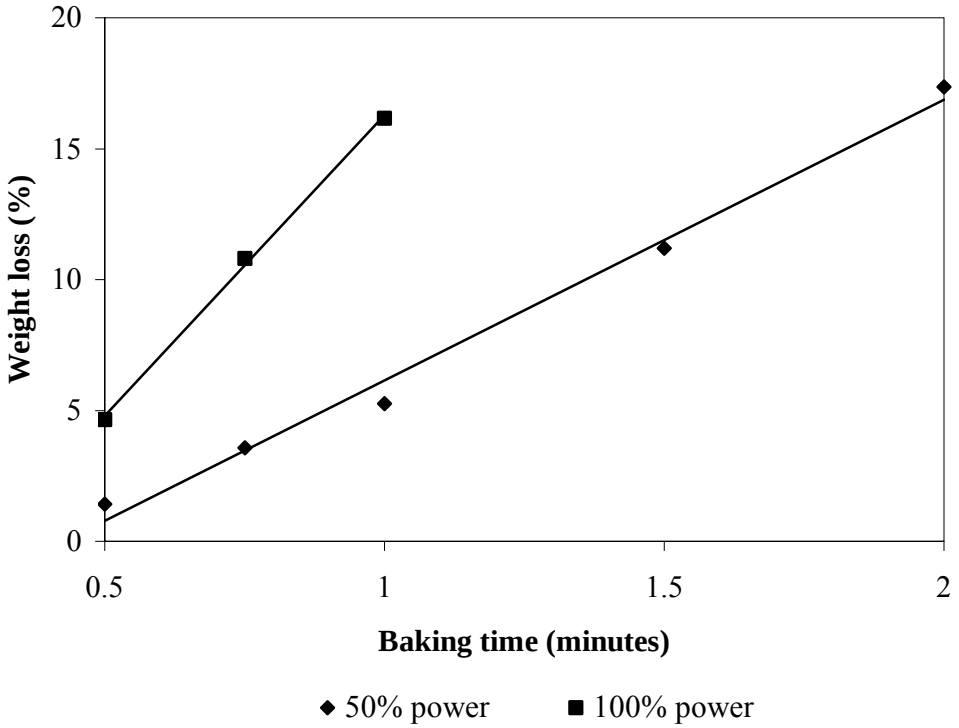

Figure 3.5 Variation of weight loss of breads during microwave baking at different oven powers

Variation of specific volumes of breads during microwave baking at different powers was shown in Figure 3.6. As can be seen from the figure, the volume expansion peak was similar to the one obtained during conventional oven treatment (Figure 3.2). The formation of starch-gluten matrix for gas entrapment and shrinkage during baking was effective for volume development.

Breads baked at 100 % power in microwave oven showed higher specific volume because of higher internal pressure and the temperatures obtained at high powers. Volume of microwave-baked cakes was shown to increase when the power of microwave oven was increased (Sumnu et al., 1999).

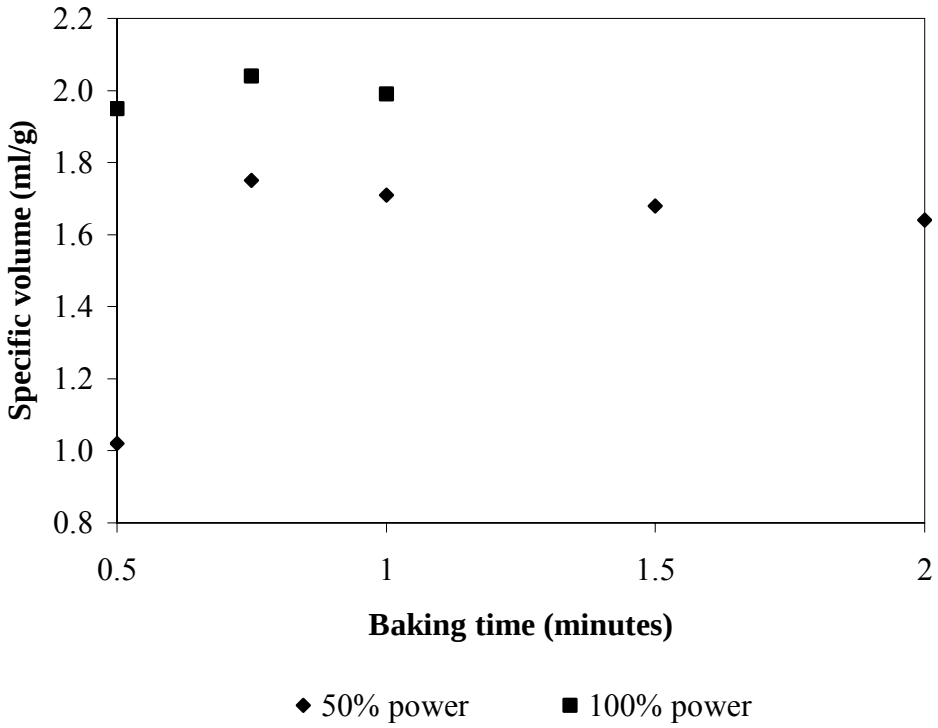

Figure 3.6 Variation of specific volume of breads during microwave baking at different oven powers

The specific volume of breads baked in microwave oven was found to be quite higher than that of conventionally baked ones (Figure 3.2 and 3.6). In microwave baking, relatively large amounts of interior heating create significant internal pressure, which might result in a puffing effect and a high volume. The internal vapor pressure produced by microwave heating caused expansion and puffing of carrots during microwave drying (Lin et al., 1998). Additionally, the bread structure was capable of retaining the gases produced and the high internal pressure inside. Since the mechanism of microwave baking is different from conventional baking, the internal pressure produced inside the porous product during microwave heating is incomparably higher than that obtained during conventional heating (Datta, 2001).

Figure 3.7. shows the variation of crumb firmness during microwave baking at different powers. The specific volume of breads was not found to be correlated with firmness during microwave baking. As time and power increased the effect of

moisture loss on firmness became more significant. High correlation was found between firmness and weight loss results (Table B.2). The rate of moisture loss was very high during microwave baking at 100% power which caused a sharp increase in firmness of breads. Therefore, specific volume and firmness of microwave baked breads were not found to be correlated.

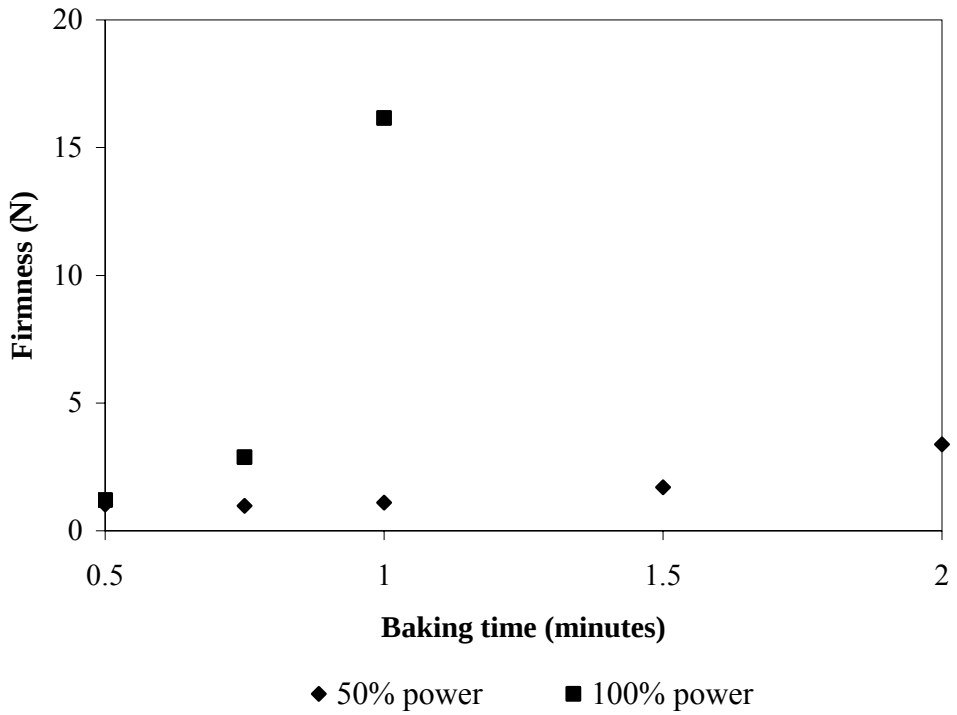

Figure 3.7 Variation of firmness of breads during microwave baking at different oven powers

Breads baked in microwave oven were found to be firmer than conventionally baked ones (Figure 3.3 and Figure 3.7). The reasons for firm texture in microwave baked breads are high moisture loss, interactions of microwave with gluten and high amylose leaching during baking (Higo and Noguchi, 1987; Shukla, 1993). Various studies showed that microwave baked products were firmer than conventionally baked ones (Ovadia and Walker, 1996; Ozmutlu et al., 2001b; Seyhun, 2002).

The effects of baking time and oven power during microwave baking on ΔE value were shown in Figure 3.8. There was no significant difference between ΔE values of breads baked in microwave oven with different baking times and oven powers. All microwave treated samples had similar colors with the dough, therefore ΔE values were very close to zero. The reason for not obtaining browning in microwave baked products is that the short baking times and low surface temperatures common to microwave processing do not promote browning reactions. Moreover, in microwave oven, heat is absorbed by the food sample and the air around the product is cold. Therefore, when the water molecules from the food system evaporate, they directly come across with this cold air around the product and condense. This causes a cooling effect and surface temperature of the product can not reach to the required high values for browning reactions to occur (Schiffmann, 1994).

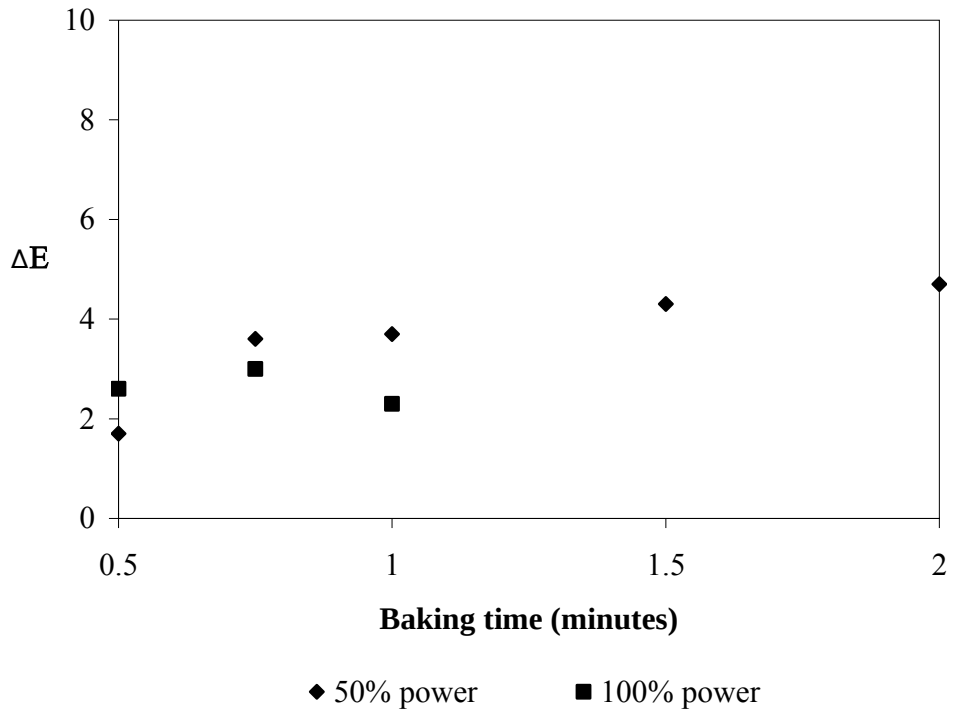

Figure 3.8 Variation of ΔE value of breads during microwave baking at different oven powers

The optimum baking condition for microwave oven was determined by using the highest specific volume and the lowest crumb firmness. Based on these criteria, baking for 0.75 min using 100% oven power was selected as the optimum baking condition for microwave oven.

3.1.3 Halogen Lamp Oven

Weight loss of the breads baked in halogen lamp oven increased with increasing halogen power (Figure 3.9). This was due to subjection of samples to more radiation in the presence of high powers. The increase in weight loss of breads during halogen lamp baking followed a linear trend as in the case of conventional and microwave baking. The coefficient of determination values were at least 0.97 (Table A.4).

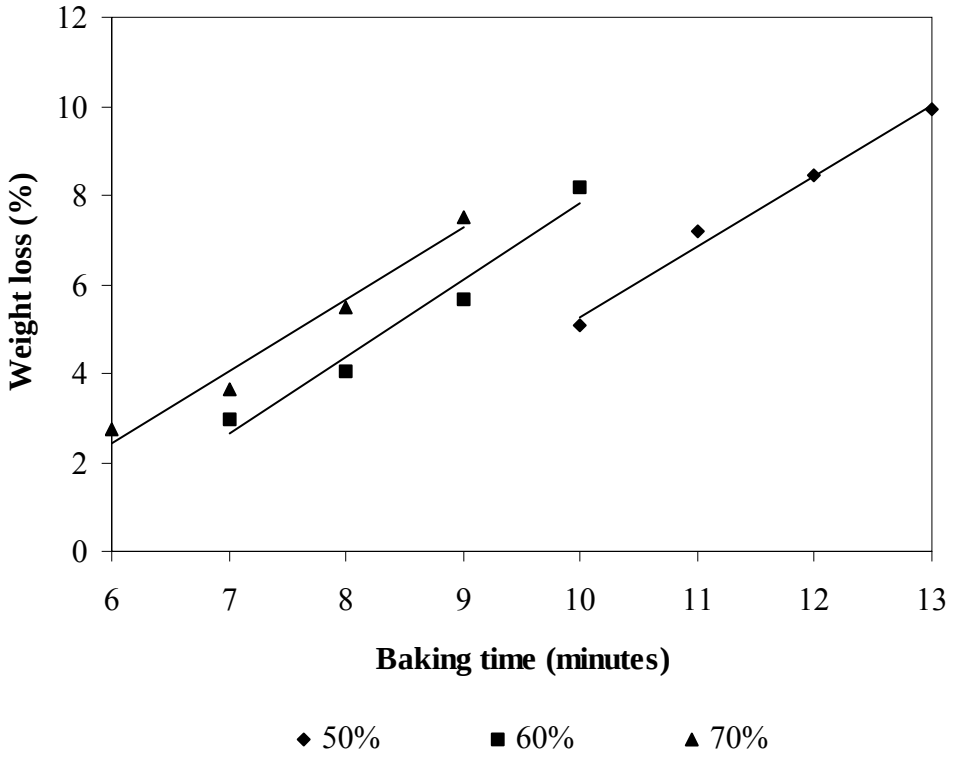

Figure 3.9 Variation of weight loss of breads during halogen lamp baking at different oven powers

Specific volume of breads baked in halogen lamp oven increased with baking time (Figure 3.10). The volume peak obtained in conventional (Figure 3.2) and microwave oven (Figure 3.6) baking could not be seen in halogen lamp oven because of the different heating mechanism of halogen lamp oven. Since halogen lamp heating provides near-infrared radiation which means low penetration depth, formation of starch-gluten matrix with high strength may be retarded. As halogen lamp heating caused accumulation of radiation at the surface a thick crust was formed suddenly. This might reduce the transfer of heat to the inner parts.

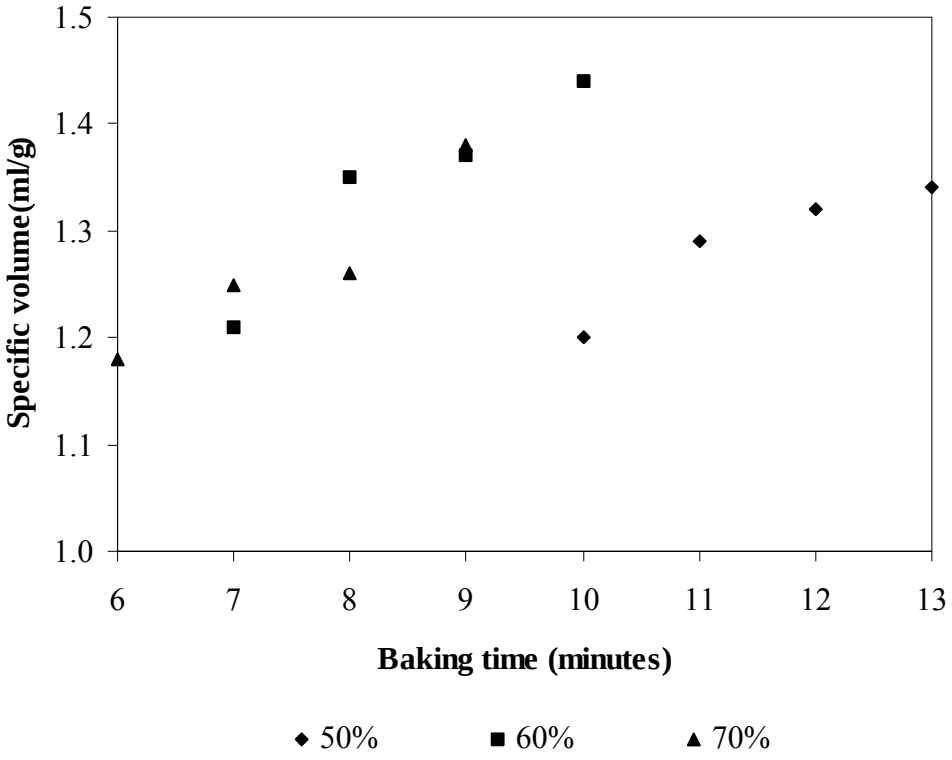

Figure 3.10 Variation of specific volume of breads during halogen lamp baking at different oven powers

Specific volume of breads baked in halogen lamp oven increased with oven power because higher halogen power provided high temperatures and shortened the time needed to reach temperatures for development of the starch-gluten matrix and other complex interactions to occur.

Figure 3.11 shows the variation in crumb firmness during halogen lamp baking at different oven powers.

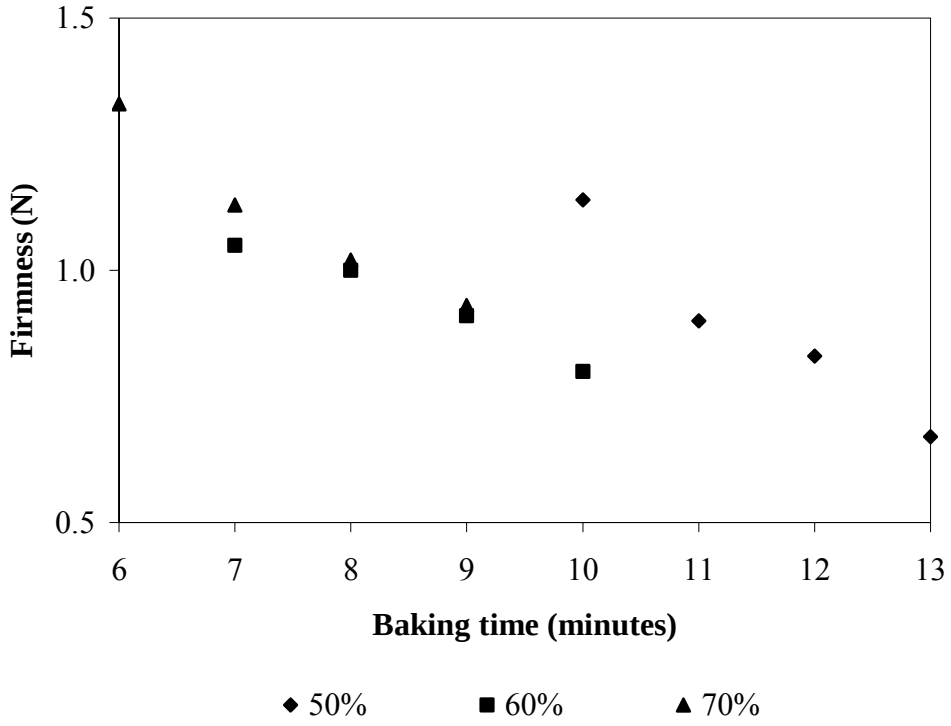

Figure 3.11 Variation of firmness of breads during halogen lamp baking at different oven powers

Like conventional baking firmness of breads was negatively correlated with specific volume. The correlation coefficients between specific volume and crumb firmness were - 0.98, - 0.90, -0.91 for different oven powers, 50%, 60%, 70% respectively (Table B.4).

ΔE values of breads baked in halogen lamp oven increased with baking time and halogen power (Figure 3.12). Since browning reactions require high temperatures and long processing times, the higher the baking time and halogen power, the higher the ΔE value that is, darker the color can be obtained. The coefficient of determination for ΔE value of breads baked in halogen lamp oven for different oven powers, were ranging between 0.94 - 0.99 (Table A.5).

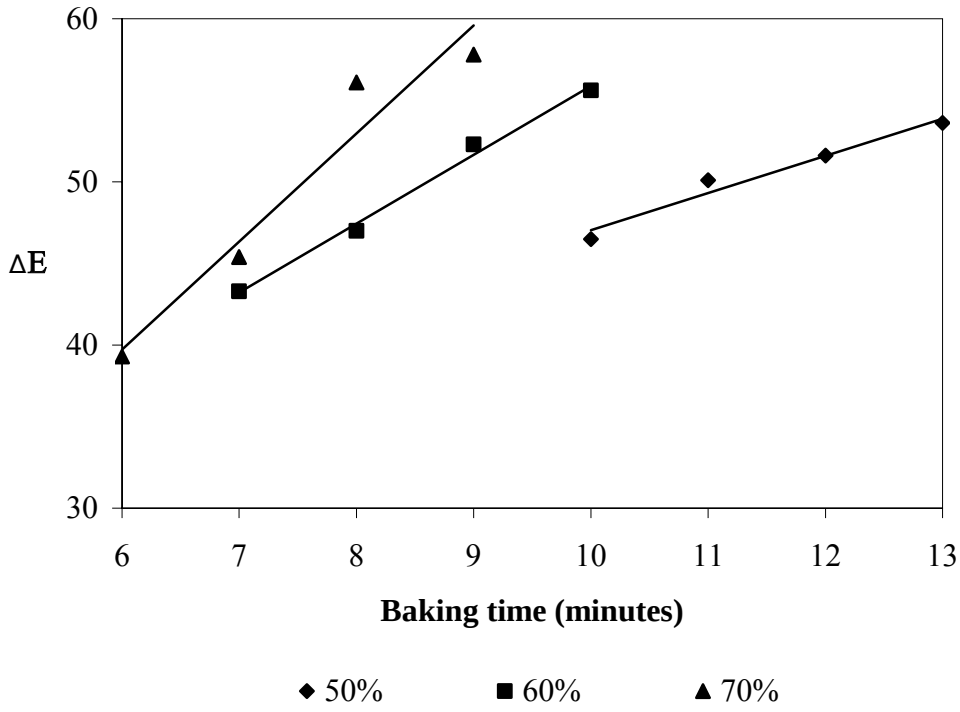

Figure 3.12 Variation of ΔE value of breads during halogen lamp baking at different oven powers

As can be seen from the figure, samples exposed to 70% halogen power showed a sharp increase in ΔE value. It is known that halogen lamp heating provides low penetration depth which causes the radiation to focus at the surface, therefore, the surface temperature of breads can reach the required values for browning. High halogen powers provided the achievement of browning at the surface in a shorter time.

Since specific volume and firmness are two of the most important parameters that reflect the quality of breads, these criteria are used for determination of optimum baking condition for halogen lamp oven. Baking time of 10 min at 60% halogen power was selected as the optimum baking condition for halogen lamp oven.

3.1.4 Halogen Lamp – Microwave Combination Oven

In the preliminary experiments, when 60 % halogen power selected from the previous study was combined with 100 % microwave power no color formation was observed at the surface of breads due to the fast baking at high microwave powers. Therefore, microwave power was reduced to 50 % to prolong the time needed for color development to occur. For 50 % microwave and 60 % halogen power combination it was observed that there was still no color development at the short baking times. Although browning occured for longer baking times breads became unacceptable (Figure 3.13-Figure 3.16). In the experiments in combination heating, very firm texture of breads became the most important problem because of the high microwave powers studied. Therefore, it was decided to combine different halogen powers with a lower microwave power (30%).

Weight loss of the breads baked in halogen lamp-microwave combination oven increased with baking time and oven power (Figure 3.13). Variation of weight loss of breads baked at different oven powers followed a linear trend (Table A.6).

The higher the microwave and halogen lamp power the higher the weight loss was observed due to subjection of samples to more microwaves or more infrared radiation. High microwave power provides relatively larger amounts of interior heating. This creates significant interior pressure and concentration gradients, which results in higher rates of moisture losses. The weight loss was the highest for breads baked with 50 % microwave oven power and 60 % halogen lamp power. This showed that in halogen lamp-microwave combination baking, the microwave power was more effective on weight loss than halogen lamp power.

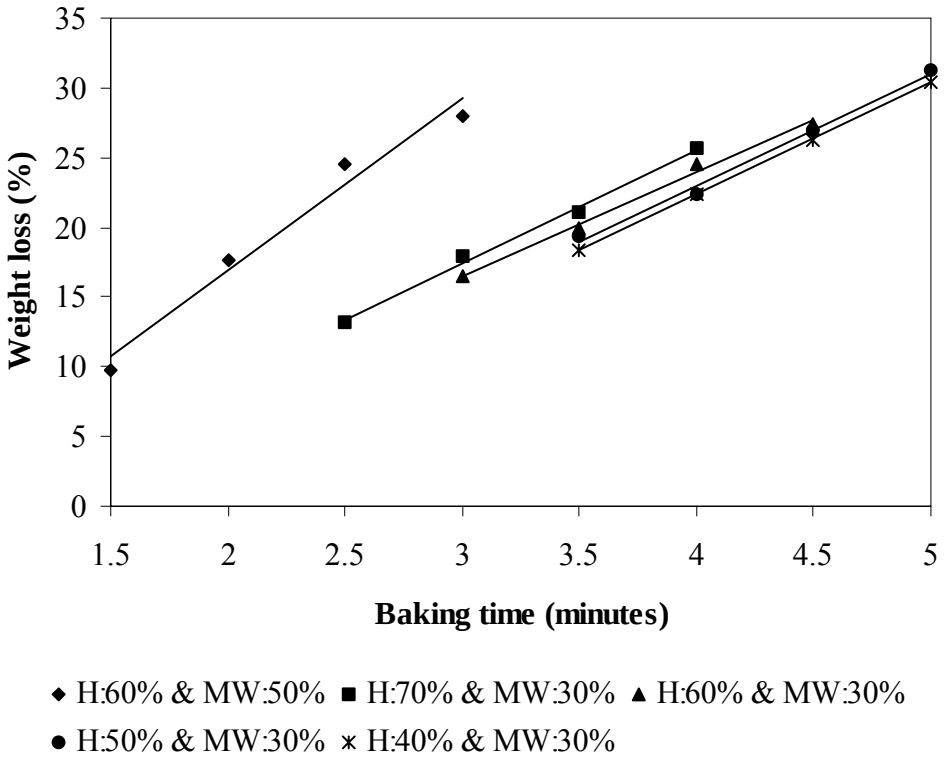

Figure 3.13 Variation of weight loss of breads during halogen lamp – microwave combination baking at different oven powers

Specific volume of breads baked in halogen lamp-microwave combination oven decreased as baking time increased (Figure 3.14).

As halogen power increased volume of the breads decreased. Since halogen lamp heating provided focusing of radiation at the surface, the thicker crust formed immediately at the surface of the samples, at higher powers compressed the interior texture and caused lower volume.

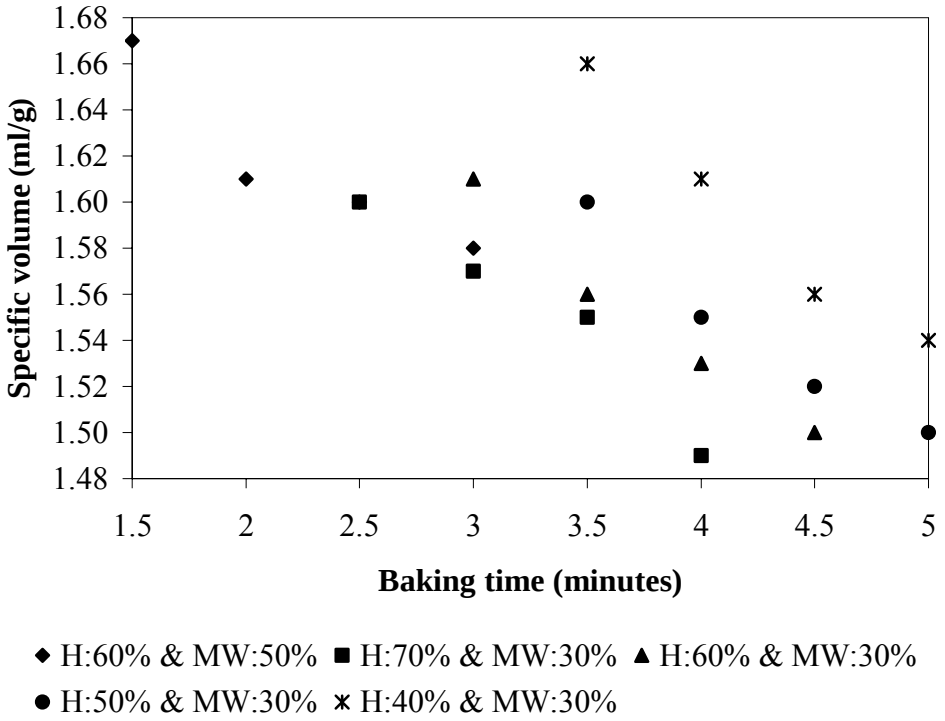

Figure 3.14 Variation of specific volume of breads during halogen lamp – microwave combination baking at different oven powers

Figure 3.15 shows the variation in crumb firmness with baking time during halogen lamp-microwave combination baking at different oven powers. The increase in microwave power increased the crumb firmness extremely showing that microwave heating is more dominant in affecting firmness in halogen lamp-microwave combination oven. The sudden increase in the firmness of breads at the final stages of baking can be explained by the extreme drying of breads.

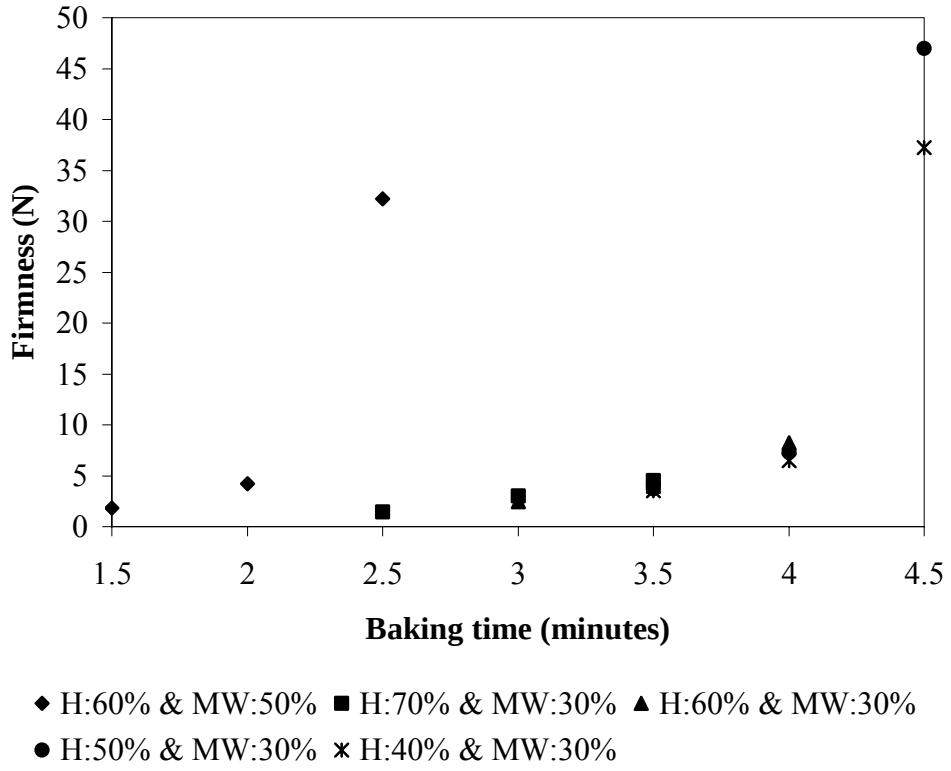

Figure 3.15 Variation of firmness of breads during halogen lamp – microwave combination baking at different oven powers

Like microwave heating specific volume of breads baked in halogen lamp-microwave combination oven was not correlated with firmness. This shows that microwave heating was the dominant mechanism in combination heating in terms of texture development.

ΔE value of breads baked in halogen lamp-microwave combination oven increased with baking time and halogen lamp oven power (Figure 3.16). The increase in halogen power might increase surface temperatures of breads, which might affect the crust color formation. Halogen lamp heating is known to provide low penetration depth and concentrate radiation at the surface, so the surface temperature can reach the required values for browning.

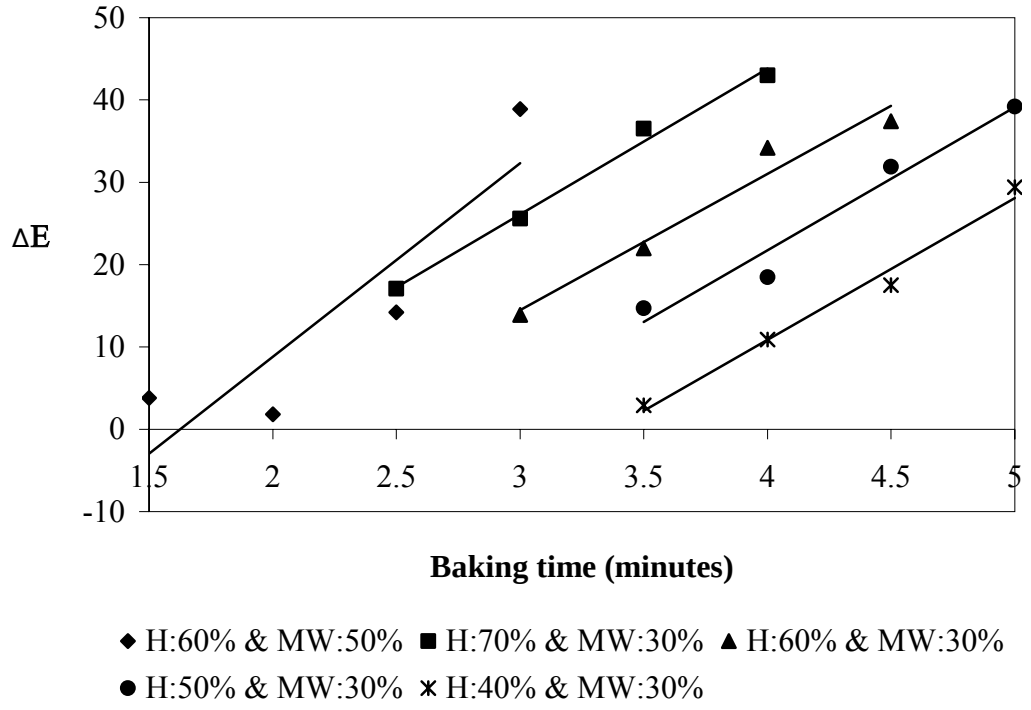

Figure 3.16 Variation of ΔE value of breads during halogen lamp - microwave combination baking at different oven powers

The coefficients of determination (r^2) for change in ΔE value of breads during baking in halogen lamp oven for different oven powers were ranging between 0.96 and 0.99 when microwave power was 30% (Table A.7). In the case of higher microwave power (50%), the data did not follow linear trend very well since color can not be achieved at the initial stages of baking ($r^2 = 0.80$).

High oven powers for halogen lamp oven provided the achievement of desired temperature values at the surface for browning easily and in a shorter time. Therefore, with halogen lamp-microwave combination heating, similar ΔE values with the conventionally baked breads could be achieved.

In determining the optimum baking condition for halogen lamp-microwave combination oven, not only high specific volume and less firm texture but also ΔE values similar to that of conventionally baked breads were taken into consideration.

As a result, breads baked at 70% halogen lamp power and 30% microwave power for 3 min provided ΔE value and specific volume similar to conventionally baked breads but the firmness of breads were still higher as compared to conventionally baked ones. When the baking time was extended darker colors could be observed but specific volume decreased and firmness increased in an unacceptably great extend.

A second order polynomial model was used to express the responses as a function of baking time and halogen power by fixing microwave power at 30%. The model equation is given as

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{12}X_{12} + b_{22}X_2^2 \quad (3.1)$$

where Y's are the dependent variables (weight loss, specific volume, firmness and ΔE values), X' s are the independent variables (baking time and halogen power) and b' s are the model constants.

Model constants and the regression coefficients of the model were determined from multiple regressions of the experimental data. The constants and regression coefficients of the model equation are given in Table D.1-D.3. Measure of fit of data (r^2) was very high in all of the quality parameters except firmness due to the very sudden increase in texture values at the last stages of baking. Model equations were used to plot contour plots to determine the effects of halogen power and baking time on different responses (Figures 3.17-3.19).

As halogen power and baking time increased weight loss of breads increased due to subjection of samples to more radiation (Figure 3.17). The increase in power after a certain value was not so effective on the variation of weight loss.

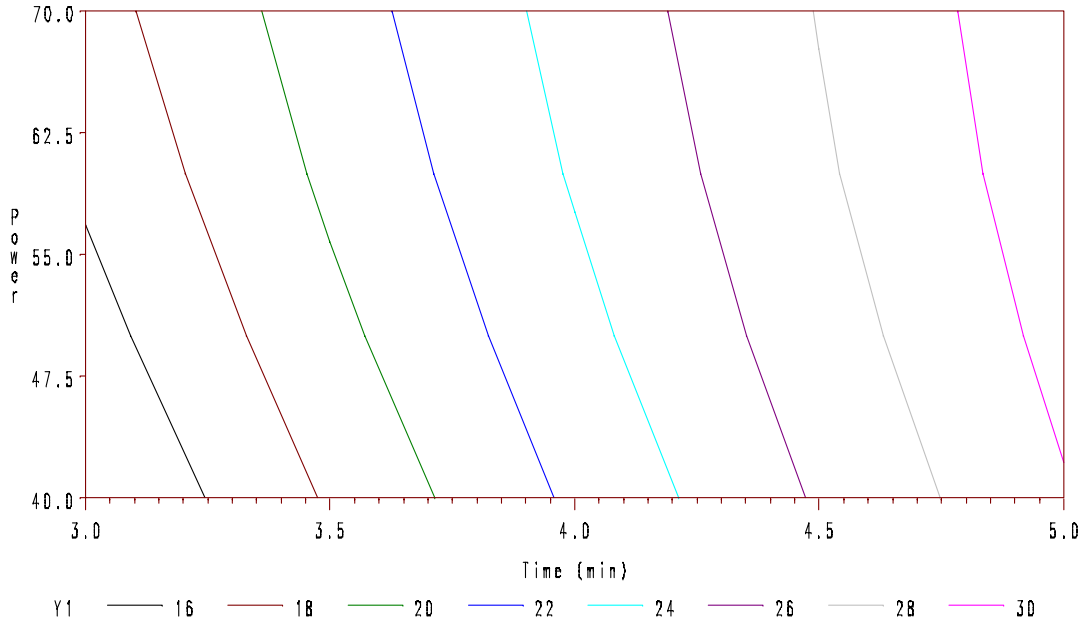

Figure 3.17 Effects of halogen power and baking time on weight loss of breads baked in halogen lamp-microwave combination oven

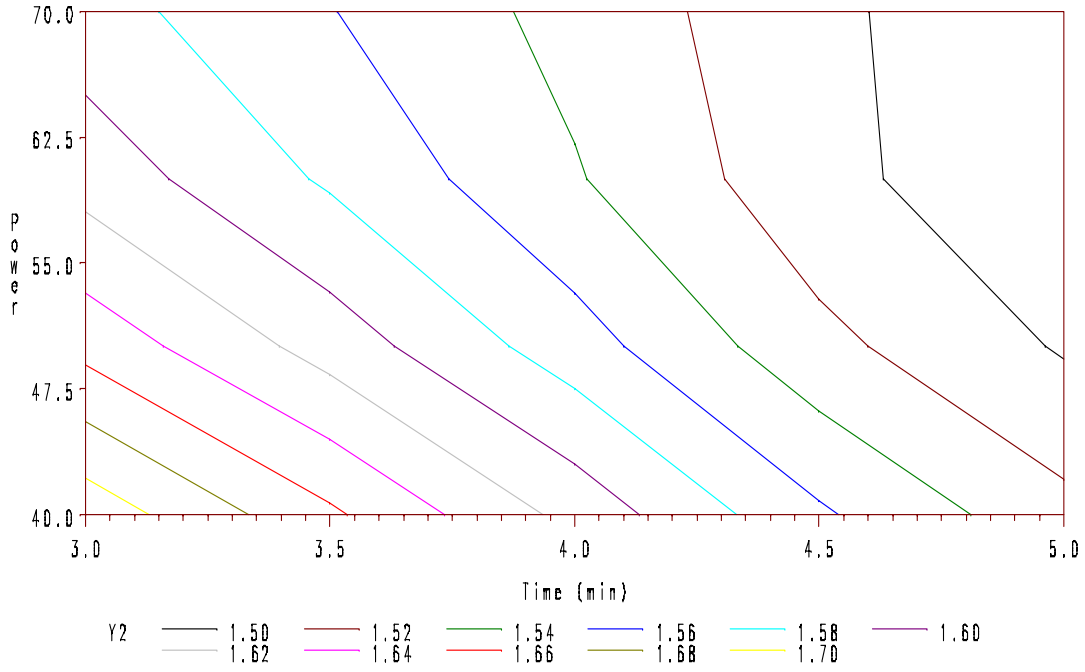

Figure 3.18 Effects of halogen power and baking time on specific volume of breads baked in halogen lamp-microwave combination oven

The increase in baking time and power reduced the volume of breads (Figure 3.18). Due to high moisture loss and drying, volume of breads decreased as baking time increased. As power increased most probably crust became thicker and heavier which compressed the breads making them firm and smaller in volume.

Figure 3.19 shows the effect of different halogen power and baking time on ΔE values of breads. As power and baking time increased ΔE values of breads increased showing that it was possible to obtain browning like conventionally baked breads by using suitable power and time combinations.

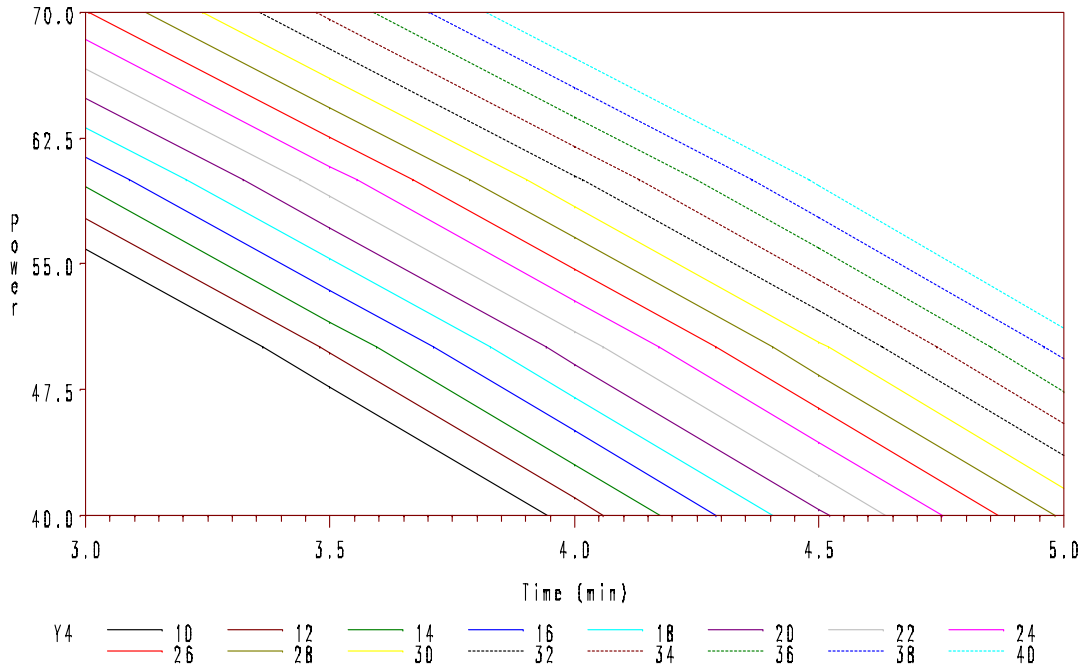

Figure 3.19 Effects of halogen power and baking time on ΔE value of breads baked in halogen lamp-microwave combination oven

3.2 Effects of Enzymes on Quality of Breads Baked in Different Ovens

The optimum baking conditions determined for each type of oven in the first part of the study were used in the investigation of the effects of different enzymes on the quality of breads. As the main problem in halogen lamp-microwave combination heating like microwave heating was the firmer texture, it was decided to use

enzymes. There was no study in literature on the effects of enzymes on the quality of breads baked in microwave and halogen lamp-microwave combination ovens. Independent variables were oven type (conventional, microwave and halogen lamp-microwave combination ovens) and enzyme type (α-amylase, xylanase, lipase, protease). The quality parameters were moisture content, specific volume, crumb firmness and color of samples. The effects of enzymes on product quality were studied not only during baking but also during storage.

3.2.1 Conventional Oven

The effects of enzymes on the moisture content of breads baked in conventional oven can be seen in Figure 3.20. It was observed that the effects of enzymes on the moisture content of breads were not significantly different (Table C.1).

Figure 3.21 shows the effects of enzymes on the specific volume of breads baked in conventional oven. Protease was found to be the most effective enzyme among the others and specific volume of breads treated with protease was found to be higher than that of the no enzyme added breads. It was previously shown that the controlled addition of proteolytic enzymes could be used for improving viscoelastic properties of dough (Linko et. al., 1997). Supplementation of the dough with proteases helps to breakdown the gluten protein so that the dough is softer and more extensible. The increased extensibility and elasticity of the gluten film helps the dough to retain the gas that evolves in the system during processing better and to form samples with high specific volume (Mathewson, 2000).

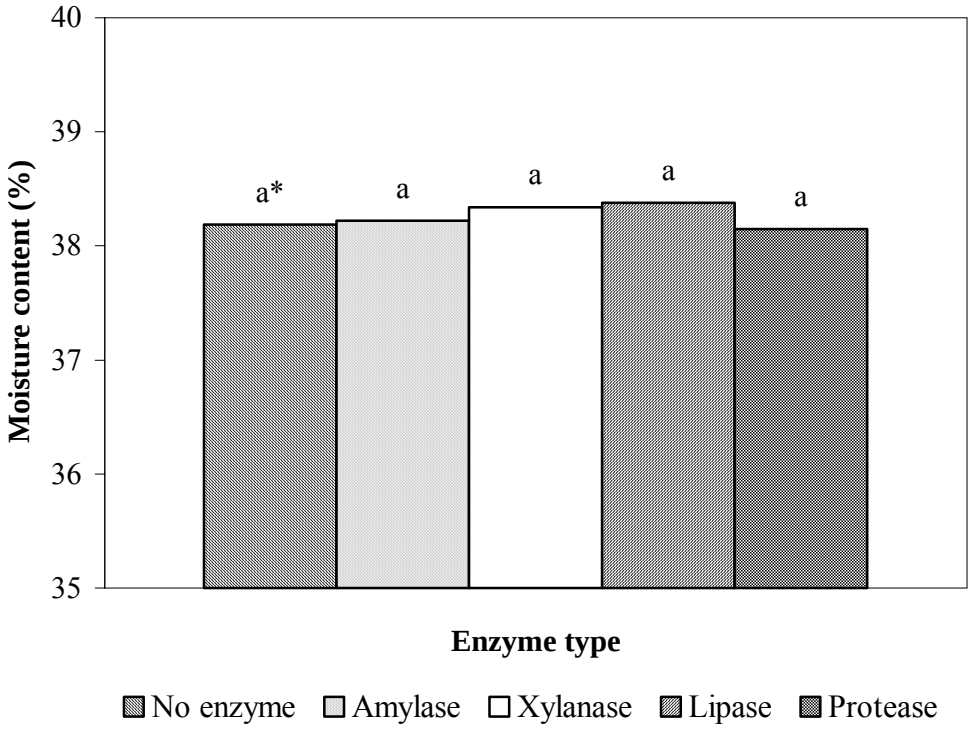

Figure 3.20 Effects of enzymes on moisture content of breads baked in conventional oven just after baking

* means bars containing different letters are significantly different ($p \leq 0.05$).

The specific volume of α-amylase containing breads was not found to be significantly different from no enzyme added breads (Table C.2). This might be due to the source of the enzyme. The source of α-amylase used in this study was fungal. Similar results were obtained in the study of Sahlström and Brathen (1997) in which they found that addition of fungal enzymes (α-amylase and its combinations with other enzymes) gave no significant increase in bread volume.

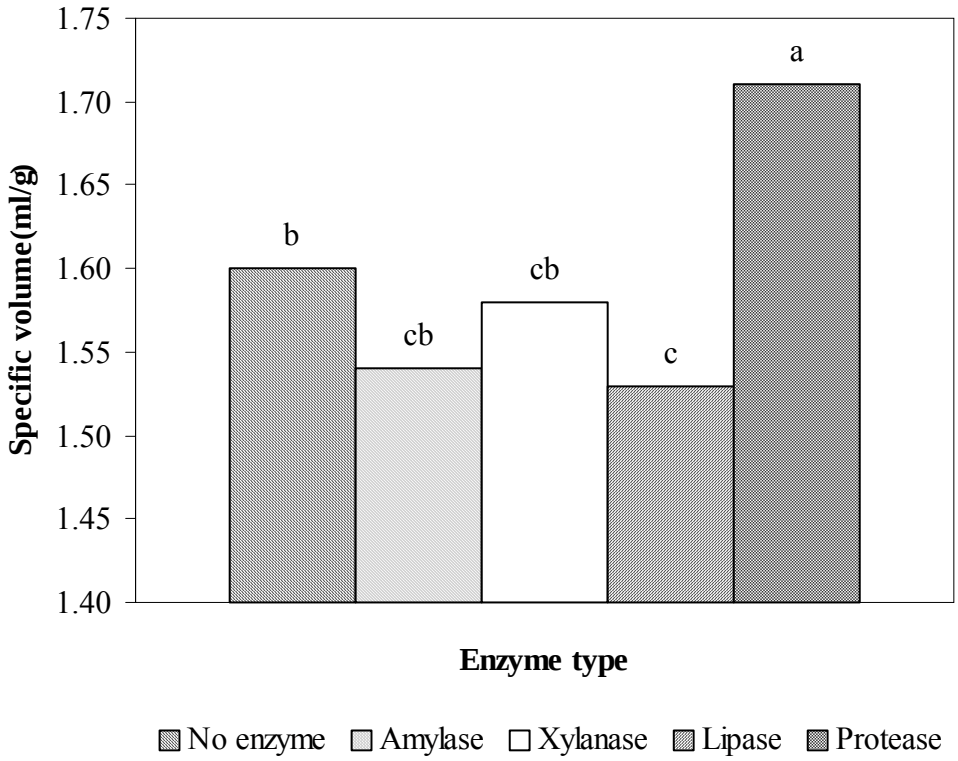

Figure 3.21 Effects of enzymes on specific volume of breads baked in conventional oven just after baking

The effects of enzymes on the firmness of breads baked in conventional oven can be seen in Figure 3.22. None of the enzymes were found to be significantly effective in reducing the initial firmness of breads baked in conventional oven (Table C.3). Enzymes are generally known to reduce the staling rate while having only a minor effect on initial firmness (Gil et al., 1999).

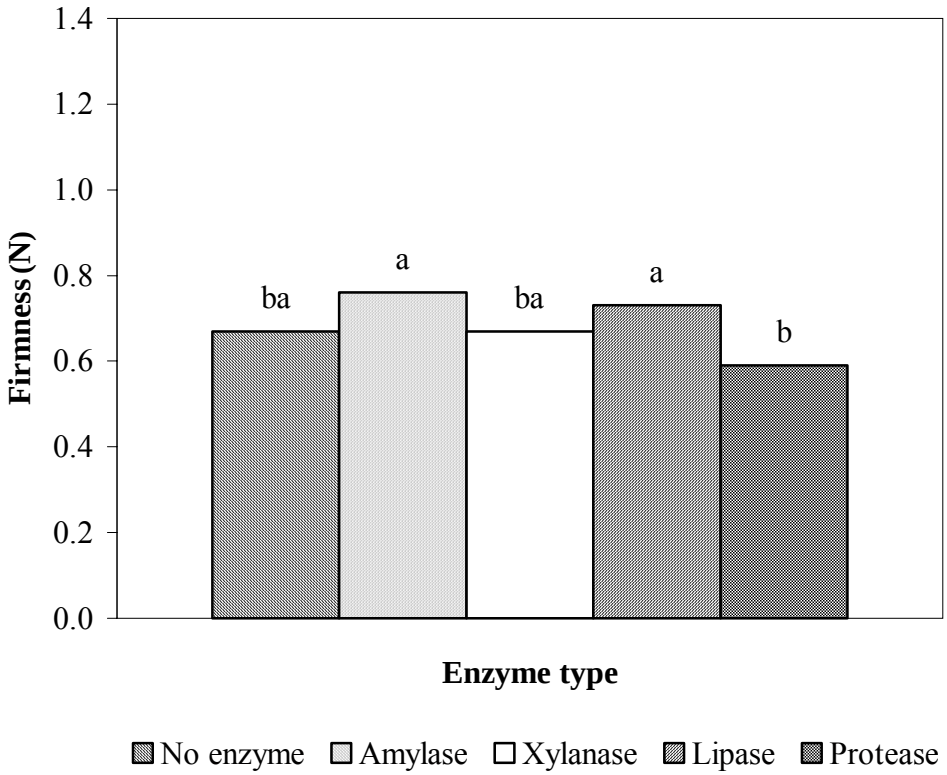

Figure 3.22 Effects of enzymes on firmness of breads baked in conventional oven just after baking

The effects of enzymes on the ΔE value of breads baked in conventional oven can be seen in Figure 3.23. The ΔE value of breads treated with protease was found to be significantly different from that of the no enzyme added breads and breads with the other enzymes (Table C.4). Development of the crust color and the product flavor result from the Maillard reactions that take place during baking. Proteases have been known to produce sufficient new amino acids or peptides required for Maillard reaction (Mathewson, 2000), so the crust color of protease added breads got darker.

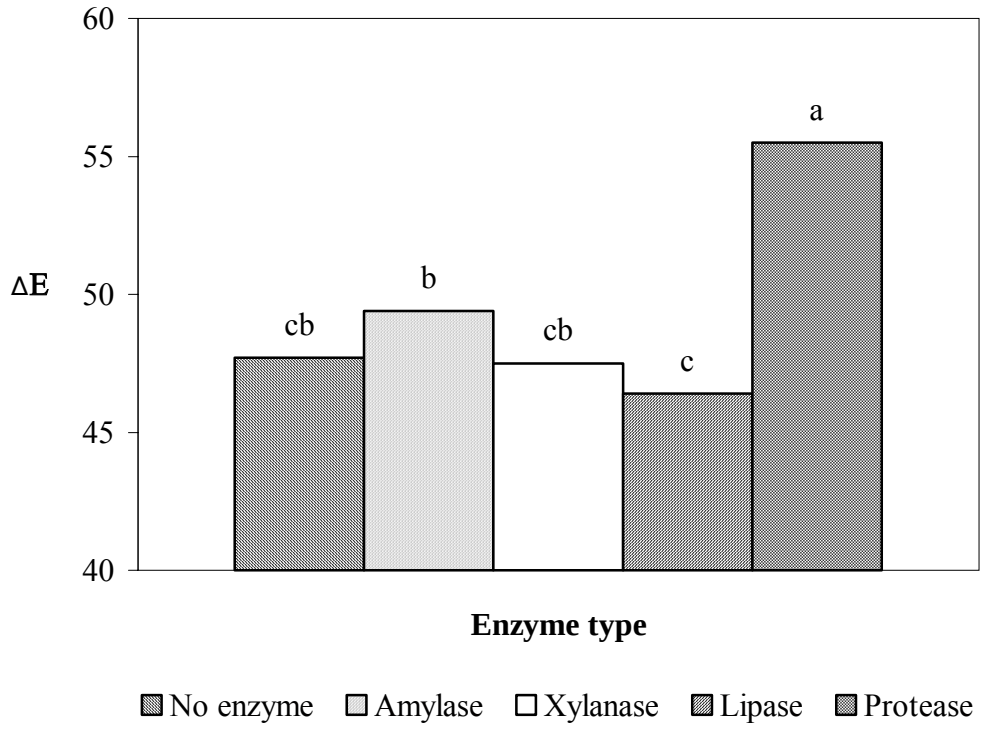

Figure 3.23 Effects of enzymes on the ΔE value of breads baked in conventional oven just after baking

3.2.2 Microwave Oven

Figure 3.24 shows the effects of enzymes on the moisture content of the breads baked in microwave oven. Similar to the results with the conventional treatment enzymes were not found to be significantly different on effecting the moisture content of breads (Table C.5).

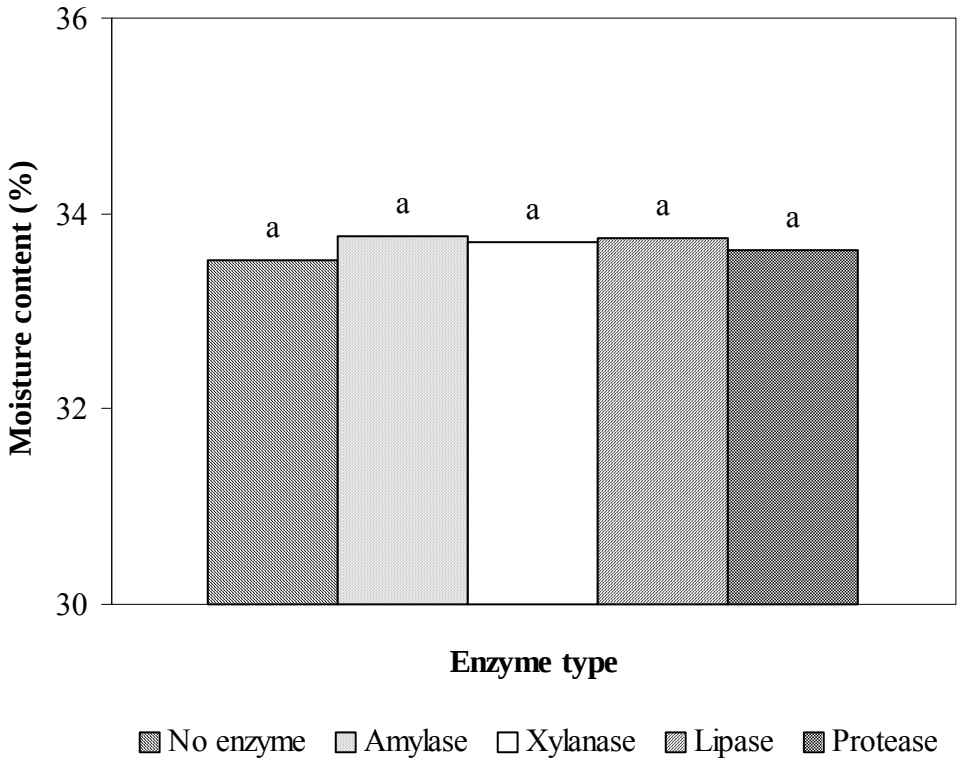

Figure 3.24 Effects of enzymes on the moisture content of breads baked in microwave oven just after baking

The effects of enzymes on specific volume of breads baked in microwave oven can be seen in Figure 3.25. All of the enzymes were found to be significantly effective to obtain breads with higher specific volumes than no enzyme added breads (Table C.6).

α-Amylase and protease were found to be significantly different from other enzymes in increasing the specific volume of microwave baked breads. The positive effect of α-amylase on specific volume of breads was due to its influence on starch. Immediately after dough preparation, the yeast starts to ferment the available sugars into alcohols and carbon dioxide, which causes rising of the dough. Amylases can be added to the dough to degrade the damaged starch in the flour into smaller dextrins, which are subsequently fermented by the yeast and the formation of additional carbon dioxide results in increased loaf volume (Maarel et al., 2002). α-Amylase

may prolong the period of dough expansion in the oven, increasing the maximum dough-piece height and loaf volume (Cauvain and Chamberlain, 1988).

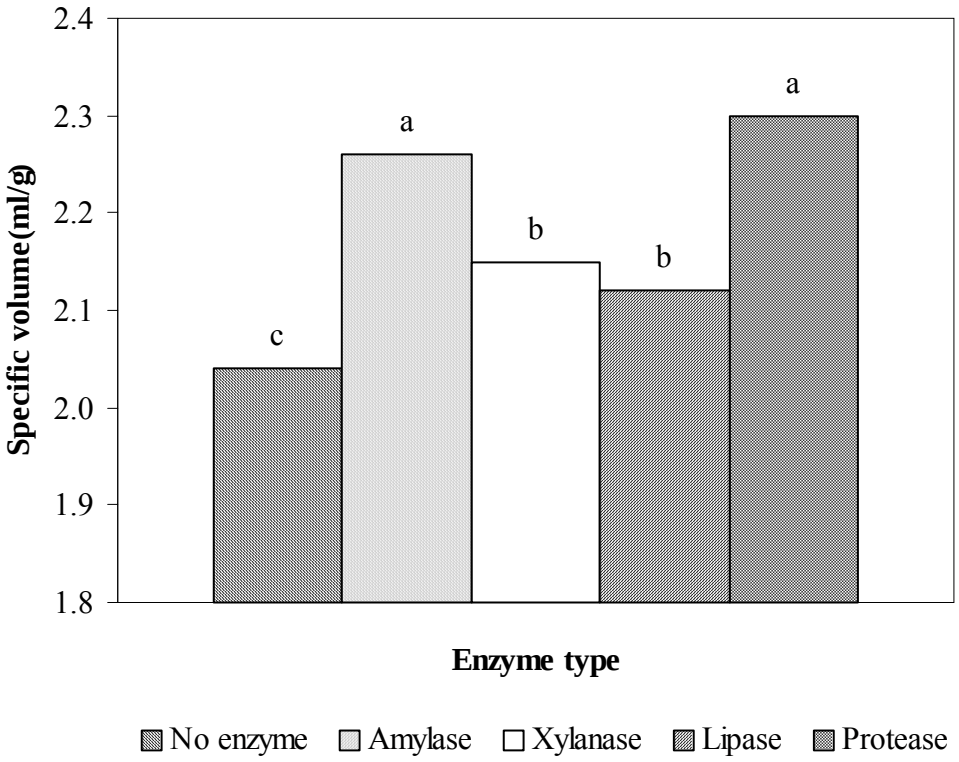

Figure 3.25 Effects of enzymes on specific volume of breads baked in microwave oven just after baking

Protease addition helps to break down the gluten protein so that the dough is more extensible. The increased extensibility of gluten film retains the gas that is evolved in the system better (Mathewson, 2000). Therefore, breads treated with protease had higher volume.

Lipases act on lipids and produce mono and diglycerides from them. Emulsifiers which include mono and diglycerides, were shown to increase the volume of microwave baked breads (Ozmutlu, et al., 2001a). Addition of lipase to the bread dough increased the volume of breads significantly as compared to no

enzyme added breads due to the effect of mono and diglycerides produced by lipase on volume.

Xylanase added breads had higher volume than no enzyme added breads. The positive effect of xylanase on bread volume may be due to the redistribution of water from the pentosan phase to the gluten phase. The increase in the volume of the gluten fraction because of water transfer increases its extensibility, which results in better ovenspring (Maat et al., 1992).

Figure 3.26 shows the effects of enzymes on the firmness of the breads baked in microwave oven. All of the enzymes were found to be significantly effective on firmness of breads baked in microwave oven meaning that breads treated with any types of the enzymes were softer than that of the control breads (Table C.7).

In contrast to conventional baking, all of the enzymes were effective on initial crumb firmness of microwave baked breads. This is due to the different heating mechanisms of conventional and microwave baking.

The firmness problem of the microwave baked bread interior is usually associated with gluten-microwave interactions though the mechanism is still not clear (Shukla, 1993). Moreover, more amylose leached during microwave baking as compared to conventional baking increases the firmness of microwave baked products (Seyhun, 2002). As α-amylases are starch hydrolysing enzymes, they could disrupt the starch network and thereby decrease the amount of available starch for amylose leaching and cause reduction in firmness (Duran et al., 2001). For this reason α-amylase was found to be effective to reduce the firmness of microwave baked breads (Figure 3.26). Proteases are capable of breaking down the gluten protein. Therefore, in the presence of protease less gluten might be available to interact with microwaves and the breads became less firm (Figure 3.26).

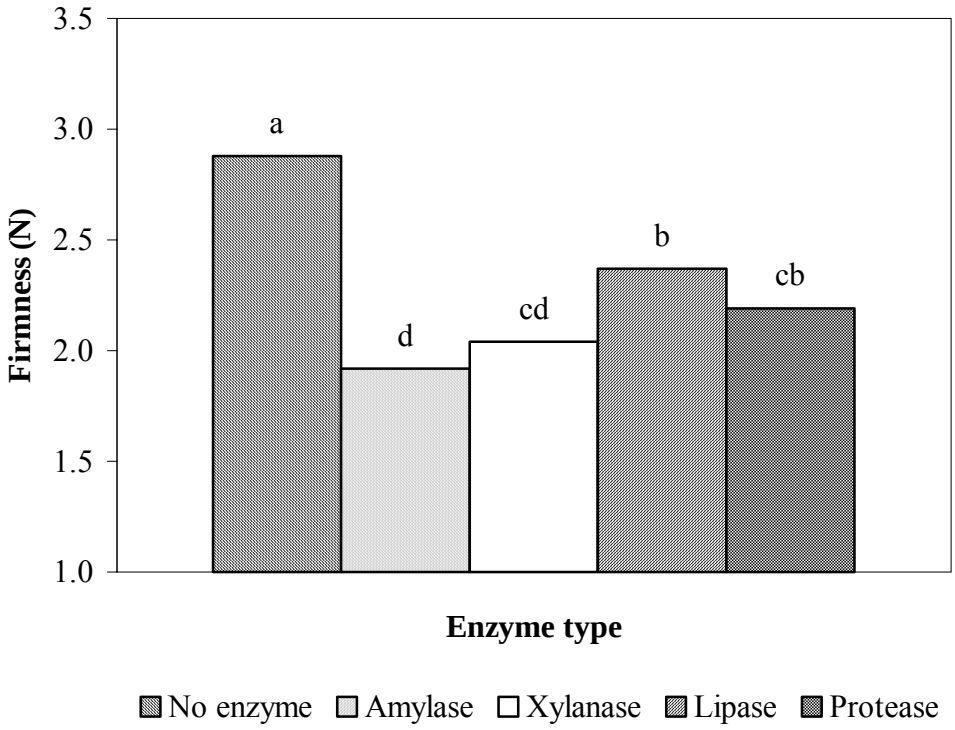

Figure 3.26 Effects of enzymes on firmness of breads baked in microwave oven just after baking

Lipases produce mono and diglycerides, the emulsifiers, from lipids, which improve crumb softness of bread (Gil et al., 1999). Monoglycerides are known as typical crumb softeners and have ability to form complexes with amylose (Stampfli and Nersten, 1995). Lipase enzyme was found to be effective to reduce the firmness of microwave baked breads due to the effect of monoglycerides produced (Figure 3.26). Emulsifiers were shown to reduce the firmness of microwave baked breads previously (Ozmutlu et al., 2001a).

Microwave breads containing xylanase enzyme were found to be softer than the ones containing no enzymes. The softening effect of xylanase has been related to water released by xylanase. The extra water can affect gelatinization and formation of amylose-lipid complex (Andreu et al., 1999). The free water makes the dough more extensible so that it can retain gases better which results in high volume (Mathewson, 2000).

The effects of enzymes on the ΔE value of breads baked in microwave oven can be seen in Figure 3.27. Protease added breads were found to have significantly different ΔE values from the others meaning that these breads were darker in color (Table C.8). But still this color development was not sufficient as compared to conventional treatment.

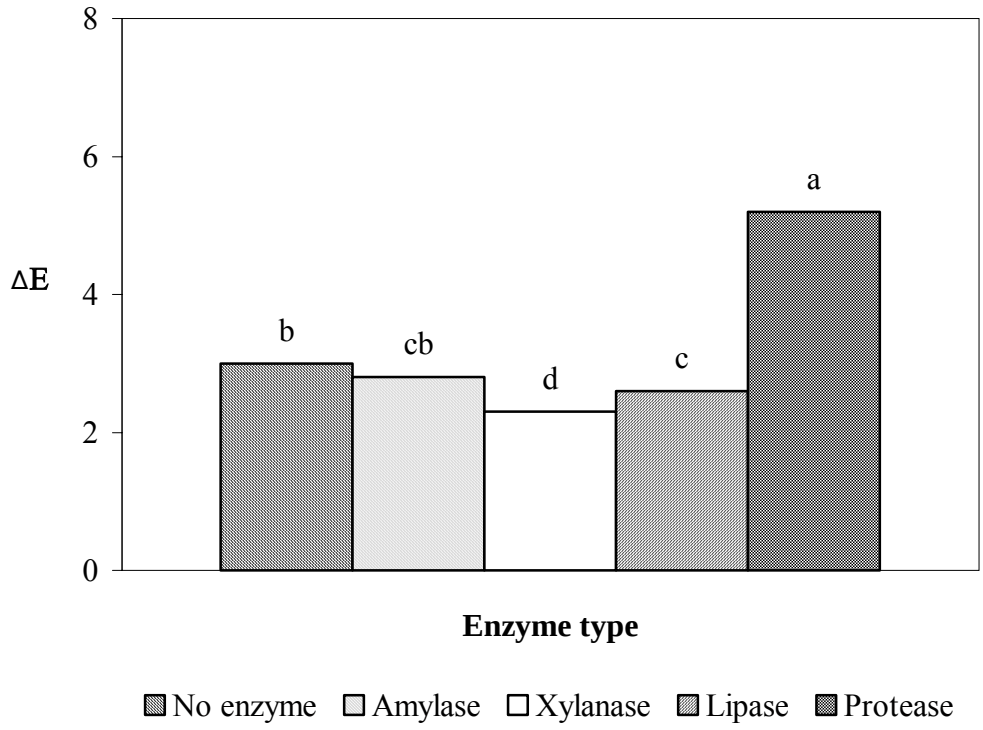

Figure 3.27 Effects of enzymes on the ΔE value of breads baked in microwave oven just after baking

It is well-known that one of the major problems associated with microwave cooking is the lack of desired color as well as flavors (Risch, 1989). The short cooking time and low temperatures common to microwave processing usually do not promote the Maillard reaction which is responsible for the production of many flavor and color compounds (Yeo and Shibamoto, 1991a). Therefore, the ΔE value of breads baked in microwave oven were close to zero which meant no color formation and similar color with the dough.

3.2.3 Halogen Lamp-Microwave Combination Oven

Figure 3.28 shows the effects of enzymes on moisture content of breads baked in combination oven. There was no significant difference between enzyme treatments in affecting moisture content of breads baked in combination oven (Table C.9).

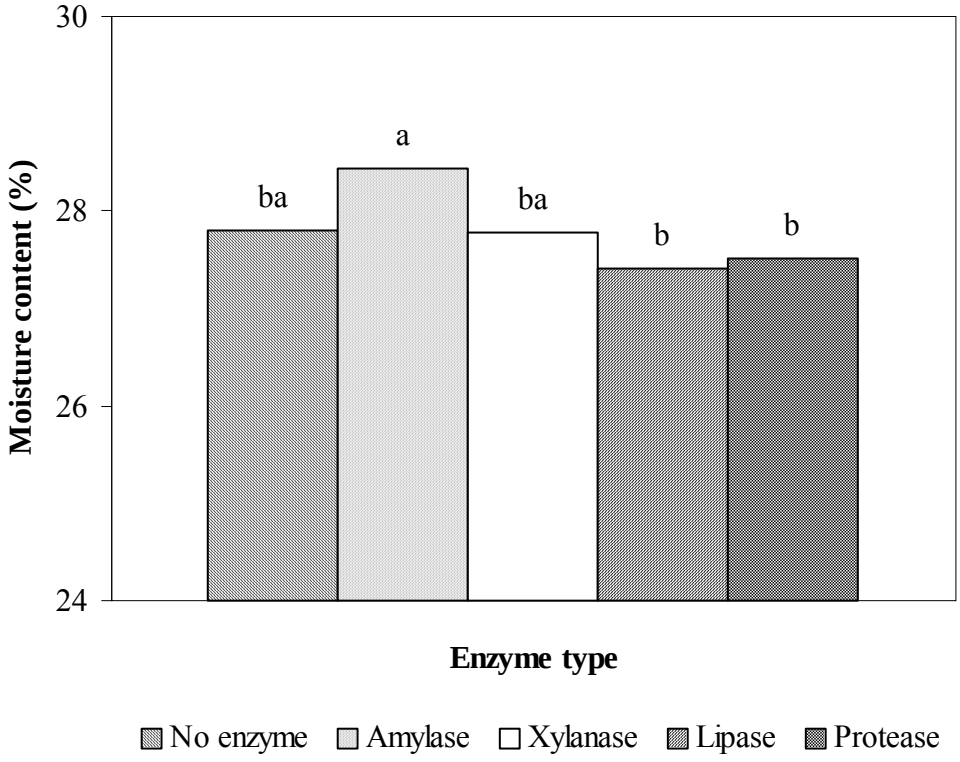

Figure 3.28 Effects of enzymes on the moisture content of breads baked in halogen lamp - microwave combination oven just after baking

The effects of enzymes on specific volume of breads baked in combination oven can be seen in Figure 3.29. Similar to the microwave treatment, protease and α-amylase were found to be significantly different from the other enzymes in affecting the specific volume of breads (Table C.10).

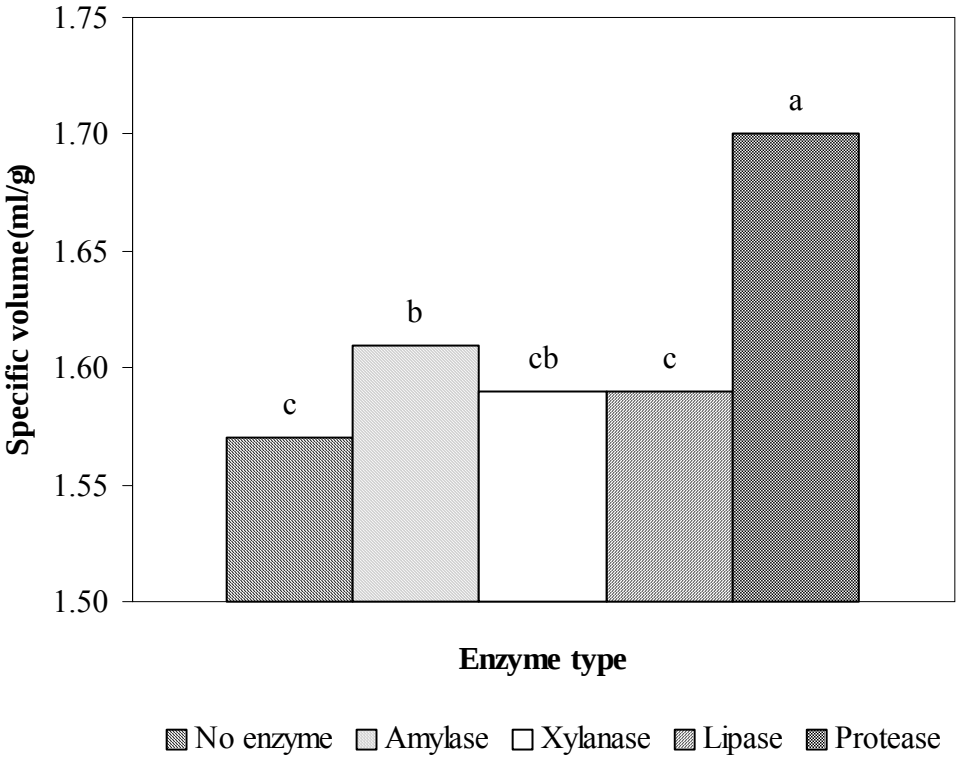

Figure 3.29 Effects of enzymes on the specific volume of breads baked in halogen lamp-microwave combination oven just after baking

Figure 3.30 shows the the effects of enzymes on firmness of breads baked in halogen lamp-microwave combination oven. Similar to the results obtained in microwave baking, all of the enzymes were found to be effective on firmness of breads during combination heating (Table C.11). The enzymes used in this study reduced the problem of firmness related with microwave heating. Since microwave heating was found to be more dominant than halogen lamp heating in combination oven, it was not surprising to see that the firmness of breads was reduced by using enzymes in combination oven, too.

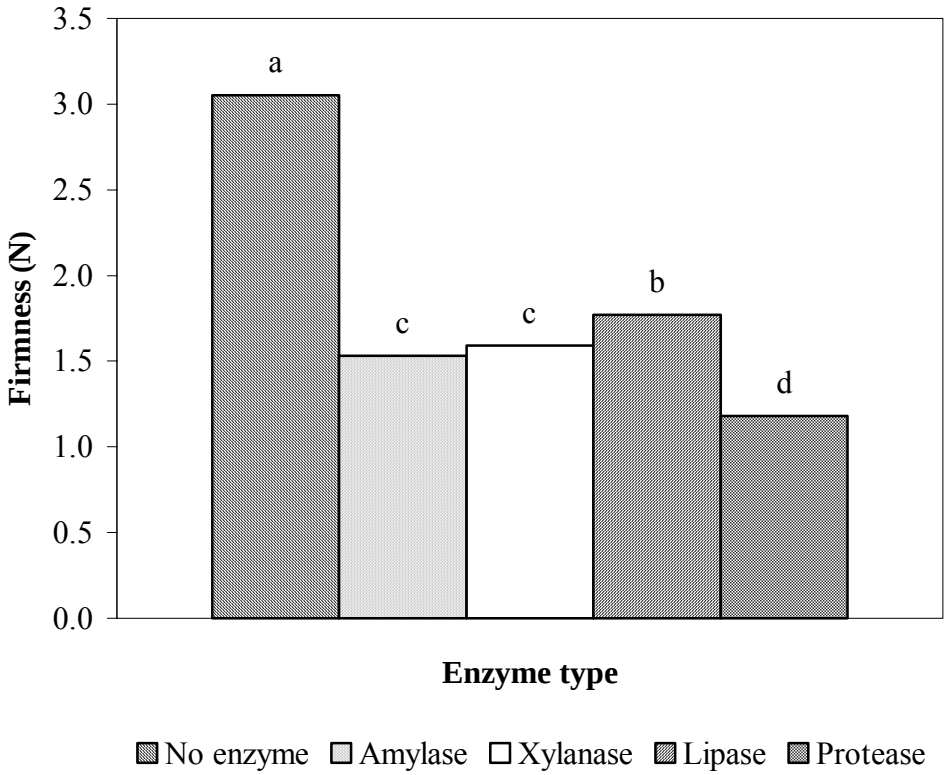

Figure 3.30 Effects of enzymes on the firmness of breads baked in halogen lamp - microwave oven just after baking

The effects of enzymes on the ΔE value of breads baked in combination oven can be seen in Figure 3.31. The color of protease added samples were significantly different from that of the control and the other enzyme added breads (Table C.12). Proteases were known to produce new amino groups to affect product color and flavor through the Maillard reaction (Mathewson, 2000).

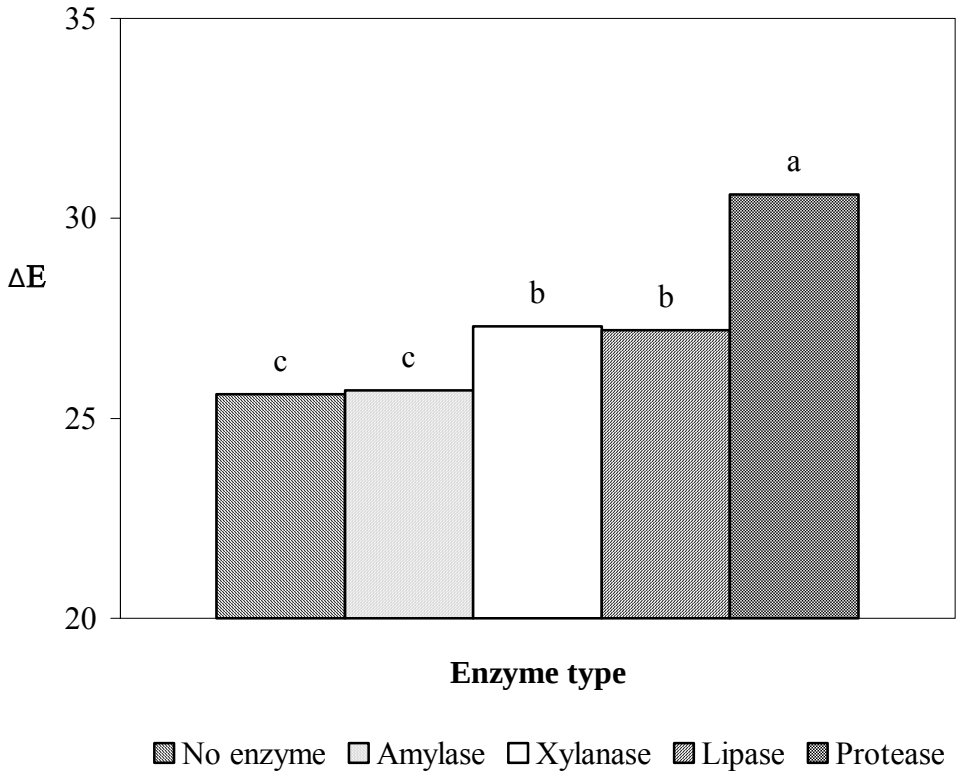

Figure 3.31 Effects of enzymes on the ΔE value of breads baked in halogen lamp - microwave combination oven just after baking

3.3 Effects of Enzymes on Staling of Breads Baked in Different Ovens

3.3.1 Conventional Oven

Figure 3.32 shows the effects of enzymes on moisture content of breads baked in conventional oven during storage. The moisture content of protease treated samples were significantly lower than that of control and the other enzymes (Table C.13). Such a behaviour was due to releasing of free water caused by the high water binding capacity of gluten because of the breakage of peptide bonds by protease enzyme (Haseborg, 1981). During storage the formed free water might have been removed and breads containing low moisture were obtained.

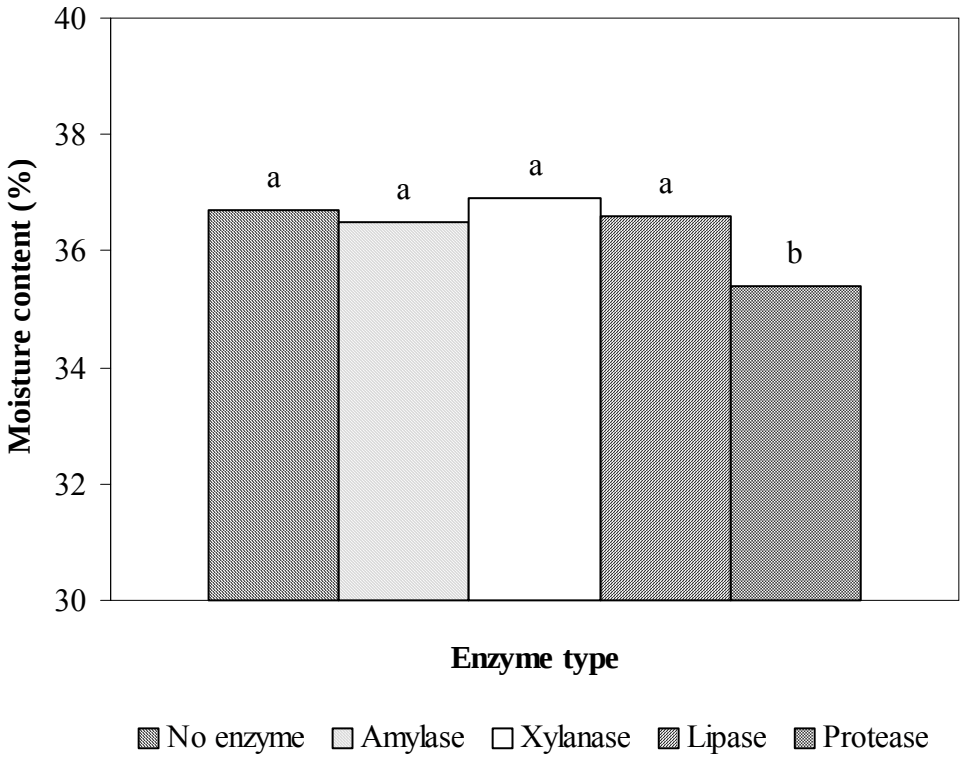

Figure 3.32 Effects of enzymes on the moisture content of breads baked in conventional oven after 2 days of storage

Firmness which is the resistance of bread crumb to deformation, is the textural attribute commonly used to assess the staling of bread (Pomeranz and Shellenberger, 1971). As can be seen in Figure 3.33, all of the enzymes were effective on controlling of firmness of breads after 2 days storage. Firmness of breads were reduced more when xylanase and protease were added.

Xylanase were found to be significantly effective on staling of breads due to its ability on affecting the water in the system. The monosaccharides and oligosaccharides resulting from the xylanase action could affect the water balance and may interfere with protein-starch interaction responsible from crumb firming during bread storage (Haros et al., 2002).

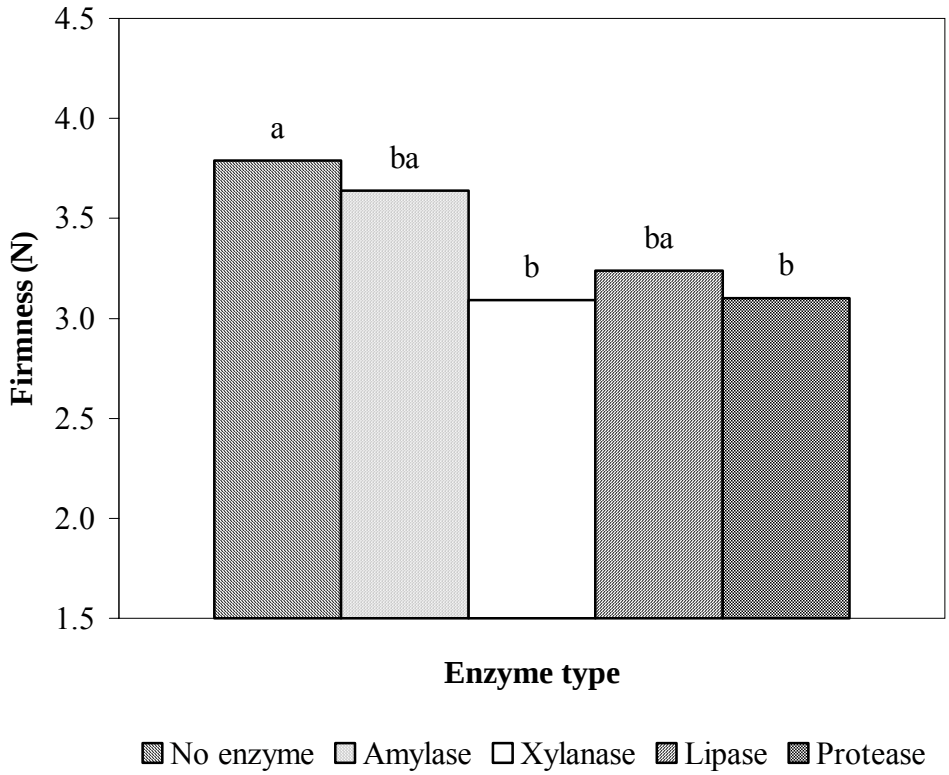

Figure 3.33 Effects of enzymes on the firmness of breads baked in conventional oven after 2 days of storage

During baking, interactions (cross-links) occur between gluten and starch. During staling, as the crumb loses kinetic energy, interactions increase in number and strength which contribute to bread firming (Martin et al., 1991). As gluten was modified by protease action, interactions between starch and gluten were weakened which caused a reduction in firmness during storage.

3.3.2 Microwave Oven

None of the enzymes affected the moisture content of breads baked in microwave oven during storage significantly (Figure 3.34). The moisture content of the samples treated with all of the enzymes were not found to be significantly different from the control (Table C.15).

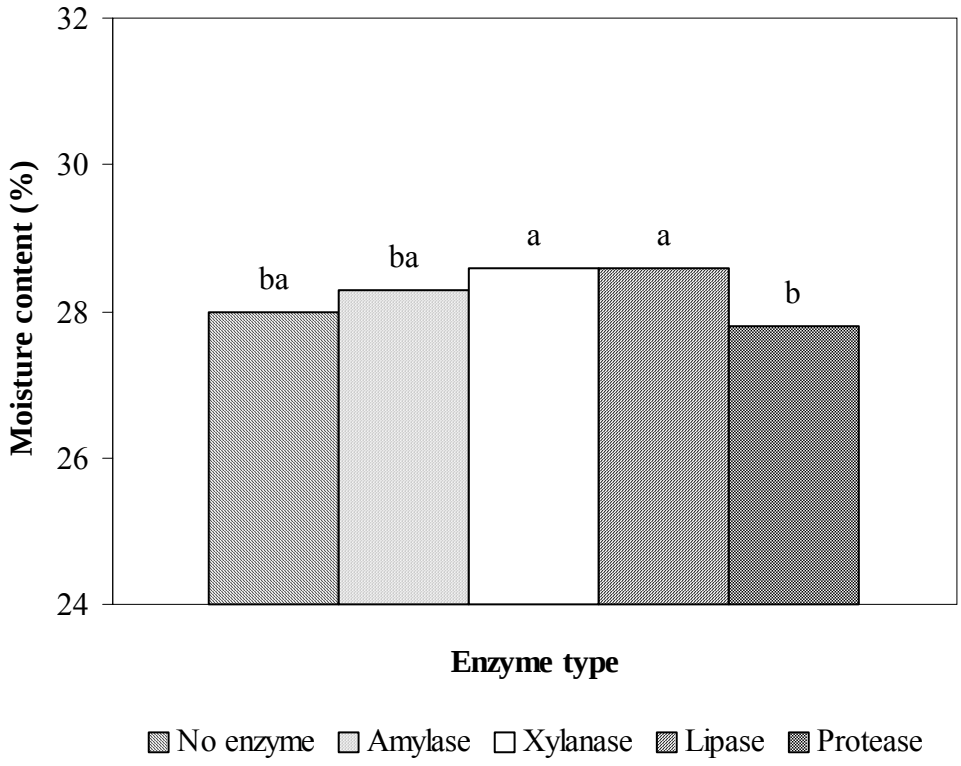

Figure 3.34 Effects of enzymes on the moisture content of breads baked in microwave oven after 2 days of storage

All of the enzymes were found to be significantly effective on firmness of breads baked in microwave oven during storage (Figure 3.35) (Table C.16).

The positive effect of α-amylase was due to its ability to produce dextrins as hydrolysis products, which interfere with amylopectin recrystallization. Amylopectin retrogradation is considered the main cause of crumb firming during storage (Andreu et al., 1999). It was also suggested that the dextrins interfered with the interactions between the swollen starch granules and the continuous protein network responsible for crumb firming in the bread during aging (Akers and Hoseney, 1994).

Protease was found to be effective on control of firmness of breads due to its weakening effect on starch-gluten interactions.

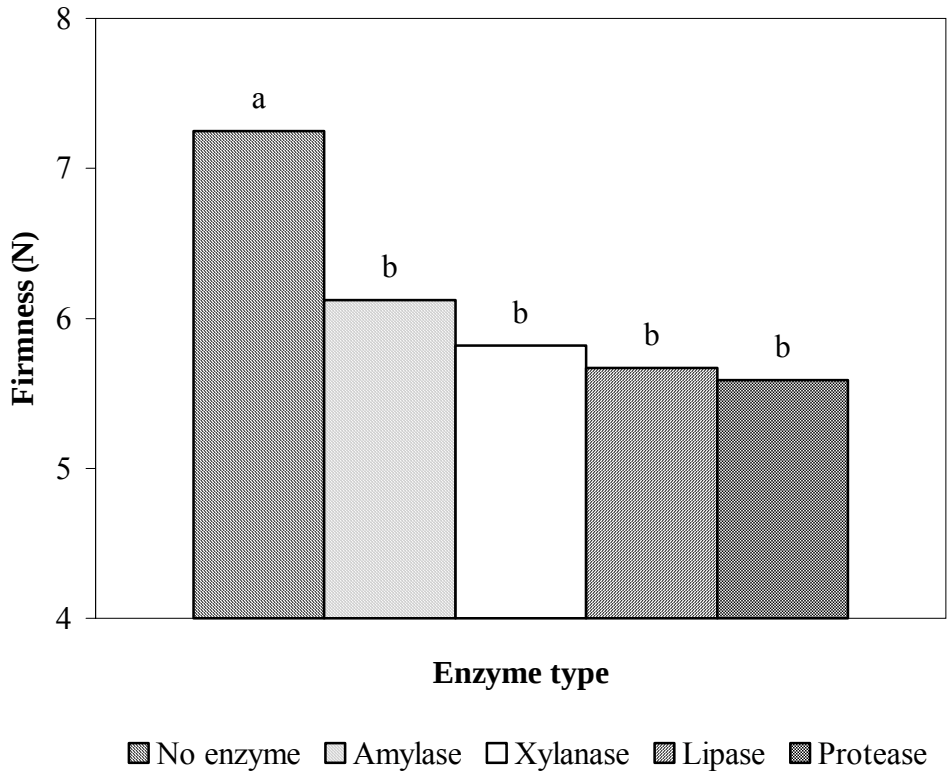

Figure 3.35 Effects of enzymes on firmness of breads baked in microwave oven after 2 days of storage

The effectiveness of lipase on the firmness of microwave baked breads during storage can be explained by the production of mono and diglycerides by lipase. Monoglycerides produced from lipase retard the firming process by forming complexes with amylose. Upon cooling, the complexed amylose will not recrystallize and will not contribute to staling of the bread crumb (Stampfli and Nersten, 1995). Besides the amylose-lipid complexes by lipase, lipase can play a role in hindering amylopectin entanglements inside starch.

The monosaccharides and oligosaccharides resulting from the xylanase action could affect the water balance and may interfere with protein-starch interaction responsible from crumb firming during bread storage (Haros et al., 2002). Therefore, by using xylanase enzyme, staling of breads baked in microwave oven were retarded.

3.3.3 Halogen lamp-Microwave Combination Oven

Enzymes except protease found to be not effective on moisture content of breads baked in combination oven during storage (Table C.17). The moisture content of samples treated with protease was obtained to be statistically different from control and the other enzymes (Figure 3.36).

The decrease in moisture content of breads treated with protease was due to its hydrolysing effects, it caused free water formation because of breakage of peptide bonds through gluten having high water-binding capacity (Haseborg, 1981) and during storage the formed water was removed and breads with low moisture content were obtained after 2 days storage.

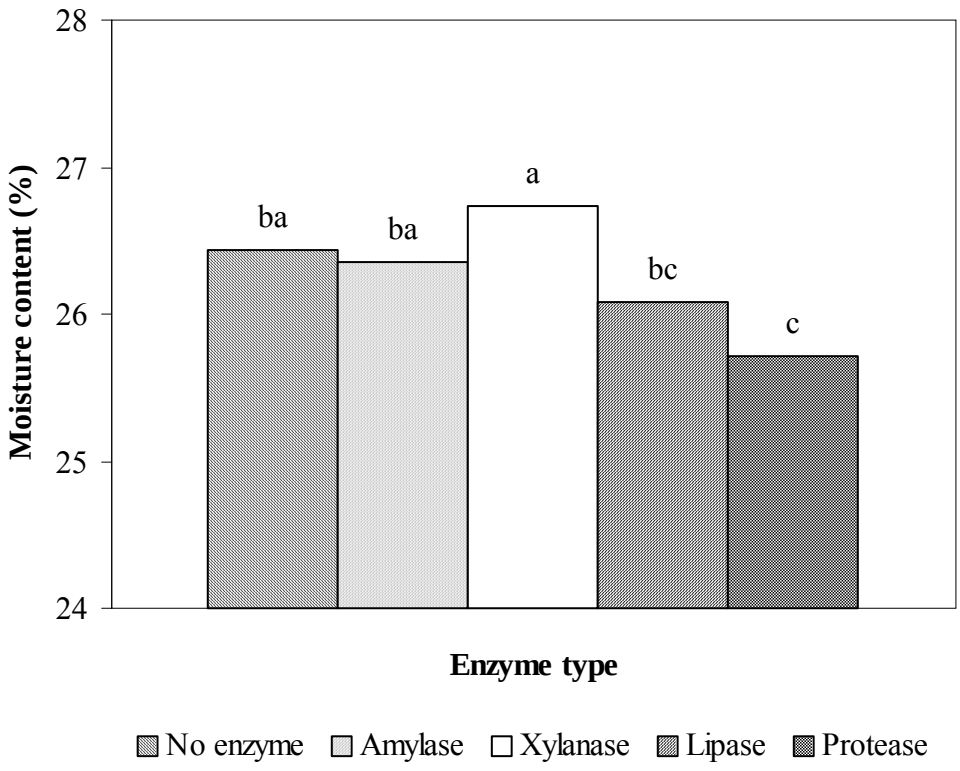

Figure 3.36 Effects of enzymes on moisture content of breads baked in halogen lamp - microwave combination oven after 2 days of storage

Figure 3.37 shows the effects of enzymes on firmness of breads baked at combination oven after 2 days storage. Like microwave baked breads all of the enzymes were found to be effective on controlling of the firmness of breads baked in combination oven during storage (Table C.18). The mechanisms of the enzyme actions on texture control in microwave baking were valid also for halogen lamp-microwave combination treatment.

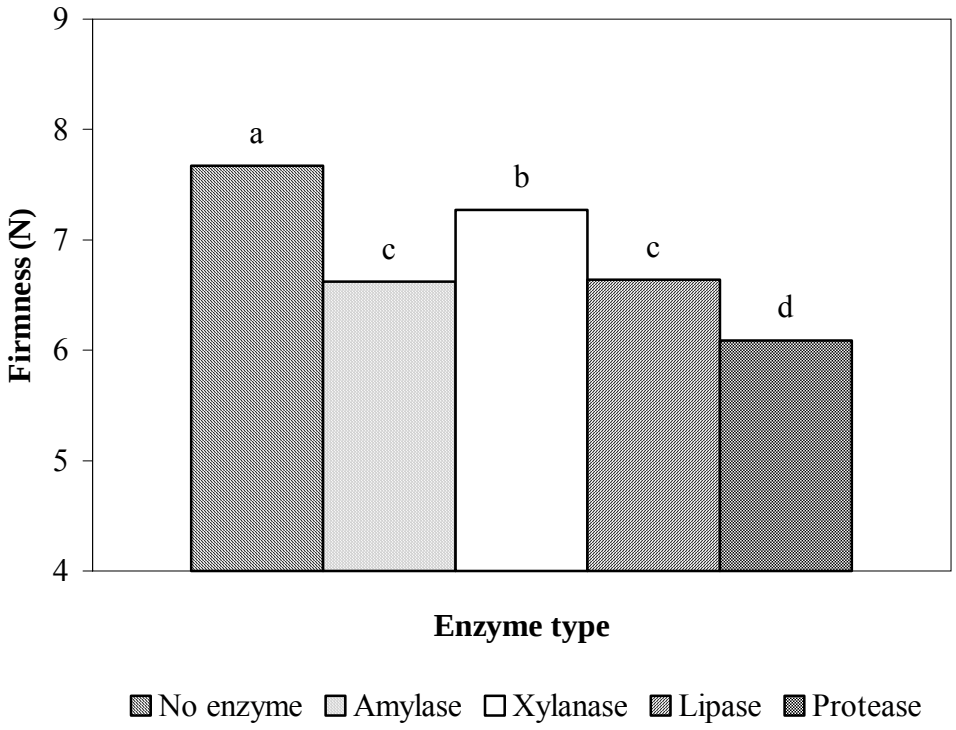

Figure 3.37 Effects of enzymes on firmness of breads baked in halogen lamp - microwave combination oven after 2 days of storage

3.4 Comparison of Quality of Breads Baked in Different Ovens

The optimum baking conditions obtained from the previous parts of the study were used to compare the effects of different baking methods on quality of breads. Figure 3.38 shows the effects of different baking methods on weight loss of breads.

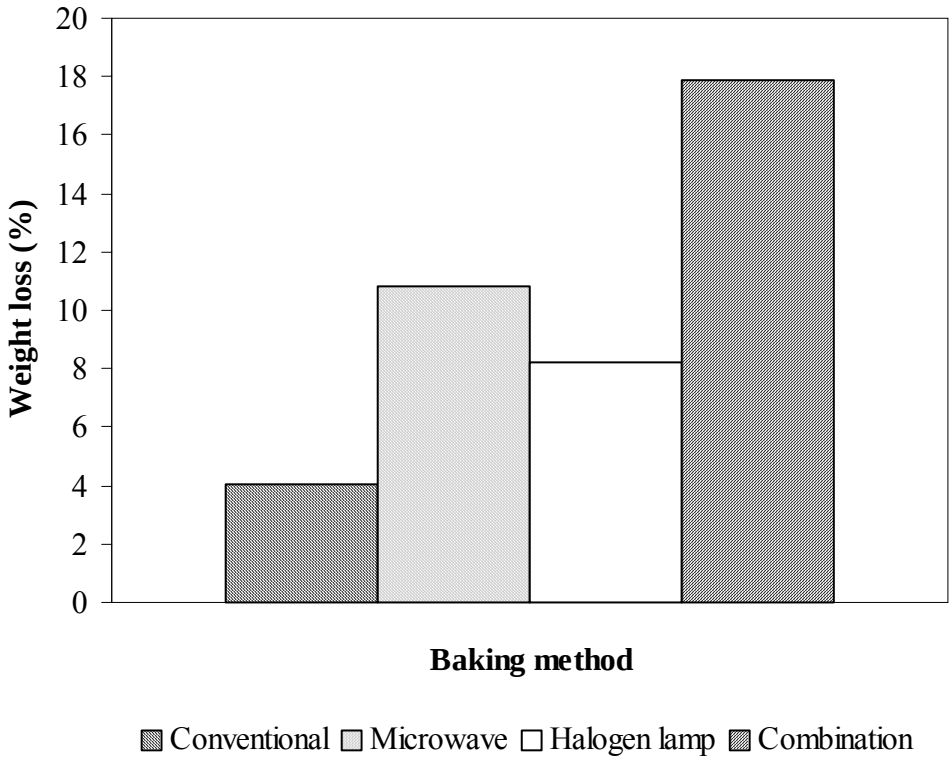

Figure 3.38 Effects of different baking methods on weight loss of breads

As can be seen from the figure, microwave and halogen lamp-microwave combination baking resulted in greater weight loss of breads during processing as compared to conventional baking which was not surprising. Microwave heating provided high moisture loss because of high internal pressure and concentration gradients which increased the flow of liquid through the food to the boundary. Moreover, the high power of the halogen lamp selected for halogen lamp-microwave combination oven provided high moisture loss.

The effects of different baking methods on specific volume of breads can be seen in Figure 3.39.

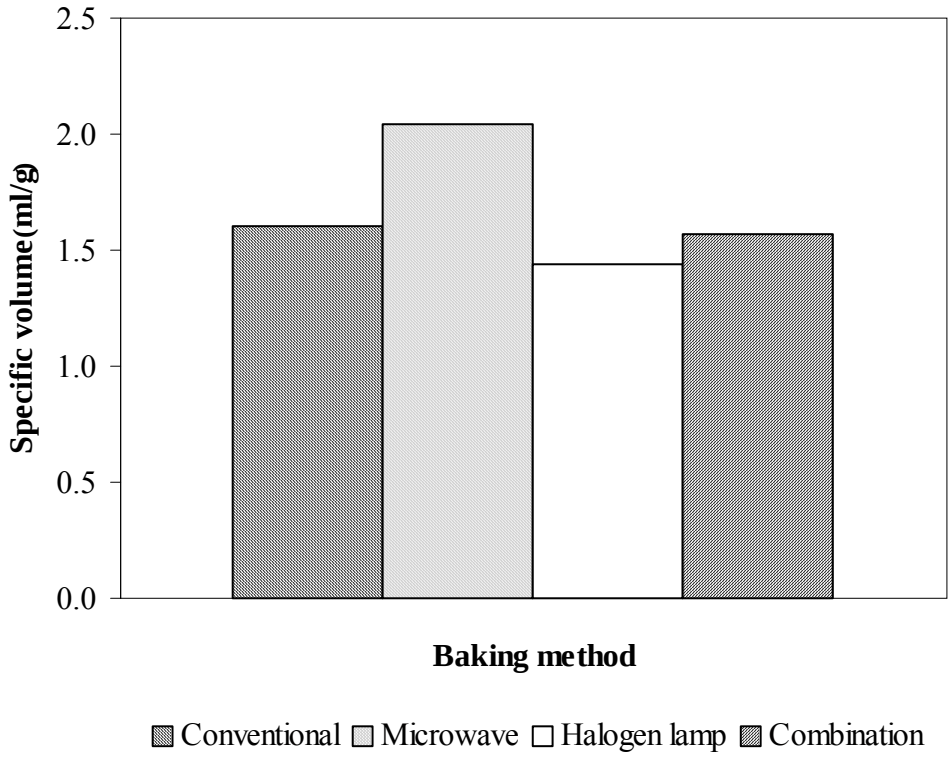

Figure 3.39 Effects of different baking methods on specific volume of breads

Microwave baking caused achievement of breads with the highest specific volume because significant internal pressure created might result in a puffing effect and a high volume. However, in halogen lamp heating a very thick crust was formed. Therefore, the interior texture might be compressed and breads with low volume were obtained. Breads baked in combination oven had specific volume ranging between that of microwave and halogen lamp treated samples. With the combination baking, it was possible to obtain breads with specific volume similar to the conventionally baked ones.

Figure 3.40 demonstrates the effects of different baking methods on firmness of breads. As can be seen from the Figure 3.40, both microwave and halogen lamp-microwave combination baking caused the breads to have the firmer texture. The reasons for firm texture in microwave-baked breads were high moisture loss,

interactions of microwave with gluten and high amylose leaching during baking (Higo and Noguchi, 1987; Shukla, 1993).

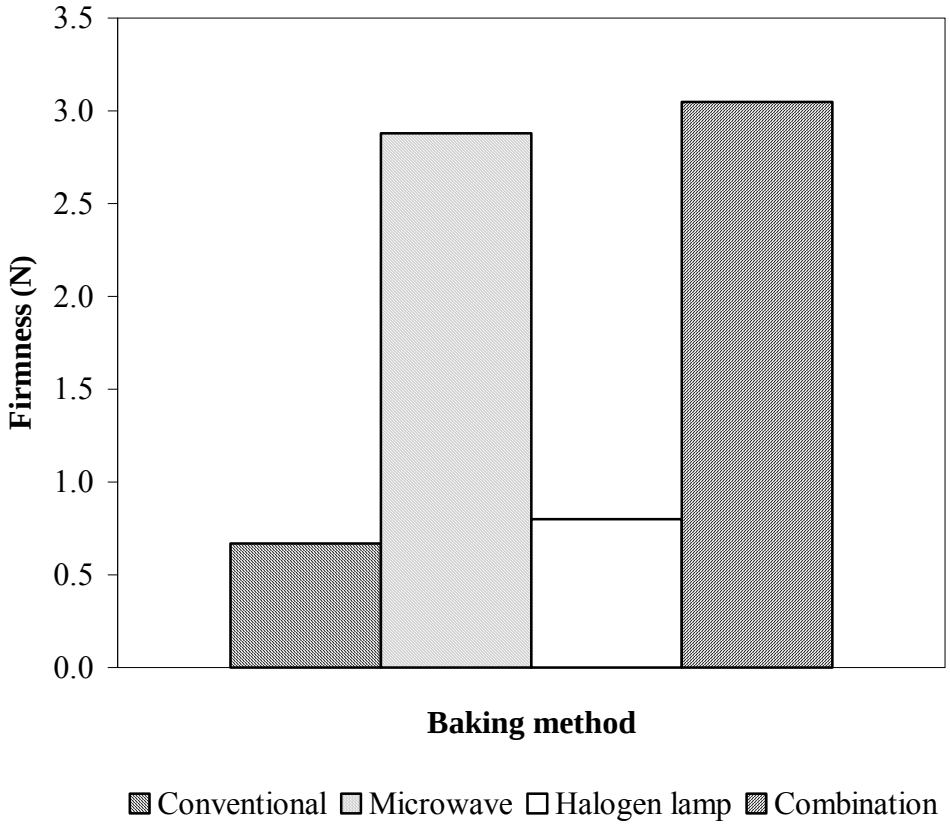

Figure 3.40 Effects of different baking methods on firmness of breads

As previously mentioned microwave heating was the dominant mechanism in combination heating in terms of texture development. Therefore, it was not surprising to obtain the similar firmness values in microwave baked breads to that of breads baked in halogen lamp-microwave combination oven.

Figure 3.41 shows the effects of different baking methods on the ΔE value of breads. Microwave baked breads had the lowest ΔE values which corresponded to a similar color value with the dough. This can be explained by the short baking times and low temperatures common to microwave processing which did not promote browning reactions. On the contrary, high halogen powers for halogen lamp oven

provided the achievement of desired color at the surface in a short time. Therefore, with halogen lamp and halogen lamp-microwave combination baking, similar ΔE values with the conventionally baked breads could be achieved.

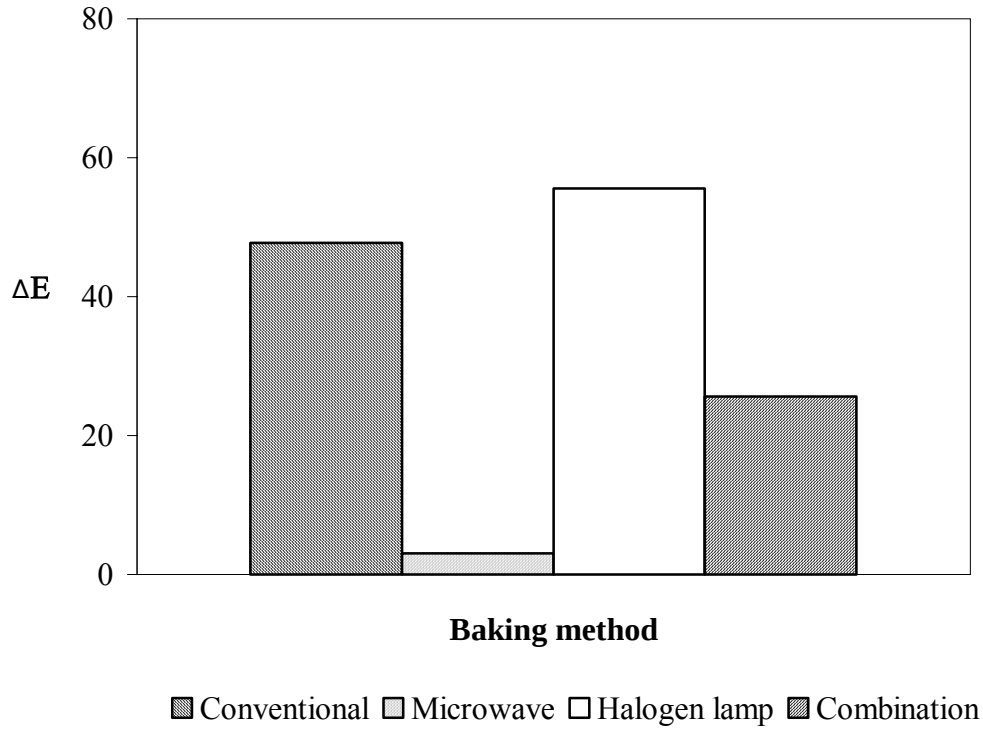

Figure 3.41 Effects of different baking methods on ΔE value of breads

Halogen lamp-microwave combination oven provided crust color and specific volume similar to conventionally baked breads but the weight loss and firmness of breads were still higher as compared to conventionally baked ones. Enzymes were added to the bread formulation especially to reduce the firmness of breads baked in halogen lamp-microwave combination oven.

Table 3.1 shows the percentage of reduction in firmness of breads baked in different ovens as compared to no enzyme added breads. Enzyme addition was found to be very much effective on firmness of breads baked in both microwave and halogen lamp-microwave combination ovens during baking and storage.

Table 3.1 Percentage reduction in firmness of breads baked in different ovens

		Enzyme type			
Oven type	**Time of analysis**	**Amylase**	**Xylanase**	**Lipase**	**Protease**
Conventional	Just after baking	0	0	0	11.94
	After 2 days storage	3.96	18.47	14.51	18.21
Microwave	Just after baking	33.33	29.17	17.71	23.96
	After 2 days storage	15.59	19.72	21.79	22.90
Halogen lamp-Microwave Combination	Just after baking	49.84	47.87	41.97	61.31
	After 2 days storage	13.69	5.22	13.43	20.60

In conventional baking, enzymes were found to be effective on reducing firmness mostly during storage. Unlike conventional baking, all of the enzymes were effective on initial crumb firmness in microwave baking. Such a result was obtained because of the difference in heating mechanisms of conventional and microwave baking. The reasons for firm texture in microwave-baked breads are high moisture loss, interactions of microwaves with gluten and high amounts of amylose leaching during baking (Higo and Noguchi, 1987; Shukla, 1993). Addition of enzymes solved most of these problems related to microwave heating and showed a positive effect on the firmness of breads baked in microwave oven. The initial firmness problem of the bread interior due to the high amount of amylose might have been reduced by addition of α-amylase and lipase enzymes. The firmness problem due to the gluten-microwave interaction and microwave induced gluten changes might be reduced by

the usage of proteases which broke down the gluten protein resulting in softer breads. Hamer (1995), suggested that xylanases could have a specific action on the rate of gluten formation and the quality of the gluten. This may explain the reported beneficial effect of xylanases on crumb structure of breads baked in microwave oven.

As microwave heating was observed to be more dominant in affecting firmness than halogen lamp heating, the effects of enzymes on reducing firmness of breads during halogen lamp-microwave combination baking or storage were found to be similar to microwave baking.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

As baking time, oven power and/or baking temperature increased, weight loss of breads increased for all oven types. Microwave baked breads had higher specific volume as compared to others. The increase in halogen lamp power decreased specific volume of breads but increased weight loss, firmness and ΔE values of breads in combination baking. Firmness was observed to be negatively correlated with specific volume in conventional and halogen lamp baking. In the case of halogen lamp baking, color development could be easily achieved at high halogen powers.

By the usage of halogen lamp-microwave combination baking, the time saving advantage of microwave baking was combined with the browning advantage of halogen lamp heating. Halogen lamp-microwave combination baking provided specific volume and crust color similar to the conventionally baked products but the weight loss and firmness of breads were still higher as compared to conventionally baked ones. Microwave heating was found to be the dominant mechanism in halogen lamp-microwave combination baking in terms of affecting weight loss and texture development. Both microwave and halogen lamp-microwave combination baking caused the breads to have the firmest crumb texture.

In conventional baking, enzymes were found to be effective on reducing firmness mostly during storage whereas in microwave and combination baking, all of the enzymes were effective on reducing initial crumb firmness and firmness during storage. The enzymes were also responsible for the increase of specific volume of breads baked in microwave and halogen lamp-microwave combination ovens. The

color of protease enzyme added breads were found to be significantly different from that of the no enzyme and the other enzyme added breads in the case of all type of ovens.

Further research is necessary to clarify the heating and staling mechanisms of halogen lamp-microwave combination baking and its effect on the reactions that occur during baking thoroughly. In order to obtain totally acceptable products baked in combination oven as compared to conventionally baked ones, the most evident problems, weight loss and firmness should be taken into account first.

In addition to the usage of enzymes, the usage of additives, such as, emulsifiers, starches, gums, etc. can be recommended to solve weight loss and firmness problems in combination oven baking. Moreover, combination enzymes, because of their synergetic effects, may be tried in reducing firmness of breads baked in combination oven. Enzymes with different concentrations may also be used in combination oven. The effects of different enzymes on the quality of different types of breads (rye, whole-wheat, etc.) baked in combination oven can also be studied.

Sensory analysis is also recommended to determine the baked flavor and bring the other quality parameters to an acceptable point so that it may be possible to obtain breads baked in combination oven that can compete with conventionally baked breads through appearance and eating quality.

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APPENDIX A

MODEL CONSTANTS

Table A.1 Model constants for weight loss of breads baked in conventional oven

y = ax + b (a: slope; b: intercept)			
	175°C	200°C	225°C
a	0.95	0.96	1.02
b	-8.21	-8.30	-8.91
r^2	0.99	0.99	0.98

Table A.2 Model constants for ΔE value of breads baked in conventional oven

y = ax + b			
	175°C	200°C	225°C
a	0.40	0.65	2.00
b	40.97	39.15	22.4
r^2	0.92	0.98	0.94

Table A.3 Model constants for weight loss of breads baked in microwave oven

y = ax + b		
	50%	100%
a	10.71	23.00
b	-4.57	-6.72
r^2	0.99	1.0

Table A.4 Model constants for weight loss of breads baked in halogen lamp oven

y = ax + b			
	50%	60%	70%
a	1.59	1.73	1.62
b	-10.63	-9.46	-7.30
r^2	0.99	0.97	0.98

Table A.5 Model constants for ΔE value of breads baked in halogen lamp oven

y = ax + b			
	50%	60%	70%
a	2.28	4.22	6.62
b	24.23	13.68	$-4*10^{-13}$
r^2	0.96	0.99	0.94

Table A.6 Model constants for weight loss of breads baked in halogen lamp-microwave combination oven (H: Halogen power; MW: Microwave power)

y = ax + b					
	H: 40% & MW: 30%	H: 50% & MW: 30%	H: 60% & MW: 30%	H: 70% & MW: 30%	H: 60% & MW: 50%
a	8.06	8.06	7.48	8.16	12.36
b	-9.93	-9.27	-5.96	-7.09	-7.81
r^2	1.0	0.99	0.99	0.99	0.97

Table A.7 Model constants for ΔE value of breads baked in halogen lamp-microwave combination oven

y = ax + b					
	H: 40% & MW: 30%	H: 50% & MW: 30%	H: 60% & MW: 30%	H: 70% & MW: 30%	H: 60% & MW: 50%
a	17.22	17.38	16.54	17.72	23.54
b	-58.01	-47.79	-35.15	-27.04	-38.29
r^2	0.98	0.96	0.96	0.99	0.80

APPENDIX B

CORRELATION COEFFICIENTS

Table B.1 Correlation coefficients of specific volume and crumb firmness of conventionally baked breads at different temperatures

	Correlation coefficient
175°C	-1.00
200°C	-0.99
225°C	-0.94

Table B.2 Correlation coefficients of weight loss and crumb firmness of microwave baked breads at different oven powers

	Correlation coefficient
50%	0.94
100%	0.90

Table B.3 Correlation coefficients of specific volume and crumb firmness of halogen lamp baked breads at different oven powers

	Correlation coefficient
50%	-0.98
60%	-0.90
70%	-0.91

APPENDIX C

ANOVA and DUNCAN TABLES

Table C.1 ANOVA and Duncan's Multiple Range Test Table for moisture content of conventionally baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 20

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	0.15273000	0.03818250	1.18	0.3601
Error	15	0.48635000	0.03242333		
Total	19	0.63908000			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	0.15273000	0.03818250	1.18	0.3601

Alpha = 0.05

Means with the same letter are not significantly different.

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	38.3750	4	lipase
A	38.3375	4	xylanase
A	38.2225	4	amylase
A	38.1850	4	no enzyme
A	38.1500	4	protease

Table C.2 ANOVA and Duncan's Multiple Range Test Table for specific volume of conventionally baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 13

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	0.05693974	0.01423494	15.85	0.0007
Error	8	0.00718333	0.00089792		
Total	12	0.06412308			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	0.05693974	0.01423494	15.85	0.0007

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	1.7067	3	protease
B	1.6000	3	no enzyme
CB	1.5750	2	xylanase
CB	1.5367	3	amylase
C	1.5300	2	lipase

Table C.3 ANOVA and Duncan's Multiple Range Test Table for firmness of conventionally baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	6	1, 2, 3, 4, 5, 6

Number of observations in data set = 22

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	0.07799881	0.01949970	3.08	0.0444
Error	17	0.10756515	0.00632736		
Total	21	0.18556396			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	0.07799881	0.01949970	3.08	0.0444

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	0.7584	5	amylase
A	0.7315	4	lipase
BA	0.6683	4	xylanase
BA	0.6666	5	no enzyme
B	0.5855	4	protease

Table C.4 ANOVA and Duncan's Multiple Range Test Table for ΔE value of conventionally baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme , amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	157.98000000	39.49500000	37.83	0.0001
Error	10	10.44000000	1.04400000		
Total	14	168.42000000			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	157.98000000	39.49500000	37.83	0.0001

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	55.5000	3	protease
B	49.4000	3	amylase
CB	47.7000	3	no enzyme
CB	47.5000	3	xylanase
C	46.4000	3	lipase

Table C.5 ANOVA and Duncan's Multiple Range Test Table for moisture content of microwave baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 18

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	0.14829444	0.03707361	0.14	0.9631
Error	13	3.37728333	0.25979103		
Total	17	3.52557778			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	0.14829444	0.03707361	0.14	0.9631

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	33.7600	4	amylase
A	33.7467	3	lipase
A	33.7075	4	xylanase
A	33.6267	3	protease
A	33.5225	4	no enzyme

Table C.6 ANOVA and Duncan's Multiple Range Test Table for specific volume of microwave baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 12

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	0.10463333	0.02615833	57.82	0.0001
Error	7	0.00316667	0.00045238		
Total	11	0.10780000			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	0.10463333	0.02615833	57.82	0.0001

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	2.3000	2	protease
A	2.2550	2	amylase
B	2.1533	3	xylanase
B	2.1150	2	lipase
C	2.0400	3	no enzyme

Table C.7 ANOVA and Duncan's Multiple Range Test Table for firmness of microwave baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	6	1, 2, 3, 4, 5, 6

Number of observations in data set = 20

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	2.09778833	0.52444708	21.06	0.0001
Error	15	0.37359167	0.02490611		
Total	19	2.47138000			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	2.09778833	0.52444708	21.06	0.0001

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	2.8825	4	no enzyme
B	2.3650	4	lipase
CB	2.1883	6	protease
CD	2.0367	3	xylanase
D	1.9167	3	amylase

Table C.8 ANOVA and Duncan's Multiple Range Test Table for ΔE value of microwave baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	15.81600000	3.95400000	169.46	0.0001
Error	10	0.23333333	0.02333333		
Total	14	16.04933333			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	15.81600000	3.95400000	169.46	0.0001

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	5.1667	3	protease
B	3.0333	3	no enzyme
CB	2.7667	3	amylase
C	2.6333	3	lipase
D	2.2667	3	xylanase

Table C.9 ANOVA and Duncan's Multiple Range Test Table for moisture content of halogen lamp-microwave combination baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 14

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	1.47550238	0.36887560	3.09	0.0735
Error	9	1.07273333	0.11919259		
Total	13	2.54823571			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	1.47550238	0.36887560	3.09	0.0735

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	28.4400	2	amylase
BA	27.8100	3	no enzyme
BA	27.7900	3	xylanase
B	27.5233	3	protease
B	27.4067	3	lipase

Table C.10 ANOVA and Duncan's Multiple Range Test Table for specific volume of halogen lamp-microwave combination baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	0.02942667	0.00735667	68.97	0.0001
Error	10	0.00106667	0.00010667		
Total	14	0.03049333			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	0.02942667	0.00735667	68.97	0.0001

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	1.6967	3	protease
B	1.6067	3	amylase
CB	1.5900	3	xylanase
C	1.5867	3	lipase
C	1.5733	3	no enzyme

Table C.11 ANOVA and Duncan's Multiple Range Test Table for firmness of halogen lamp-microwave combination baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	6	1, 2, 3, 4, 5, 6

Number of observations in data set = 20

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	8.21297000	2.05324250	171.53	0.0001
Error	15	0.17955000	0.01197000		
Total	19	8.39252000			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	8.21297000	2.05324250	171.53	0.0001

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	3.0450	4	no enzyme
B	1.7725	4	lipase
C	1.5850	4	xylanase
C	1.5275	4	amylase
D	1.1800	4	protease

Table C.12 ANOVA and Duncan's Multiple Range Test Table for ΔE value of halogen lamp-microwave combination baked breads formulated with different enzyme types just after baking

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	49.04666667	12.26166667	117.15	0.0001
Error	10	1.04666667	0.10466667		
Total	14	50.09333333			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	49.04666667	12.26166667	117.15	0.0001

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	30.5667	3	protease
B	27.3333	3	xylanase
B	27.2000	3	lipase
C	25.6667	3	amylase
C	25.5667	3	no enzyme

Table C.13 ANOVA and Duncan's Multiple Range Test Table for moisture content of conventionally baked breads formulated with different enzyme types after 2 days storage

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	3.87769333	0.96942333	6.25	0.0087
Error	10	1.55040000	0.15504000		
Total	14	5.42809333			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	3.87769333	0.96942333	6.25	0.0087

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	36.8700	3	xylanase
A	36.7000	3	no enzyme
A	36.5967	3	lipase
A	36.5033	3	amylase
B	35.4333	3	protease

Table C.14 ANOVA and Duncan's Multiple Range Test Table for firmness of conventionally baked breads formulated with different enzyme types after 2 days storage

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	6	1, 2, 3, 4 ,5, 6

Number of observations in data set = 19

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	1.54418886	0.38604721	2.41	0.0980
Error	14	2.23802167	0.15985869		
Total	18	3.78221053			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	1.54418886	0.38604721	2.41	0.0980

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	3.7900	3	no enzyme
BA	3.6425	4	amylase
BA	3.2433	3	lipase
B	3.0980	5	protease
B	3.0900	4	xylanase

Table C.15 ANOVA and Duncan's Multiple Range Test Table for moisture content of microwave baked breads formulated with different enzyme types after 2 days storage

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	1.41989333	0.35497333	4.02	0.0338
Error	10	0.88260000	0.08826000		
Total	14	2.30249333			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	1.41989333	0.35497333	4.02	0.0338

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	28.5833	3	lipase
A	28.5567	3	xylanase
BA	28.3433	3	amylase
BA	28.0300	3	no enzyme
B	27.7900	3	protease

Table C.16 ANOVA and Duncan's Multiple Range Test Table for firmness of microwave baked breads formulated with different enzyme types after 2 days storage

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	6	1, 2, 3, 4, 5, 6

Number of observations in data set = 27

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	8.29981657	2.07495414	2.83	0.0490
Error	22	16.10485750	0.73203898		
Total	26	24.40467407			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	8.29981657	2.07495414	2.83	0.0490

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	7.2500	5	no enzyme
B	6.1150	6	amylase
B	5.8160	5	xylanase
B	5.6650	5	lipase
B	5.5888	6	protease

Table C.17 ANOVA and Duncan's Multiple Range Test Table for moisture content of halogen lamp-microwave combination baked breads formulated with different enzyme types after 2 days storage

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	4	1, 2, 3, 4

Number of observations in data set = 15

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	1.77230667	0.44307667	10.42	0.0014
Error	10	0.42506667	0.04250667		
Total	14	2.19737333			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	1.77230667	0.44307667	10.42	0.0014

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	26.7300	3	xylanase
BA	26.4400	3	no enzyme
BA	26.3600	3	amylase
BC	26.0800	3	lipase
C	25.7167	3	protease

Table C.18 ANOVA and Duncan's Multiple Range Test Table for firmness of halogen lamp-microwave combination baked breads formulated with different enzyme types after 2 days storage

Class	Levels	Values
Enzyme types	5	no enzyme, amylase, xylanase, lipase, protease
Replications	6	1, 2, 3, 4, 5, 6

Number of observations in data set = 19

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	6.03773333	1.50943333	32.19	0.0001
Error	14	0.65646667	0.04689048		
Total	18	6.69420000			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Enzyme type	4	6.03773333	1.50943333	32.19	0.0001

Duncan Grouping	**Mean**	**N**	**Enzyme Type**
A	7.6700	4	no enzyme
B	7.2700	4	xylanase
C	6.6400	4	lipase
C	6.6167	3	amylase
D	6.0900	4	protease

APPENDIX D

REGRESSION TABLES

Table D.1 Regression table for weight loss of breads baked in halogen lamp-microwave combination oven

General Linear Models Procedure

Dependent variable: Y1 Weight loss

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	167.94202690	33.58840538	612.03	0.0016
Error	2	0.10976060	0.05488030		
Total	7	168.05178750			

R-square	C.V.	Root MSE	Y1 Mean
0.999347	1.128242	0.23426545	20.7637500

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
X1	1	0.21565496	0.21565496	3.93	0.1859
X2	1	0.09135513	0.09135513	1.66	0.3260
X1*X1	1	0.03955015	0.03955015	0.72	0.4853
X1*X2	1	0.02935528	0.02935528	0.53	0.5406
X2*X2	1	0.06040570	0.06040570	1.10	0.4042

Parameter	Estimate	$P_r > \| T \|$
INTERCEPT	-29.80168000	0.2594
X1	13.38768000	0.1859
X2	0.35344400	0.3260
X1*X1	-0.51184000	0.4853
X1*X2	-0.03279600	0.5406
X2*X2	-0.00129120	0.4042

Table D.2 Regression table for specific volume of breads baked in halogen lamp-microwave combination oven

General Linear Models Procedure

Dependent variable: Y2 Specific volume

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	0.01539090	0.00307818	63.73	0.0155
Error	2	0.00009660	0.00004830		
Total	7	0.01548750			

R-square	C.V.	Root MSE	Y2 Mean
0.993763	0.440210	0.00694982	1.57875000

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
X1	1	0.00002783	0.00002783	0.58	0.5271
X2	1	0.00024931	0.00024931	5.16	0.1510
X1*X1	1	0.00000014	0.00000014	0.00	0.9621
X1*X2	1	0.00005946	0.00005946	1.23	0.3827
X2*X2	1	0.00027550	0.00027550	5.70	0.1395

Parameter	Estimate	$P_r > \mid T \mid$
INTERCEPT	2.596080000	0.0446
X1	-0.152080000	0.5271
X2	-0.018464000	0.1510
X1*X1	-0.000960000	0.9621
X1*X2	0.001476000	0.3827
X2*X2	0.000087200	0.1395

Table D.3 Regression table for ΔE value of breads baked in halogen lamp-microwave combination oven

General Linear Models Procedure

Dependent variable: Y3 ΔE value

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	2004.27928387	400.85585677	91.07	0.0001
Error	10	44.01509113	4.40150911		
Total	15	2048.29437500			

R-square	C.V.	Root MSE	Y3 Mean
0.978511	8.504595	2.09797739	24.66875000

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
X1	1	2.75016583	2.75016583	0.62	0.4476
X2	1	1.66567460	1.66567460	0.38	0.5522
X1*X1	1	0.00475712	0.00475712	0.00	0.9744
X1*X2	1	0.00003359	0.00003359	0.00	0.9979
X2*X2	1	1.33965271	1.33965271	0.30	0.5933

Parameter	Estimate	$P_r > \| T \|$
INTERCEPT	-90.31009007	0.2053
X1	16.82240551	0.4476
X2	0.68548393	0.5522
X1*X1	0.05877782	0.9744
X1*X2	0.00041611	0.9979
X2*X2	0.00352142	0.5933