CHARACTERIZATIONS OF FLAXSEED ENRICHED WHEAT DOUGH AND BREAD PRODUCT

TANUNDORN VENG

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Thesis	Characterizations of Flaxseed Enriched Wheat Dough and Bread Product
Student	Mr. Tanundorn Veng
Student ID	63601158
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Thesis Advisor	Asst. Prof. Dr.Eakasit Sritham

ABSTRACT

This research was aimed at investigating the effects of flaxseed enrichment on wheat dough and bread product and exploring the application of using infrared radiation (IR) technique to measure the surface temperature of bread during baking. Flaxseed enrichment was made at 10%, 15% and 20% flour weight basis. Large deformation rheological characteristics of fresh and refrigerated dough samples (at 4°C for up to 35 days) were obtained using the Kieffer-type extensibility rig. The degree of syruping in refrigerated dough was measured using a centrifugal technique. The instrumental textural property of bread was determined using a texture profile analysis (TPA) technique. The specific volume of bread loaf was measured using rapeseed displacement method. Bread samples were also stored at 4°C and 18°C for up to 7 days to observe the staling behavior inferred from the evolution of bread crumb hardness. It was found that flaxseed could be added up to 15% without any significant effect on the rheological parameters of dough including the peak load, the deformation at peak load and the distance to rupture point, and on the textural parameters (hardness, cohesiveness, springiness and chewiness) of bread product. A significant reduction of specific volume of bread loaf was detectable when flaxseed enrichment levels were 15% and 20%. In general bread crumb hardening occurred with a higher rate at 4°C compared to that at 18°C. The addition of flaxseed could help retard the hardening rate of bread samples. For refrigerated dough, the degree of dough syruping was suppressed upon the addition of flaxseed. A significant correlation between the degree of dough syruping and some physical properties of bread including specific volume, hardness, cohesiveness, and chewiness was found. As compared to a baking process with a fixed temperature setting, baking with a step-change temperature setting yielded bread product with lesser weight loss. The baking process with the temperatures of 180°C, 120°C, and 170°C for stages 1, 2, and 3, respectively, allowed bread samples to be properly cooked. The emissivity (ε) value of bread tended to linearly decrease with the increasing surface temperature. A high correlation between the surface and the core temperatures of bread loaf suggests the possibility of using IR technique for a real-time, non-contact temperature measurement to monitor and control the baking process.

Keywords: Bread, Dough, Emissivity, Extensibility, Flaxseed, Refrigerated Dough

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NOMENCLATURE

Symbol		
DDS	Degree of dough syruping	%
$D\text{-}Peak$	Deformation at peak load	mm
$D\text{-}Rupture$	Deformation at rupture point	mm
H_{avg}	Average value of hardness	N
H_t	Hardness at time t	N
H_{pred}	Predicted or fitted hardness	N
H_0	Hardness at initial time	N
H_∞	Hardness at infinity time	N
k	Rate constant	
M_i	Initial mass	g
M_f	Final mass	g
n	Avrami exponent	
R^2	Coefficient of determination	
$t_{1/2}$	Half-life	day
V_{loaf}	Volume of bread loaf	cm^3
v_{loaf}	Specific volume of loaf	cm^3/g

CHAPTER 1

INTRODUCTION

1.1 Rationale

Bread is the staple food that could be found in any corner of the world. Bread has become a part of daily meals since its invention by the ancient Egyptians.

Bread has long been consumed worldwide. The bread market is currently growing with the size of USD 208.7 Billion and is expected to continually grow at a compound annual growth rate (CAGR) of 3.6% during 2023-2029. North America and Europe are considered as the biggest consumers of bread, while the increasing demand has also been reported in other emerging economic regions of the globe, primarily in China [1].

Although bread is one of the staples of our diet and has nutritional value, we also know that bread may contain high calories. Nowadays people are conscious of the health and nutritional value of their food. That's why they are developing more nutritious bread.

Bread has different types with different shapes, colors, textures, and flavors. Bread is also made from many materials. Bread might not be considered a healthy food since its composition which usually made of flour with high protein content. However, there are other kinds of bread made from whole wheat flour called whole wheat bread. This kind of bread is better in nutritional value such as the fiber content, vitamins, and minerals which are retained in the bran layer of the wheat in the ingredients but in exchange for them, the bread will come with some undesirable aspects compared to the white bread [2]. The enrichment of flaxseed as the source of dietary fiber has been reported to have some undesirable profiles on the dough's characteristics and the bread. The study of the stickiness of the dough development as well as the reduction of the bread's loaf were investigated in the fortified bread.

There has been declared the loss of textual perception and darker color upon the addition of flaxseed [3], [4].

Some attributes such as physical characteristics including texture, flavor, and crust color must be archived for consumer acceptance. These characteristics could be formed from the early stage of preparation like formulation, storing, and baking step. Getting bread with good quality is becoming interesting for the bakers and it requires a lot of techniques in other to achieve that goal. Choosing the right raw materials or addition of some nutritional supplement ingredient should be helpful for the health aspect improvement but the usage of the right quantity must be studied to avoid any undesirable outcome on the bread product.

For the prebaking bread, the impaired appearance might usually come with the bread product. The solution should be concerned and studied. Baking is also the vital step since baking temperature is one of the influental factor that affect the quality of final bread product. Optimization of baking temperature must be considered for gaining the bread quality as well as avoiding drawbacks like weight loss. The application of some noncontact measurements might also be required in terms of contamination prevention and implementation on the industrial scale.

1.2 Objectives

The objectives of this research were:

1) To investigate the effects of flaxseed enrichment on rheological characteristics of dough
2) To study the quality and staling behavior of flaxseed enrichment bread product
3) To investigate the effects of flaxseed enrichment on syruping behavior of refrigerated dough
4) To explore the possibility to use infrared thermography technique to measure the crust and crumb temperatures of bread during baking.

1.3 Scope of the Study

1) The effects of flaxseed enrichment on dough and bread product were studied by adding ground flaxseed for three different levels including 10%, 15% and 20% flour weight basis. Rheological property of dough was measured using a large deformation test with the Kieffer-type extensibility rig. Instrumental textural quality of bread was determined using a texture profile analysis (TPA).
2) Staling behavior of flaxseed fortified bread was observed at two different storage temperatures: 4°C and 18°C, for up to 7 days. The magnitude of staling was determined from crumb hardness.
3) Dough refrigeration experiment was carried out at 4°C for up to 35 days. The degree of dough syruping was measured using a centrifugal technique.
4) For noncontact temperature measurement, bread baking was carried out in the temperature range of 120 – 190°C using three different three-stage temperature settings including 180°C-120°C-170°C, 180°C-120°C-180°C, and 180°C-120°C-190°C. The temperature measurements were made using a thermal image camera and an infrared sensor.

1.4 Expected Outcomes and Significance

1) The influences of flaxseed addition on wheat dough rheological characteristic which could affect the processability and on bread properties which might have adverse effects on consumer acceptability and bread shelflife.
2) The influences of flaxseed additional on syruping behavior of dough are crucial information to obtain refrigerated dough with acceptable quality.
3) The emissivity value obtained from the temperarture measurement based on infrared radiation is an important parameter for the application of a real-time, noncontact temperature measurement as a tool to help controlling the final quality of baking product.

CHAPTER 2

LITERATURE REVIEW

2.1 History of Bread

The history of bread has begun since the very first civilization of human history. The evidence indicated the existence of bread bread-making 22,500 years ago when people started farming and raising animals in the Neolithic Revolution. At that time, archeological research mentioned that people started to transform the gains they planted into food by cooking since they could not eat them raw and the methods they might have used were sprouting, fermenting, roasting, boiling, and baking. Baking was a better way of cooking since it could provide both nutritional value and practical usage compared to other methods. The archaeological digs also found that systematic starch collecting, and grinding happened a thousand years before agriculture's inventions such as the grindstone [1]. The history of bread was also associated with some of the country's history like the Uruk, considered the world's first city. The Urak literature mentioned that bread was at the center of their concept of civilization. In ancient Egypt, bread and beer were paired, offered to deities, and staples for daily life as well.

2.2 Common Ingredients of Bread

Bread recipes normally consist of bread flour as the main ingredient, water, as well as yeast as leavening argent, and other flavored substances like salt and sugar. There are four of them which are the main ingredients for bread making [2].

2.2.1 Flour

First of them is flour which is the most important ingredient giving the bread characteristic. Protein is the main component that could only be gotten from the flour. The more protein content, the more gluten formation in the dough. The gluten could only be formed from the protein when the dough is mixed. It is a stretchy material providing dough strength and allows it to rise. The protein content varies depending on the kind of flour used. For example, pastry flour contains around 9%, all-purpose flour contains 10.5%, bread flour has 12.5% and high-gluten bread has 14% of protein content. The bakers could also mix different kinds of flour in other to get the dough with the amount of protein content they wanted. But they should consider the outcome effects since different flour could provide their own uniqueness to the bread. Whole wheat flour is made of the whole kernel of wheat which also include the bran and it could interfere with the gluten formation while mixing. It makes the dough rise slowly and produces the bread with a denser texture, but it could provide a nutty flavor and nutrition to the bread. Rye flour contains less gluten but more sugar than wheat flour, this makes the dough sticky and rip apart easily. It takes more time for baking at the low temperature used and the bread gotten is dense and gummy.

2.2.2 Rising Agent

It is the ingredient that makes the dough rise because of fermentation. They could be yeast, preferment made with yeast, and starters that contain bacteria and wild yeast. The most common we could normally be found in the bakery is yeast in different forms such as fresh yeast, active dry yeast, and instant yeast. Fresh yeast is a block consisting of active yeast cells in a sugar-water casing. It is preserved by refrigeration with a shelf life of two weeks or could be frozen for a few months. It can be added to the flour or crumbled onto the dough later in the mixing process with the amount of two to four times more than the use of dry yeast. Active yeast is easier to find and much more convenient than fresh yeast but there are detrimental effects on bread dough. It comes in small packets or in a jar in the form of small granules which contain mostly dried yeast. It could be kept in a sealed package for over a year without refrigeration. Once open, it could be stored in the refrigerator for months. Before usage, it needs to be mixed with warm water in other to activate it. Adding it to cold water could kill the yeast since it is sensitive to cold, and it could then release a chemical called glutathione that provide a bad effect on gluten. The last type is instant yeast which is commonly used in the bakery. It is developed in the combination of the convenience of active dry yeast and the quality of fresh yeast. It is the little granules of yeast cells encased in a sugar coating and dried with a special process, so it is also just like the dried yeast. Unlike active dried yeast, it is not sensitive to cold, and it does not need to be activated before usage. It could be added to the flour or sprinkled onto the dough during the mixing process.

2.2.3 Water

The simplest ingredient among others is water. Though it has important characteristics for dough forming. Water works as the solvent hydrating all the ingredients and enabling the molecule to move about in the dough.

2.2.4 Salt

Salt is normally noticed to give the salty flavor to the bread but there is more to it. Salt can dehydrate the bacteria and work as a preservative to prolong the shelf life of the bread. It also dehydrates the yeast and slows down the fermentation reaction in the dough which gives a longer time for the fermentation process and allows more flavor development. Furthermore, it could also make the gluten structure become stronger by stabilizing the gluten network in the dough.

2.3 Wheat dough

The various texture of baked products is created from the structure of dough. It is composed of three important elements including water, flour's gluten proteins, and its starch granules to create an integrated, cohesive mass. Dough is a mixture of water and flour. Flour is generally presents more than water in dough and it is stiff enough to be manipulated by hand. Water is used to bind with gluten proteins and to the surface of the starch granules to form a semisolid gluten-water matrix. This structure is temporary until it is heated or cooked, starch granules absorb water creating a solid permanent solid structure in the form of a sponge-like network of starch and proteins filled with millions of tiny air pockets called “Crumb”. While the outer surface became dry and dense in texture called the “Crust”.

Gluten is a complex mix of some wheat proteins that don't dissolve in water but do form associations with water molecules and each other. Proteins are long, chain-like molecules developed from smaller molecules called amino acids. The majority of the gliadins and glutenins, which make up the gluten proteins, are about a thousand amino acids long. Glutenin proteins are long chains, while gliadins are shorter and globular. Glutenin is responsible for the elasticity of dough, while gliadin is responsible for the extensibility— the dough’s ability to stretch without ripping [2]. A short chain of the gliadins only binds to each other or to glutenin proteins. As the glutenin bound to one another in a variety of ways, creating a vast, tightly knit network. Sulfur-containing amino acids can form strong sulfur-sulfur bonds with the same amino acids at the ends of other glutenin chains. The availability of oxidizing agent-oxygen in the air is required for the binding as well as certain substances produced by yeasts or dough improvers. Most of the amino acids in the coiled middle stretch of the glutenin molecule form weaker, temporary bonds with similar amino acids (hydrogen and hydrophobic bonds). Glutenin chains thus link up with each other end-to-end to form super-chains a few hundred glutenins long, and coiled stretches along their lengths readily form many temporary bonds with similar stretches along neighboring gluten proteins, resulting in an extensive interconnected network known as the "Gluten”. Because the gluten is both elastic and plastic, it could withstand pressure and return to its original form when the pressure is released. This makes it could extend to consolidate the carbon dioxide gas created by yeast and oppose the breaking point by the air pocket walls expension [3].

2.4 Dough Preparation

Mixing all of the ingredients is the first step in making bread. When flour and water meet, a number of things happen. Water is absorbed by broken starch granules, and enzymes break down the exposed starch into sugars. Alcohol and carbon dioxide are produced by the yeast cells as they consume the sugars. The first strands of gluten are formed by the coils of neighboring molecules that form many weak bonds with one another after the glutenin proteins absorb some water and spread out into their elongated coils. The dough takes on a semblance of a fibrous appearance, and we can feel it joining together. When it is stirred, the protein aggregates join together to form visible filaments. Simultaneously, numerous substances in the flour cause breaks in and blocking of the end-to-end bonds of the gluten molecules, and so an initial shortening of the gluten chains. The gluten molecules begin to bond end-to-end and form long chains as the oxygen from the air and oxidizing compounds from the yeast enter the dough.

The development or kneading of the dough is the next step. The dough is stretched, folded over, and compressed numerous times during this step. The gluten network is strengthened by this manipulation. It unfolds the proteins further, orients them side by side, and encourages the development of many weak bonds between neighbors. Additionally, strong end-to-end bonds are formed between the glutenin molecules, resulting in a cohesive network of extensive gluten chains. The dough becomes gradually stiffer, more difficult to work with, and has a fine, satiny appearance. Kneading also aerates the dough. Pockets of air are trapped and squeezed under pressure into smaller, more numerous pockets as it is repeatedly folded over and compressed. The final bread will have a finer texture as more pockets are created during kneading. A large portion of the air pockets are integrated as the mixture arrives at its maximum stiffness. The dough will then move on to the next stage of fermentation, which will enable it to rise through the production of gas. At temperatures around 35°C, yeasts produce the most carbon dioxide, but they also produce larger quantities of sour and unpleasant-smelling byproducts.

For a relatively short rising time of a few hours, it is frequently recommended to ferment at a temperature of 27°C. Lower temperatures may extend fermentation times by an hour or more and with them the generation of desirable yeast flavors. In the end, the dough could be baked to provide the bread as the final product [3].

2.5 Bread Baking

Baking is one of the most essential parts of the process of breadmaking. Since the bread quality could be defined from the baking step, choosing a good condition to bake the bread should be a concern for the bakers. The temperature could be the main parameter concerned for baking because it is the important factor affecting the baked product in any food processing. Cooking food at too low temperature could make the food uncooked, but the too high temperature could overcook or burn the food as well. In breadmaking, the appropriate baking temperature could provide the bread with good quality since the optimum temperature is needed for each step of the cooking mechanism in the baking process.

According to [4] the baking of bread normally devided into 3 stages. Each stage of baking, there's specific mechanism as well as the reaction happens and it had been demonstrated as follows. At Zone 1, the bread should be baked by varying the temperature to stay in a range of 180° to 210°C, letting the temperature at the center of the bread or core temperature started increasing until it reaches around 40°C. At this temperature, it allowed the creation of an enzymatic reaction inside the bread as well as the growth of yeast activity releasing carbon dioxide. The volume of bread was expended. For the baking in the Zone 2, the core temperature should stay around 40°C to 60°C. For archiving this, the bread should be baked at the temperature in a range of 90°C to 120°C. At this temperature, some activities of enzymes are still occurring as well as the growing of yeast like the first stage of baking. For Zone 3, the temperature at the center of the bread should start increasing from 60°C to 98°C and stay stable for a period. The evaporation of moisture and gelatinization actively happened at the temperature of 98°C to 99°C. At this core temperature, the surface temperature was in the range of 150°C to 205°C allowing the browning reaction to occur on bread surface. The temperature should be set stable for about 10 min to make the browning reaction happen as well as to evaporate some organic compounds producing the bread’s smell.

2.6 Bread Staling

Staling is the physical-chemical changes occurring during bread storage that lead mainly to an increase of crumb firmness and loss of freshness. The process of Staling, which takes place in the days following baking and appears to involve the loss of moisture, results in a dry, hard, and crumbly interior to the bread. It turns out that bread will stale even when there’s no net loss of moisture from the loaf. When cooked starch is then cooled, it hardens as a result of starch retrogradation, recrystallization, migration of water out of the granules, and other processes. The simple straight-chain amylose molecules undergo retrogradation during the initial firming of freshly baked bread, which is nearly complete within a day of baking. The granule's branched amylopectins, which make up the majority of starch molecules, are also retrograde. However, they expel water much more slowly over the course of several days because of their irregular structure, which causes them to form crystalline regions [5].

2.7 Dietary Fiber

Dietary fiber is one of the nutrients that provide health benefits to humans. By the definition, any the parts of fruits, vegetables or nuts which cannot be digested by humans are considered as the dietary fiber. It is the mixture of plant carbohydrate polymers such as polysaccharides and oligosaccharides, hemicellulose, cellulose, resistant starch, pectin substance, inulin, and gums [6]. Dietary fiber found to help prevent some diseases including diabetes, obesity, coronary heart disease, bowel cancer, and gallstone [7]. The addition of dietary fiber becomes one of the best choices for enriching the nutritional value of food products, especially bread which is known as the most common staple food. In exchange, the supplementation of dietary fiber into the bread formula could also provide some effect on the product characteristics because of water-holding capacity, oil-holding and swelling capacity, viscosity, and gel-forming capacity [8].

2.8 Fiber Fortification

Fiber fortification is the addition of fiber into the bread formula. There are a lot of sources of fiber that can be added to the breadmaking process. Cereal bran is one of the common sources of fiber that can be used such as the bran of the crop such as oat and wheat. Other sources like fibrous components from the nature including apple or orange fiber, potato, beets, and carrots are also applicable [8].

2.9 Flaxseed

Flaxseed is one of excellent sources of dietary fiber which widely find its application as functional as well as nutritional. Flaxseed, or Linseed (*Linum Usitatissimmum*), also known as Alsi, Jawas, Aksebija in Indian languages, is a blue flowering rabi crop and a member of the family Linaceae. The usage of flaxseed is one of the good not because of its dietary fiber source but also other supplements. Flaxseed contains high in polyunsaturated fatty acid (73% of total fatty acid), moderate in monounsaturated fatty acid (18% of total fatty acid) with are both good fatty acid while the bad one, unsaturated fatty acid has only in low amount (9% of total fatty acid). Moreover, it also has linoleic acid or omega 6 about 16% and -linolenic acid (ALA or omega 3) about 57% of total fatty acid [9]. However, in bread products, the enrichment of flaxseed could give rise to some undesirable effects on the bread products when the addition reached a scope of usage. The darker color was found in the flaxseed enriched bread compared to the normal one. The level of flaxseed added also gain the water absorption, as well as the reduction of dough stickiness which could lower the bread specific volume as the result [10].

2.10 Refrigeration of Dough

As refrigeration takes an important part in the food sector, refrigerated dough also plays an essential role in the bakery industry. In order to achieve conveniences and possibilities, the bakers started to use the preservation technique to keep their dough as the primary product of the bread. The high efficiency of refrigerated dough could provide a long extension of product distribution time which preserves the quality of the final product. Besides, the slow fermentation process taking place under refrigerated condition allows yeast more time to break down starch in the dough which improves the flavor in the dough. There are however some common issues arising from refrigeration. Other than moisture loss or drying out, syrup is usually developed at the surface dough. The refrigerated dough was also found to provide reduced bread volume. The structure of dough should be strong enough to hold the carbon dioxide produced by the yeast during fermentation so that optimum bread volume can be obtained. Both gas production by yeast from fermentable sugars and gas retention of dough play a critical role [11], [12].

2.11 Dough Syruping

Dough syruping is the phenomenon of the immigration of a brownish liquid to the dough surface after prolonged dough storage [13]. The main reason for this phenomenon could be caused by the degradation of arabinoxylans (AX) during the refrigeration period which possibly made the dough lose its water-holding capacity [14].

Arabinoxylans are cell wall polysaccharides that consist of -1,4-linked D-xylopyranosyl unit substituted with -L-arabinofuranosyl unit at the position of C(O)-2 and/or C(O)-3. Within this material, two different classes are distinguished. They are water-extractable (WE-AX) which consist of approximately one-third of the total AX fraction in wheat flour and the other two-thirds are water-unextractable (WU-AX) [15]. Between those two, they also share the almost same structure [16]–[18] but they have different functions [19] as well as physicochemical properties [15]. Xylanase is any of a class of enzyme, glycosyl hydrolyze families which impact the physicochemical properties of AX [20]. With this enzyme, the WU-AX can be solubilized into a high 2 molecular weight solubilized AX (HMW-S-AX) which increases the viscosity. Xylanase also then degrades the high molecular weight water-extractable AX (HMW-WE-AX) and HMW-S-AX to Low molecular weight water-extractable AX (LMW-WE-AX) and Low molecular weight solubilized AX (LMW-S-AX) and decrease the viscosity. Also, WU-AX solubilization induces loss of water-holding capacity [21].

2.12 Noncontact Temperature Measurement

In the past, the only way to observe the temperature of one object was the usage of the thermometer which generally could be done by contact directly with the surface of those objects. In the food industry, this kind of measurement should be avoided since it would affect the appearance and quality of the food product. Because of advanced technology, noncontact temperature measurement allowed us to cope with this problem. It could reduce the time as the measurement could be done faster even for the moving object that would helpfully be used in the industrial sector. It is safe since it can measure the object at a high temperature without touching it. The contamination of food, as well as the physical damage, could be eliminated [22].

Thermal image (TI) or infrared (IR) thermography is a two-dimensional surface temperature measurement that is usefully used in food for the advantage of non-destructive quality [23]. It is a noninvasive system recording temperature by measuring the infrared radiation emitted by a body’s surface [24].

2.13 Dough Extensibility Test Technique

Dough extensibility is the dough's strength and a factor in a baked good's consistency and quality. In dough, extensibility is one component of a delicate balancing act that begins with mixing. At the point when the gluten network is created, it makes both extensible and elastic properties — or the capacity to stretch and get back to its original form. However, the dough will not form properly during the fermentation, proofing, or baking stages as it expands and retracts if one of these characteristics is stronger than the other. There are many ways to determine these dough’s properties and the using of Kieffer-type extensibility rig is one of the common use in dough extensibility test. The test will be done by applying the force, pulling the dough until the breaking occure. The usage of texture analyzer will provide the graph allowing the dough rheological properties’s investigation (Figure 2.1).

Through the graph, the maximum force the dough could stand can be determined. This parameter called “Peak Load” and it defines the elastic limit of dough or the dough’s tensile strength. As this value is higher meaning the dough has more elstic property or tensile strength. Plastic deformation and strain hardening of the dough begin when the dough reaches its elastic limit. Necking begins as the load exceeds the dough's strength, and the dough eventually breaks when it reaches its breaking point. During the dough's extension, the mean load is the average load over a predetermined time period. While the maximum force measuring the tensile strength, the area under the graph measuring the work done to extend and break the dough sample. The distance to the rupture point defines the extensibility of the dough. The dough is more extensible is the distance value is greater [25]

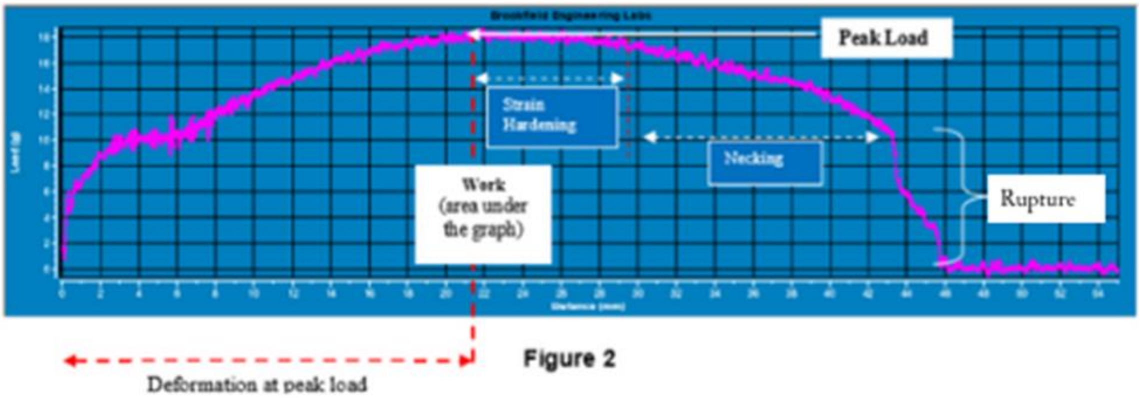

Figure 2.1 Dough extensibility graph providing from texture analyzer [25].

2.14 Texture Profile Analysis (TPA)

Texture Profile Analysis is a well-known double compression test for determining foods' textural properties. It is sometimes utilized in different industries, like pharmaceuticals, gels, and personal care. A texture analyzer is used to compress samples twice during a TPA test to see how they behave when chewed. The TPA test was frequently called the "two bite test" as the reason that the surface analyzer imitates the mouth's biting action. The magnificence of TPA as a analytical strategy is that it can evaluate numerous textural parameters in only one trial [26]. Most of textural parameters could be determined from a single TPA graphic (Figure 2.2) provided from the Textural Profile analyzer equipment.

Hardness is defined as the peak force that occurs during the first compression. The hardness need not occur at the point of deepest compression, although it typically does for most products. Springiness defines how well a product physically springs back after it has been deformed during the first compression or the recovery rate of a material after deformation. It is expressed as a ratio or percentage of the original downstroke compression. Springiness is measured several ways, but most typically, by the distance of the detected height during the second compression divided by the original compression distance. Cohesiveness defines how well the product withstands a second deformation relative to its resistance under the first deformation or the extent to which material can be deformed before it ruptures. It is determined by the area of work during the second compression divided by the area of work during the first compression. Chewiness defines the length of time or the number of chew required to masticate a solid food to a state ready for swalling. It is calculated as the result of multiplying the Hardness, Cohesiveness, and Springiness [26], [27].

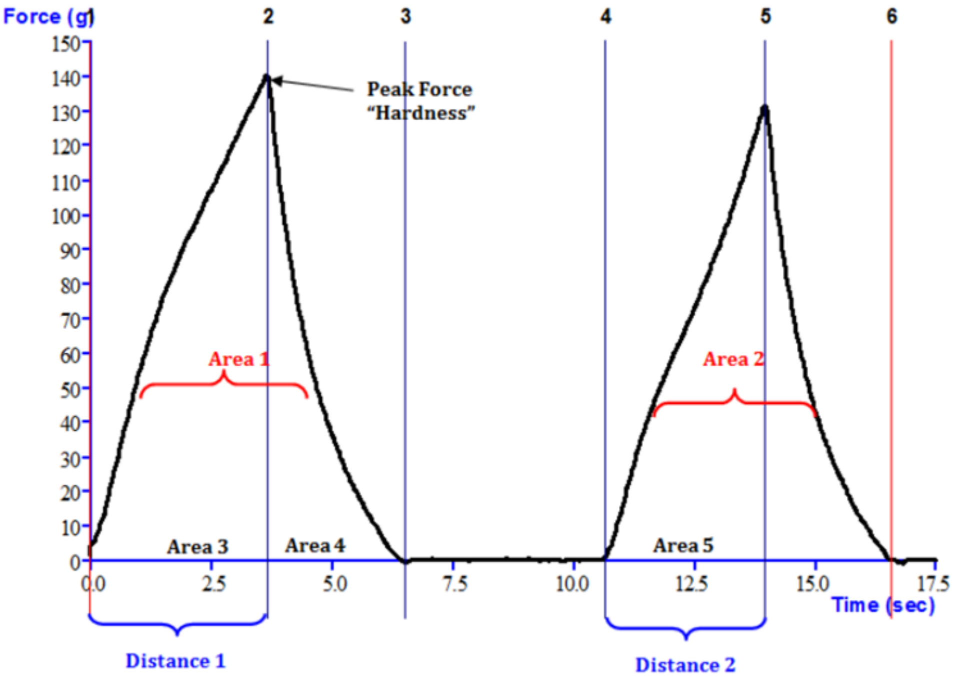

Figure 2.2 TPA graphic provided by Texural profile analyzer equipment [26].

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Characterizations of Fresh Dough and Bread Product: Samples and Measurements

3.1.1 Sample Preparation

Ground flaxseed was prepared by heating raw flaxseed (Heritage brand) at 90°C for 10 min using a hot air oven (UM500, Memmert) and grinding with a food grinder (MX-J210GN, Panasonic). After grinding, ground flaxseed was sieved using a 30-mesh screen to obtain ground sample with consistently fine particles.

The base formulation of dough, or a control treatment, contained approximately 3.13% sugar, 1.25% salt, 1.88% yeast, 9.38% butter, and 62.50% water, flour mass basis (fmb). Flaxseed fortified samples were then prepared by adding ground flaxseed into the base formulation for three different levels including 10%, 15%, and 20% fmb.

The process to prepare dough sample started with mixing all of dried ingredients mentioned above for 3 min using a locally available mixing equipment (B10C, MIXER). Next, water was added and the mixing was continued for 7 min. The mixture was then kneaded manually for 10 min to obtain dough. Finally, dough samples were proofed by wrapping with parafilm sheet and resting at room temperature for 50 min. The process of sample preparation is graphically presented in Figure 3.1. Bread samples were obtained by baking the dough at a fixed temperature of 165°C for 50 min using an electric oven [EOT3805K, Electrolux (Figure 3.2)].

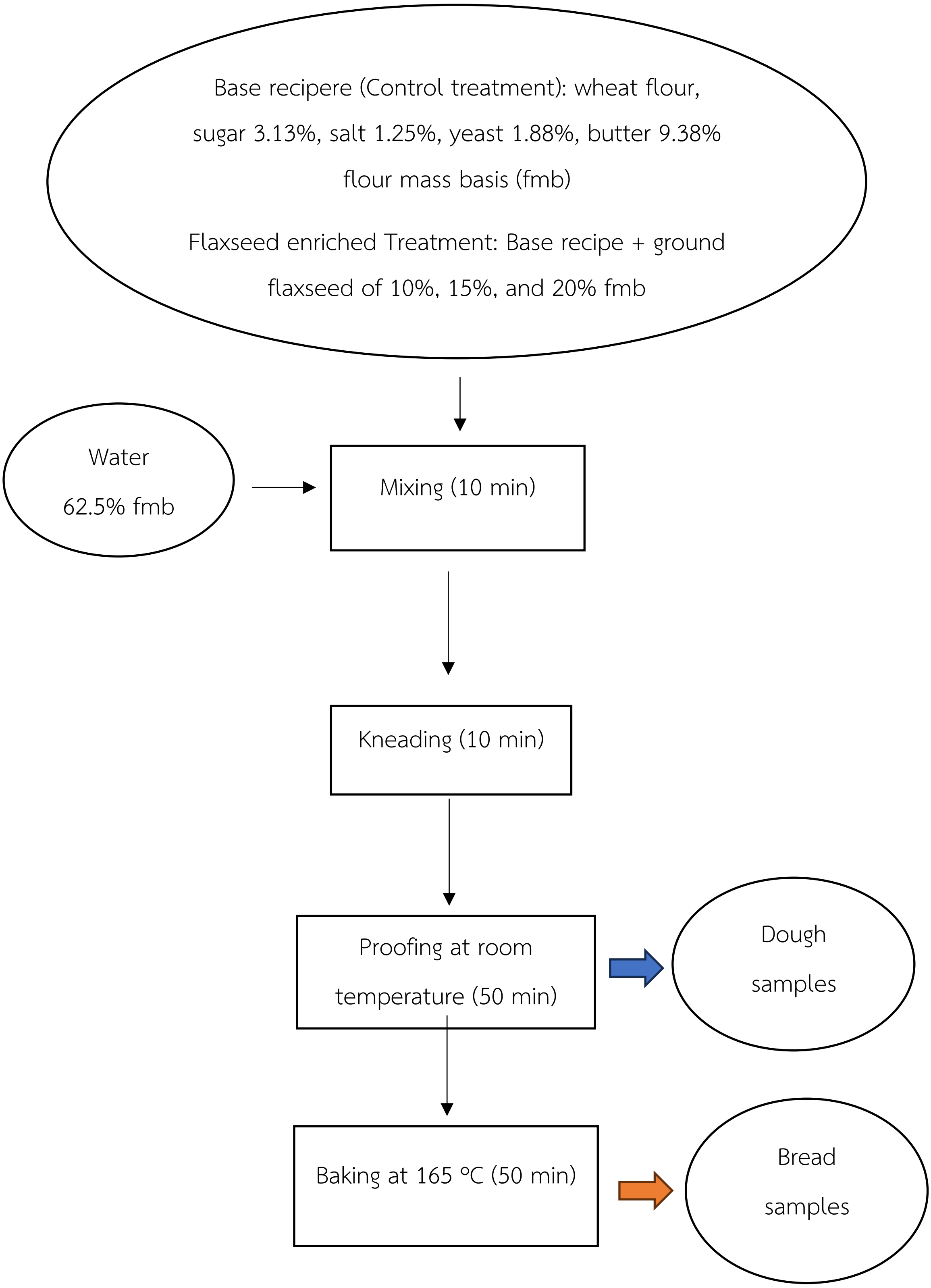

Figure 3.1 A flowchart representing sample preparation procedure.

Figure 3.2 The electric oven (EOT3805K, Electrolux) used for baking in this study.

3.1.2 Extensibility Test of Dough

The strength of dough samples was measured using a large strain tensile test. The test was conducted using the Kieffer-type extensibility rig equipped to the TA.XT*plus* texture analyzer (Stable Micro System, Surrey, UK). Test specimens each having the dimensions of 10mm × 10mm × 90mm were prepared. Each specimen was formed with approximately 5 g of dough sample using a laboratory-made acrylic mold. Once formed, specimens were rested at room temperature for one hour prior to running the test. A dough specimen was held in place by clamping both ends between the two base plates. The test was conducted by pulling the specimen at the middle part upward with a 6-mm diameter hook at a speed of 5 mm/s [28] until the specimen reached breaking point and rupture (see also Figure 3.3). The parameters of interest included the distance to the rupture point (D-Rupture), the maximum force the dough could stand (peak load), and the deformation at peak load (D-Peak). Determination of these parameters was made with the aid of the Texture Expert^{TM} software bundled with the TA.XT*plus* texture analyzer. The test procedure is also given schematically in Figure 3.4.

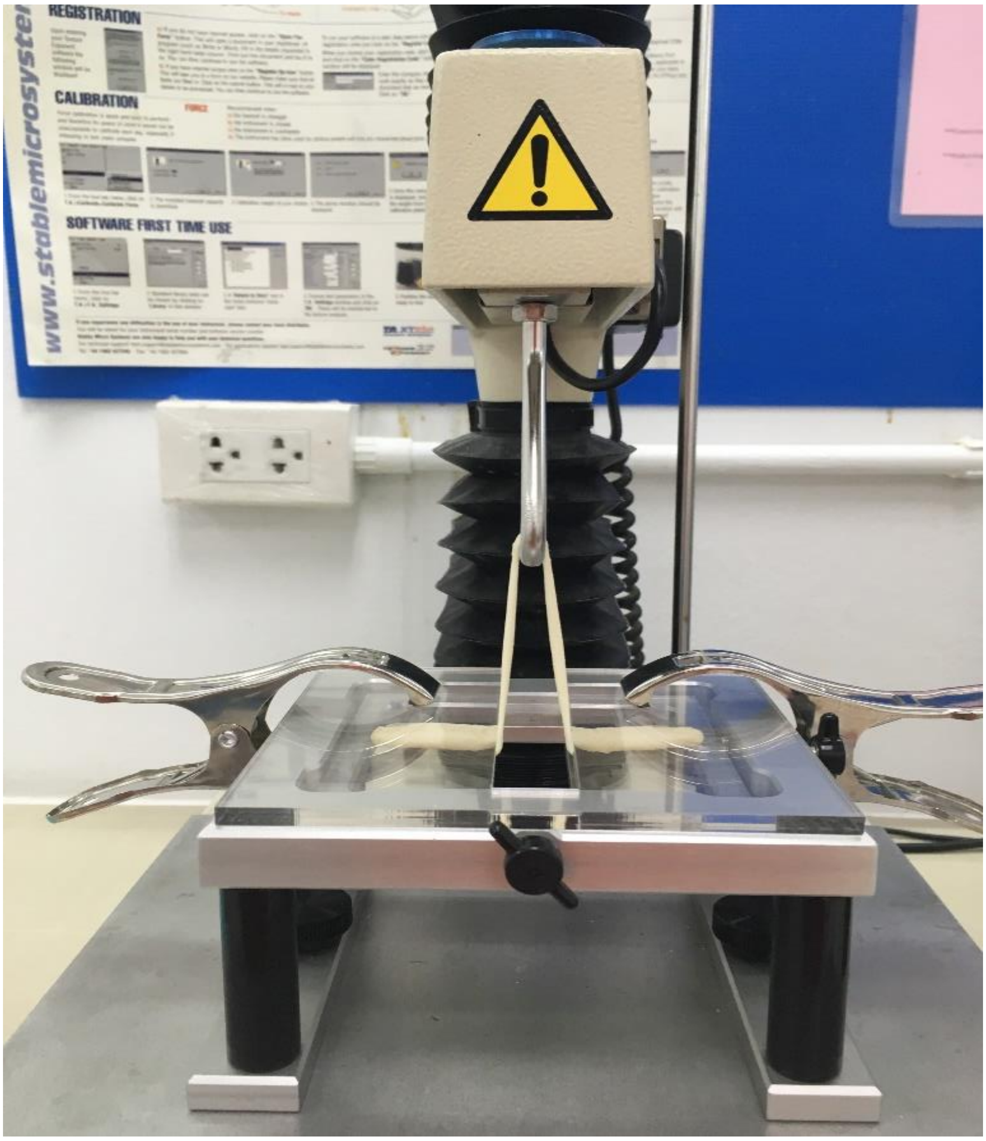

Figure 3.3 Large deformation of dough specimen during extensibility test using the Kieffer rig equipped to the TA.XT*plus* texture analyzer (Stable Micro System, Surrey, UK).

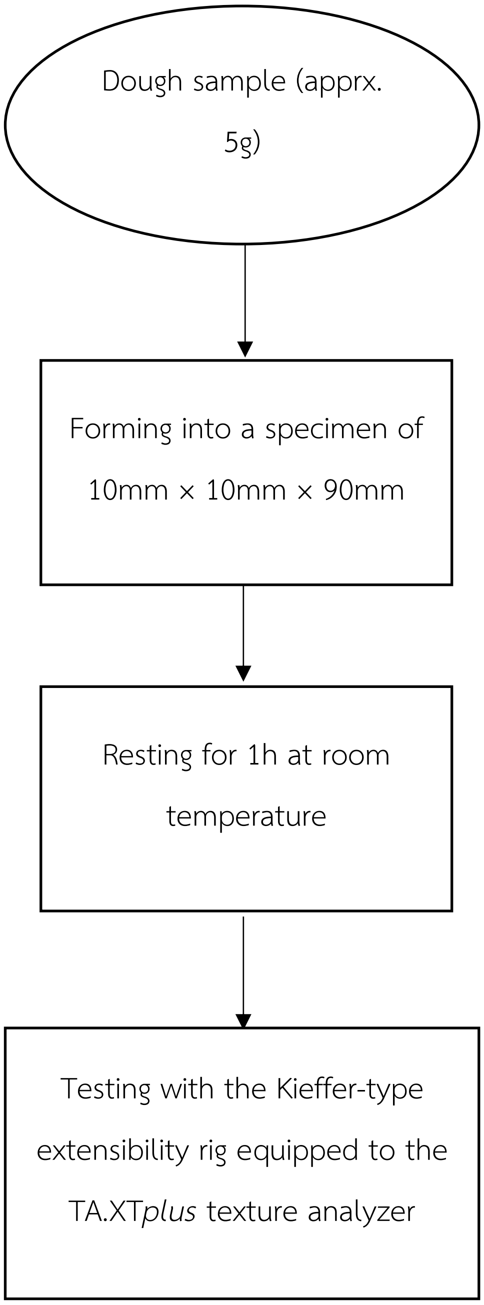

Figure 3.4 The extensibility test procedure to measure dough strength.

3.1.3 Textural Characterization of Bread from Fresh Dough

The instrumental textural characterization of bread crumb was carried out using the Texture Profile Analysis (TPA) technique. The test was done under compression mode on the TA.XT*plus* texture analyzer (Stable Micro System, Surrey, UK) equipped with a 50-mm diameter cylindrical probe (Figure 3.5). Test specimens were prepared by cutting bread loaves into 2-cm thick slices. Bread speimens were double compressed at a speed of 2 mm/s until reaching 50% of their original height. Room temperature during the test was within 23±2°C. The textural parameters including hardness, cohesiveness, springiness, and chewiness were then inferred from the TPA plots using the Texture Expert^{TM} software bundled with the TA.XT*plus* texture analyzer. The test procedure is given schematically in Figure 3.6.

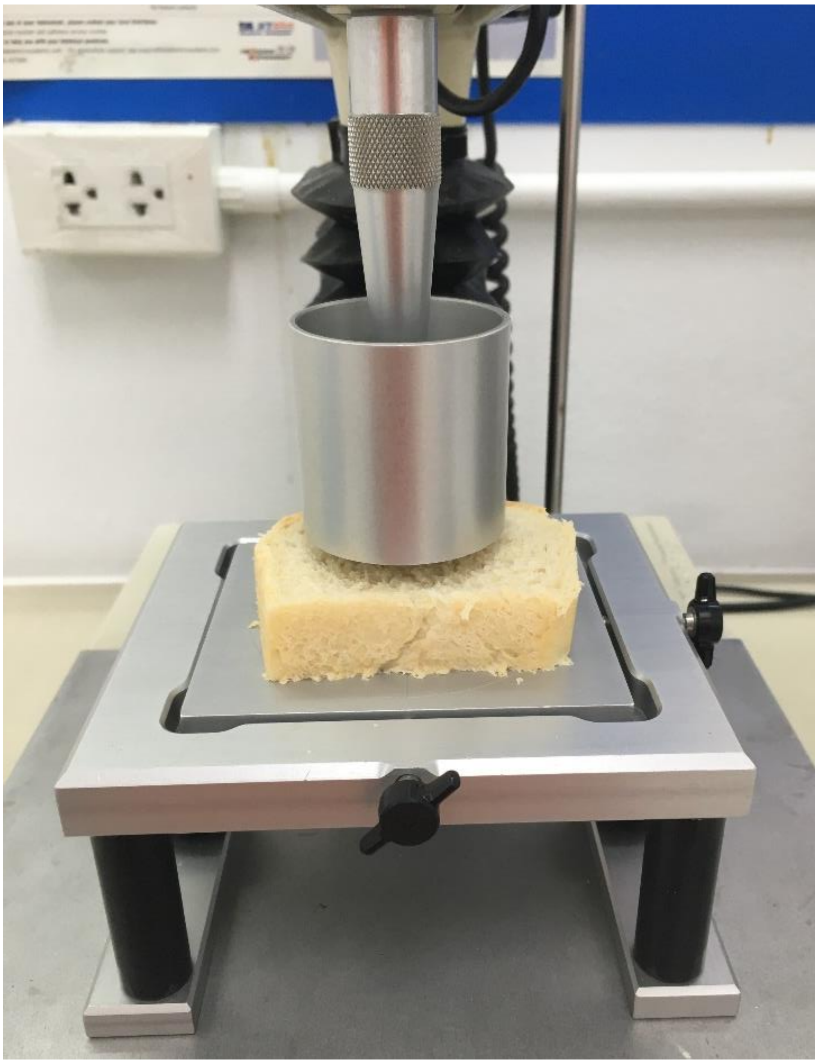

Figure 3.5 Bread crumb specimen on TA.XT*plus* texture analyzer equipped with a 50-mm diameter cylindrical probe.

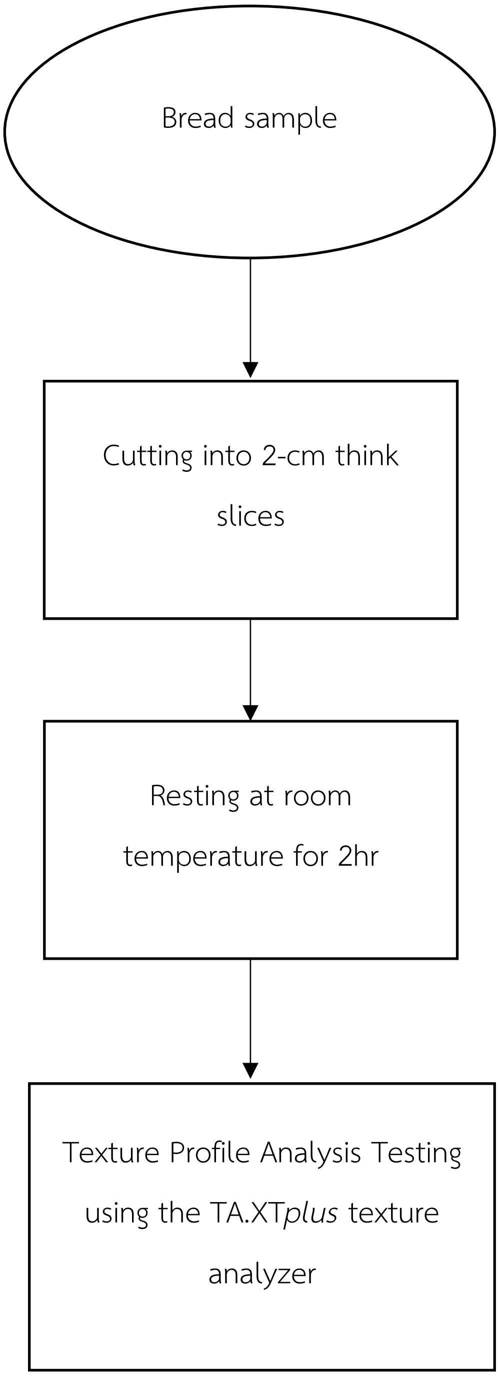

Figure 3.6 The texture profile analysis (TPA) test procedure to characterize textural property of bread samples.

3.1.4 Determination of Bread Loaf Specific Volume

Bread loaf specific volume was determined using a rapeseed displacement according to the AACC international method 10-05 [29]. In this study, a clear plastic container with the dimension (width x lenght x height) of 14.3cmx14.2cmx7.8cm was used. First, the container was over filled with rapeseed and then the excess amount of rapeseed was carefully swept off using a straight-edge ruler. The volume of rapeseed that retained in the container was measured using a graduated cylinder and recorded as V_{seed1}. This amount of rapeseed was set aside for further step. A bread loaf sample was weighed with a digital balance and the weight was recorded as m_{loaf}. Next, the empty container was placed on a collecting tray, and a bread loaf was placed inside the container. The container was again refilled with the rapeseed that was set aside, and the excess amount of rapeseed was carefully swept off. The volume of rapeseed that remained in the collecting tray was measured and recorded as V_{seed2}. Then the volume of bread loaf (V_{loaf}) was calculated using Equation 3.1 and the specific volume of the bread loaf (v_{loaf}) was determined using Equation 3.2:

$$V_{loaf}(cm^3) = V_{seed1} - V_{seed2} \tag{3.1}$$

$$v_{loaf}\,(cm^3/g) = V_{loaf}/m_{loaf} \tag{3.2}$$

The procedure to determine the specific volume of bread loaf is given schematically in Figure 3.7.

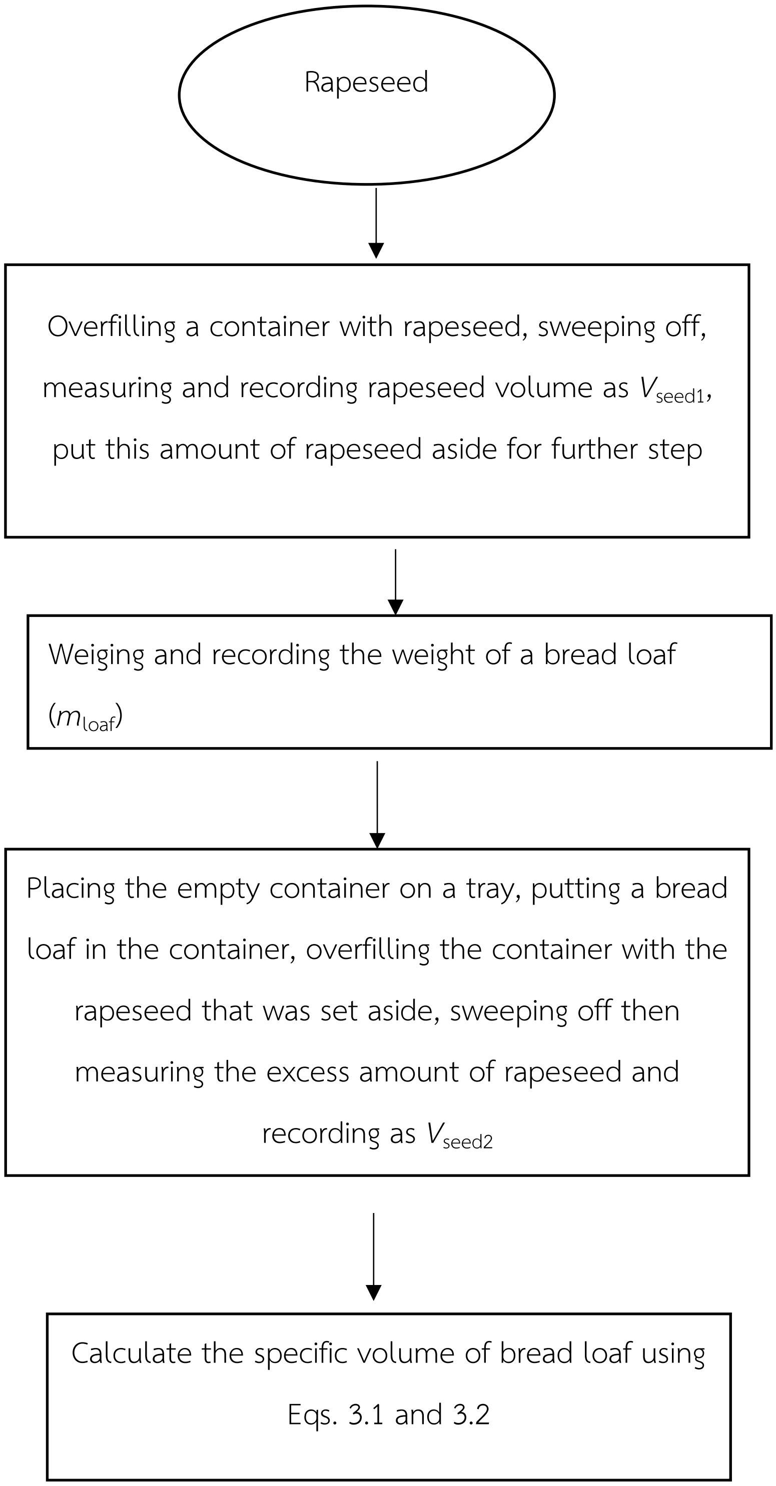

Figure 3.7 The procedure to determine the specific volume of bread loaf using rapeseed displacement technique.

3.1.5 Determination of Bread Moisture Content

The moisture content was determined using a hot-air oven according to the AACC 44-15A standard method [30]. Bread samples of 2-5 g each were placed in dried and known weight aluminum pans. Samples were dried in a hot-air oven (model: UM500, Memmert) at 105°C for 16-18 h or until the weight of sample did not chang sample pans were promptly moved to cool down on a desiccator. Samples were weiged using a 2-decimal places digital balance (model UX3200G Shimadzu). Moisture content was then calculated from the difference of sample weights before and after drying and expressed as a percentage of the sample weight before drying.

3.1.6 Measurement of Bread Staling

In this study, the progress of bread staling was observed from the evolution of bread hardness over the storage period for up to 7 days. Experiments were conducted at two different storage temperatures, 4°C and 18°C. The hardness data of bread samples were obtained from the TPA test, as explained in section 3.1.3, after the 1st, 4th, and 7th days of storage. The evolution of bread hardness was explained mathematically using the Avrami equation (Equation 3.3) [31]:

$$(H_\infty - H_t)/(H_\infty - H_0) = \exp(-kt^n) \tag{3.3}$$

where H_0 is the hardness at the t=0 or initial time, H_t is the hardness at time t, $H\infty$ is the hardness at infinite time, n is the Avrami exponent and k is a rate constant [32], [33].

The Avrami parameters were obtained by fitting experimental data to Equation 3.3 with the assist of a “solver” tool in Excel (Microsoft Corporation, Washington, USA) using least squared minimization technique. The goodness of fit was explained in term of coefficient of determination (R^2) which was calculated using Equation 3.4:

$$R^2 = 1 - \sum(H_i - H_{pred})^2 / \sum(H_i - H_{avg})^2 \tag{3.4}$$

where H_{pred} is the fitted or predicted hardness, H_i is the hardness at time i, and H_{avg} is the average value of the harness.

For more practical explanation, a half-life value of hardeness evolution ($t_{1/2}$) was also determined. The half-life value is the time when the shelf life reaches 50% before the breadcrumb hardness becomes leveling-off.A faster hardening process is indicated by a shorter half-life. Equation 3.5 was used for the calculation of half-life ($t_{1/2}$):

$$t_{1/2} = (-ln\ 0.5/k)^{1/n} \tag{3.5}$$

3.2 Characterizations of Refrigerated Dough and Bread Product: Samples and Measurements

3.2.1 Sample Preparation

Materials and sample preparation for this part of the study were similar to that for fresh dough experiment. The details can be found in section 3.1.1.

3.2.2 Dough Refrigeration

Dough samples were placed in clear plastic boxes and stored in a refrigerator at 4°C up to 35 days. During refrigeration, dough samples were randomly picked out on the 3th, 7th, 14th, 21st and 35th days for determining the magnitude of syruping and for baking test. These experiments was done with fresh dough (or day zero) as well.

3.2.3 Quantfication of Dough Syruping

The amount of dough syruping during refrigeration was measured using the Allegra® X-30R Series Benchtop Centrifuge (Beckman Coulter) shown in Figure 3.8 and the degree of dough syruping (DDS) was calculated using Equation 3.6. A sample size was approximatrly 3 - 4 g. Samples were centrifuged at 10854g under a temperature of 4°C for 30 min. Then centrifugal tubes were put upside down for 2 h to separate the brownish liquid which leached out from dough during refrigeration, the so called dough syrup. The DDS was calculated from the difference between the mass of dough before and after centrifugation and explained as percentage of the initial mass as follows:

$$DDS\ (\%) = [\,(M_i - M_f\,)\ /\ M_i\,] \times 100 \tag{3.6}$$

where M_i is the initial mass of a dough piece before centrifugation, and

M_f is the final mass of a dough piece after centrifugation.

Figure 3.8 The Allegra® X-30R Series Benchtop Centrifuge (Beckman Coulter).

3.2.4 Characterizations of Bread from Refrigerated Dough

To observe the effects of refrigerating dough on baked product, bread samples that were obtained with refrigerated dough at difference refrigerated times were subjected to instrumental textural characterization and specific volume determination. The methods were similar to those given in sections (See 3.1.3 and 3.1.4).

3.3 Noncontact Temperature Measurements for Bread Baking: Samples and Measurements

3.3.1 Sample Preparation

The dough samples were formulated with, by weight, wheat flour (50%), cold water (25%), sugar (10%), margarine (5.8%), chicken egg (3%), milk powder (2.5%), butter (1.8%), salt (0.85%), and instant yeast (0.75%). All the ingredients except instant yeast were first mixed together and rested for 40 minutes. Instant yeast was then added and samples were continuely kneaded for 10 more minutes to obatain dough. The dough samples were then divided into pieces each weighing approximately 70 g, formed to a round shape, and proofed at room temperature (25°C) for 150 minutes. Baking experiment was conducted using an electric oven (Zanussi, ZOT103KX). Before starting each baking test run, the oven was allowed to stabilize at the seleted baking temperature for 10 minutes.

3.3.2 Instrumentation

Hand-held digital thermometers (Fluke 52-II) equipped with type-K thermocouple temperature sensor were used to measure the temperatures of the oven and the sample during baking. Both of the core and surface temperatures of sample were collected. The measuring junctions of the thermocouples were placed at 4 different spots vertically along the wall of the oven and the oven temperature was obtained by averaging the temperature values measured from tese 4 spots. The core temperature of sample was measured by inserting the thermocouple into the sample so that the measuring junction was righ at the center of the sample. A miniature infrared sensor (MI, Raytex Coporation) was used for measuring the intensity of infrared energy during baking and the emissivity (ε) of the sample. The infrared sensor was placed on the top position of the oven. The fact that the surface of the bread was considerably flat and smooth without angle changing during baking would allow capturing the infrared energy emitted from the sample to be reasonably effective. The emissivity of bread was also measured with a thermal image (TI) camera (Model TI 32, Fluke) due to its ability to compensatethe reflexed energy or background temperature (T_{BG}) which could not be obtained with the IR sensor.

3.3.3 Baking Experiment

Two different baking temperature schemes were conducted for baking experiment. The first baking scheme was a traditional constant baking temperature which was set at 180°C in this study. The oven temperature was equilibrated at the set point temperature for 10 minutes before starting the experiment. In another scheme, baking experiment was carried out with three stages, called step-change temperature baking. The baking temperature was set differently for the three sequential stages. This was to simulate the baking temperauture zones that the product encouters during moving through a continuous baking facility at a commercial level. According to Therdthai et al. [4], at Zone 1, baking temperature was varied within a range of 180° to 210°C allowing the core temperature of dough to gradually increase until reaching around 40°C. In Zone 2, baking temperature was varied within a range of 90° to 120°C and the core temperature of dough increased from 40°C to 60°C. At Zone 3 of baking, the core temperature increased from 60°C to 98°C at which it was maintained for 10 more minutes to allow browning reaction to continue yielding a proper crust color.

3.3.4 Emissivity Determination

Both of a TI camera and an IR sensor were used to determine the emissivity ($\boldsymbol{\varepsilon}$) of a sample in this study. With the TI camera, the $\boldsymbol{\varepsilon}$ value was first guessed, then the value of background temperatruer (T_{BG}) in the TI camera was adjusted until the reading temperature was similar to that observed with a thermocouple. The T_{BG} represented the reflected energy from the surroundings under the experimental condition being studied. Next, the obtained T_{BG} value was used as an input, and the true sample emissivity was acquired by adjusting this value until the reading temperature was equal to the one from a thermocouple. For he IR sensor, the true sample emissivity value was obtained by carefully adjusting this value so that the reading temperature was equal or closest to the one measured with a thermocouple which was attached at the top surface of the sample.

3.3.5 Determination of Bread Weight Loss

The weight loss of bread was calculated from the weight of sample bread before and after baking and the following formula calculated it:

$$W_{Loss} = \frac{W_i - W_f}{W_i} \times 100 \tag{3.7}$$

where $W_{i:}$ weight of bread before baking (g)

W_f: weight of bread after baking (g)

W_{Loss}: weight loss (%)

3.4 Statistical Analysis

The completely randomized design (CRD) was used through the experimentation. Experiments were either made in duplicate or triplicate. The IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., NY, USA) was used for the statistical analysis. The analysis of variance (ANOVA) and the multiple comparison of means using the Turkey's test were made at 0.05 level of significance. The linear regression was used to obtain the relationship between surface and core temperature.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Characteristics of Dough and Properties of Bread Product

4.1.1 Rheological Characteristic of Dough

For bakery production, dough strength significantly affects subsequent processes including fermenting, proofing and baking. It is therefore prime important to assure that the strength of dough is at a proper level. The gluten matrix in dough gives rise to both extensible and elastic attributes which collectively represent the dough strength. These attributes need to be balanced in order that the final bake product with desirable qualities can be obtained.

Though the addition of some other components in bread recipe could provide nutritional or functional benefits, it may, on the other hands, impare the integrity of gluten network and could lead to the decrease of dough strength. It was therefore interesting how flaxseed fortification in the range of 10%-20% affects the strength of wheat dough and the final qualities of bread.

The strength of flour dough is commonly measured using load-extention tests, e.g. the Kieffer dough and gluten entension rig and a Brabender extensograph. The Kieffer rig could be viewed as a small-scale of the Brabender with lower strain rates applied [34].

Experimental data obtained from the Kieffer extensibility test were in the form of load-distance plot from which the large strain rheological parameters of dough could be inferred. The three common rheological parameters include the maximum peak force (peak load), the deformation at the maximum peak force (D-peak), and the distance to rupture point (D-rupture). The peak load is a measure of tensile strength—an elastic limit of a sample. The higher peak load indicates the more elastic component. The D-peak is a measure of elasticity. The D-rupture is a measure of the extensibility: the greater value of D-rupture indicates that the sample is more extensible [25].

In this study, the strength of dough sample was measured using the extensibility test. The typical graph result received from the textural analyzer is shown in Figure 4.1. From the load-distance plots, it could be generally observed that there is a difference between each graph for each treatment. Concerning the maximum force or peak load, the results demonstrated that the greatest peak value was found in the graph of the control sample and it decreased eventually for the treated sample from 10% to 20% of flaxseed enrichment where the lowest value was observed. This suggested that the force used for pulling up the dough to the point it could stand was decreasing in function of flaxseed added. Same as the area under the plot which was also found reduced in each treatment exhibited lower of energy work for breaking the dough upon the addition of flaxseed. The decrease of the length under the plot to the point of rupture showed the loss of dough extensibility when the level of flaxseed addition increased.

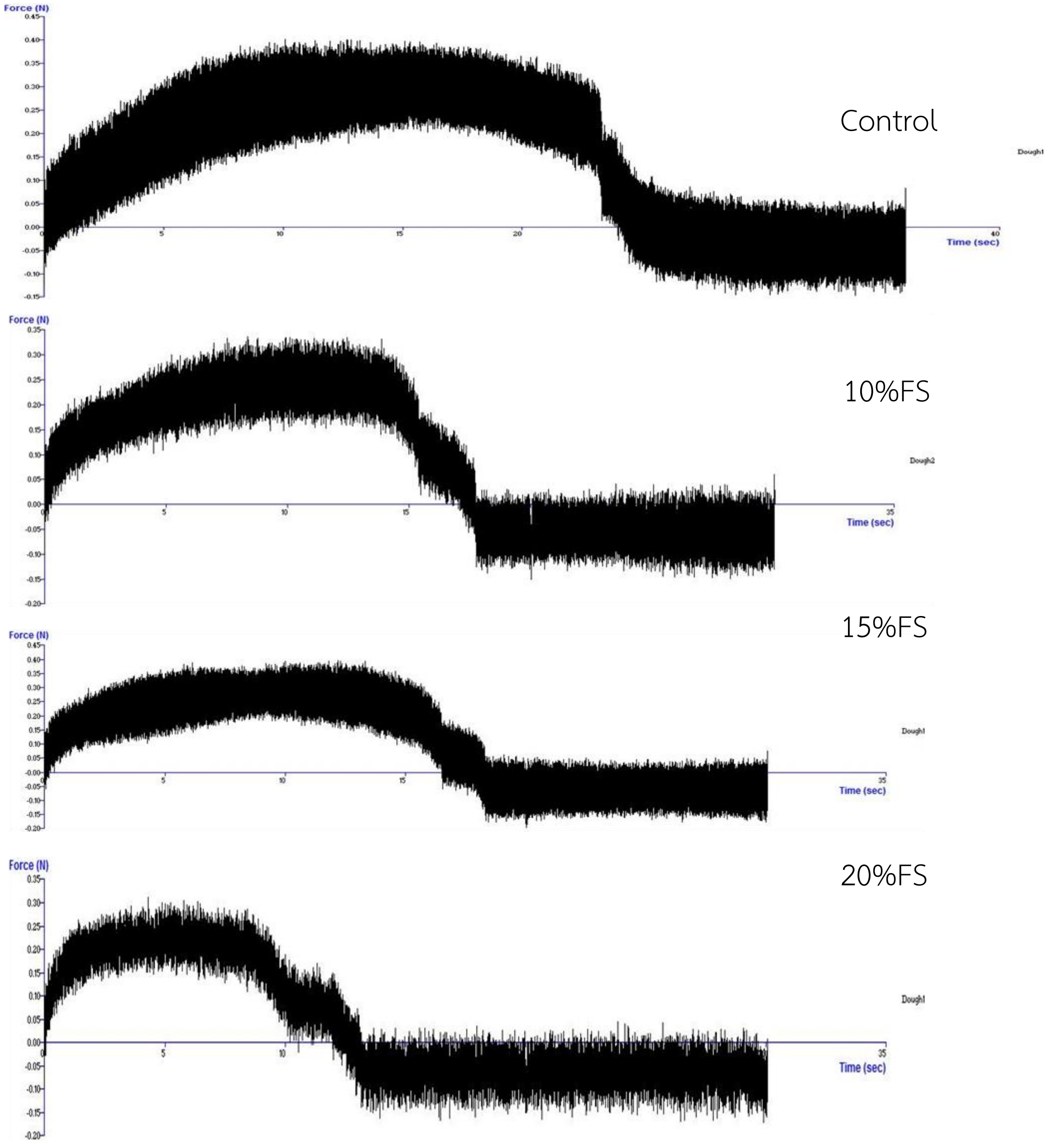

Figure.4.1 A typical force-time plot obtained from extensibility test of dough sample using the Kieffer extensibility rig equipped on a TA.XT*plus* texture analyzer for the control (0%), 10%, 15% and 20% of flaxseed enriched samples.

The analytical results from the data was showed in Figure 4.2. The maximum peak force or “peak load” inferred from the load-distance plot appeared to decrease upon the addition of flaxseed in bread recipe. The highest peak load was observed from the control treatment with the value of 0.44 N while this parameter for dough samples with flaxseed added were in a range of 0.31-0.37 N. The peak load tended to decrease with the increasing level of flaxseed fortification as shown in Figure 4.2. This finding suggested that the addition of flaxseed caused the tensile strength of dough to decrease. However, from statistical analysis, ground flaxseed could be added up to 15% without a significant effect on this value.

Similar to the trend of change of peak load, the deformation at maximum peak force or D-peak of dough samples tended to decrease with the increasing amount of flaxseed added particularly at 20% enrichment level, as can be seen in Figure 4.3. The result from statistical analysis confirmed that the decrease of D-peak was significant ($p<0.05$), compared to the control treatment, only when the enrichment was at 20%. This was not the case when the addition of flaxseed did not exceed 15%. The D-peak value form the control treatment with 0% -15% flaxseed ranged from approximately 64-75 mm while this value for the 20% flaxseed treatment was about 40.3 mm.

Another rheological parameter of dough in this study was the distant to rupture point or “D-rupture”. This parameter is a measure of extensibility of dough. The higher the D-rupture, the greater the extensibility of the dough [25]. It could bee seen from Figure 4.4 that the control treatment showed the highest D-rupture with the value of approximately 107.2 mm. The trend of change for the D-rupture value upon the addition of flaxseed in bread recipe was similar to that for the peak load and the D-peak. The D-rupture continuely decreased with the increasing level of flaxseed enrichment. This values of parameter for the treatment with 10%, 15%, and 20% flaxseed were approximately 96.8 mm,89.6 mm, and 59.5 mm, respectively. The result from statistical analysis revealed that the decrease of D-rupture value was significant only when flaxseed enrichment level was at 20%. The reason for this phenomenon might be the dilution effect of gluten which was reported in previous studies [9], [35]. Gluten matrix could be disrupted by both the soluble and insoluble cell wall materials presenting in flaxseed.

Rheological properties of wheat dough could be generally influenced by various activities during processing including biochemical, microbiological, and physio-chemical processes. Besides, certain ingredients could also affect the property of dough. In prior studies, it was reported that water absorption of dough increased upon the addition of flaxseed [36], [37]. The mucilage or gum presented in flaxseed could be accounted for the cause of this as there was the evidence from Farinograph test. This gum could compete with gluten for water because of its water absorption capacity. As a result, it could slow the development time of dough. The stability and mixing tolerance index (MTI) changed upon the increasing level of flaxseed enrichment, from 0% to 15%. Consequently, the physical interruption made flaxseed enriched dough weakened as a result of gluten matrix dilution [37].

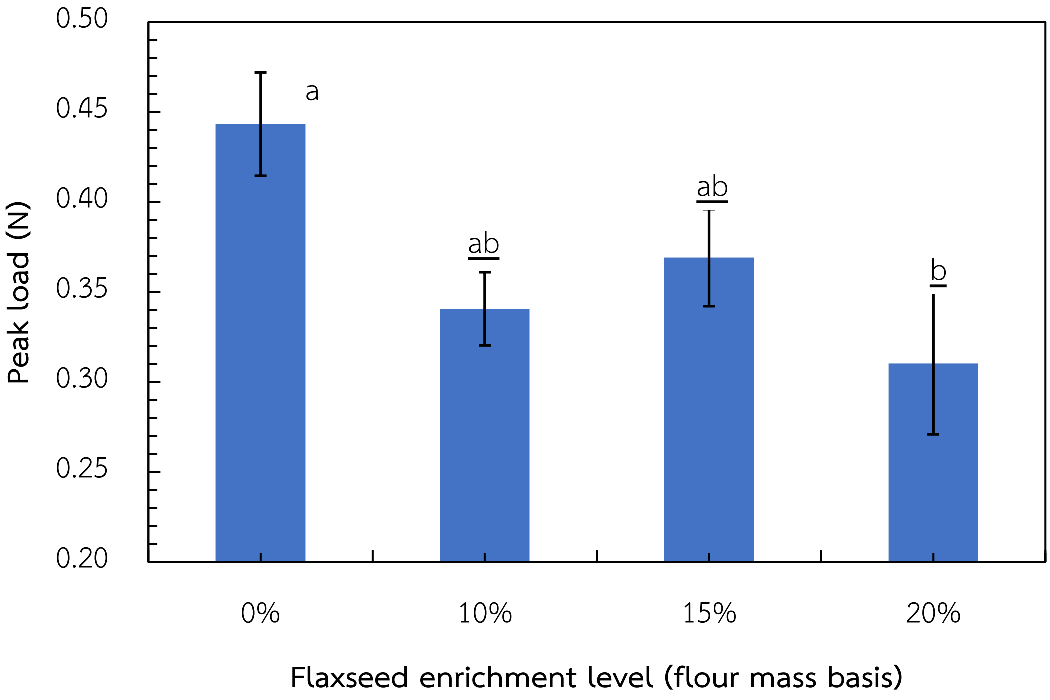

Figure 4.2 Peak load data of fresh dough samples obtained from the Kieffer extensibility test. Data are treatment means and error bars are standard deviation (n=2). Means with different letters differ significantly ($p<0.05$).

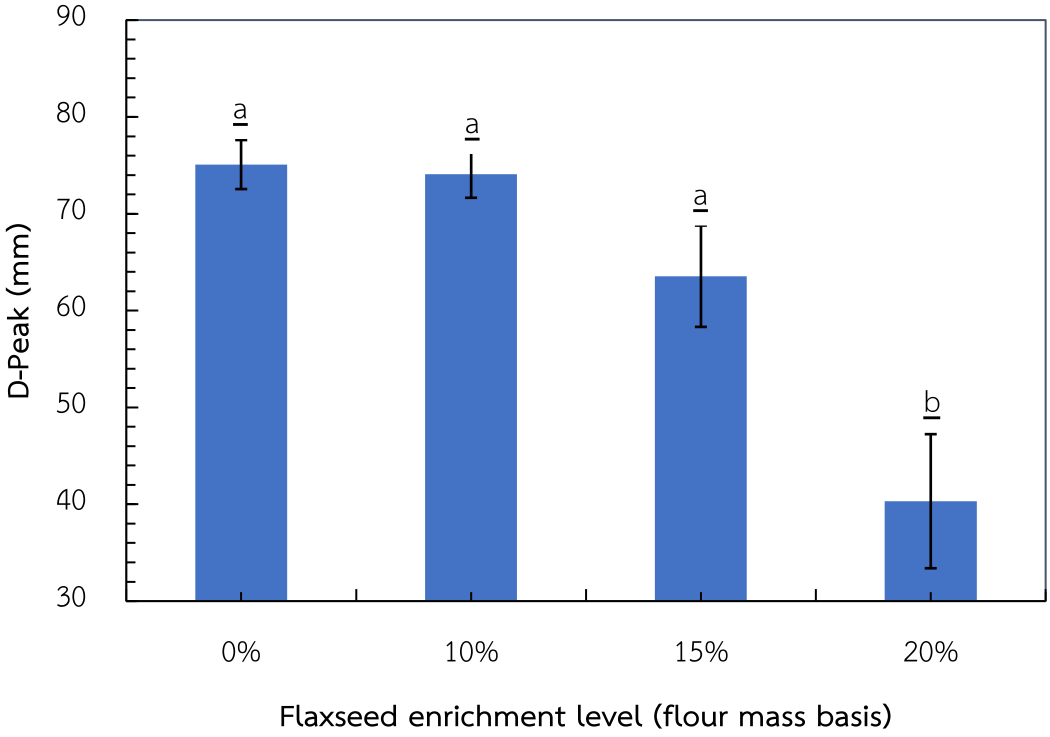

Figure 4.3 D-Peak data of fresh dough samples obtained from the Kieffer extensibility test. Data are treatment means and error bars are standard deviation (n=2). Means with different letters differ significantly ($p<0.05$).

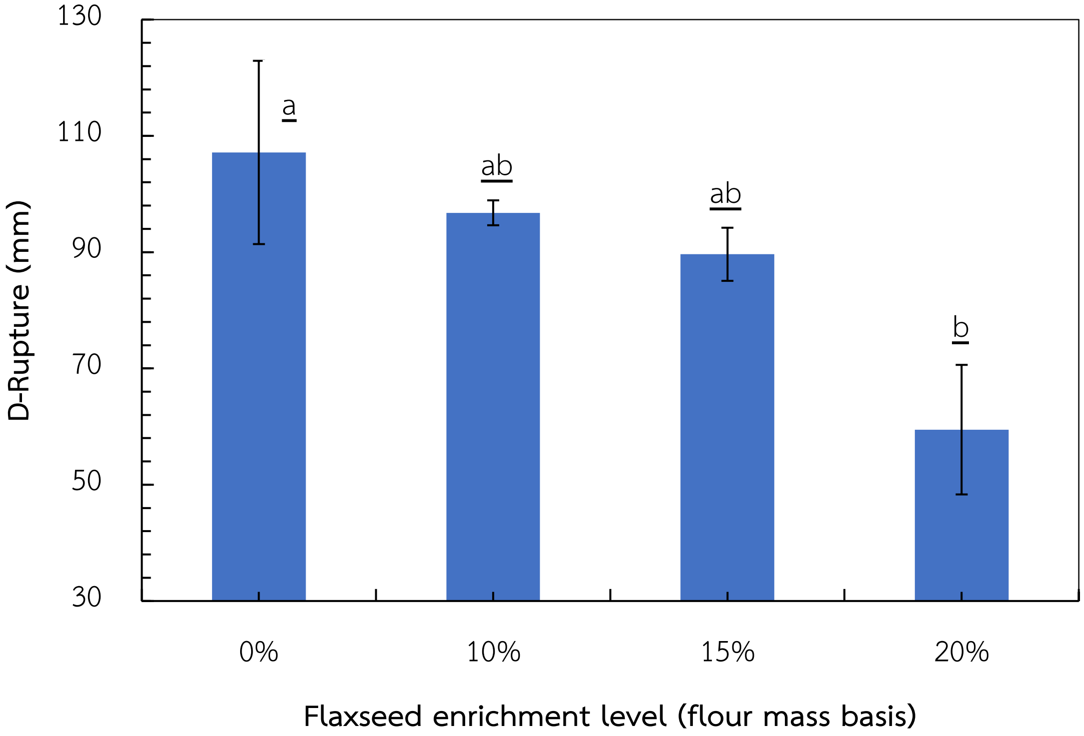

Figure 4.4 D-Rupture data of fresh dough samples obtained from the Kieffer extensibility test. Data are treatment means and error bars are standard deviation (n=2). Means with different letters differ significantly ($p<0.05$).

4.1.2 Specific Volume of Bread Baked from Fresh Dough

The specific volume of bread is among the very influential quality parameters to consumers. In this study, it was observed that the addition of flaxseed to bread recipe led to the decrease of bread loaf specific volume. The control treatment had a highest specific volume of 4.83 cm^3/g, and this quality parameter of bread samples gradually decreased to 4.68 cm^3/g, 4.35 cm^3/g, and to 4.30 cm^3/g, respectively for flaxseed enrichment levels of 10%, 15%, and 20% (Figure 4.5). However, statistical analysis reavealed that only the specific volume of the treatment with 20% flaxseed enrichment that significantly decreased from that for the cobtrol treatment. The addition of flaxseed for 10% and 15% did cause the specific volume of bread loaf to differ from that of neither the control treatment nor the treatment with 20% flaxseed addition.

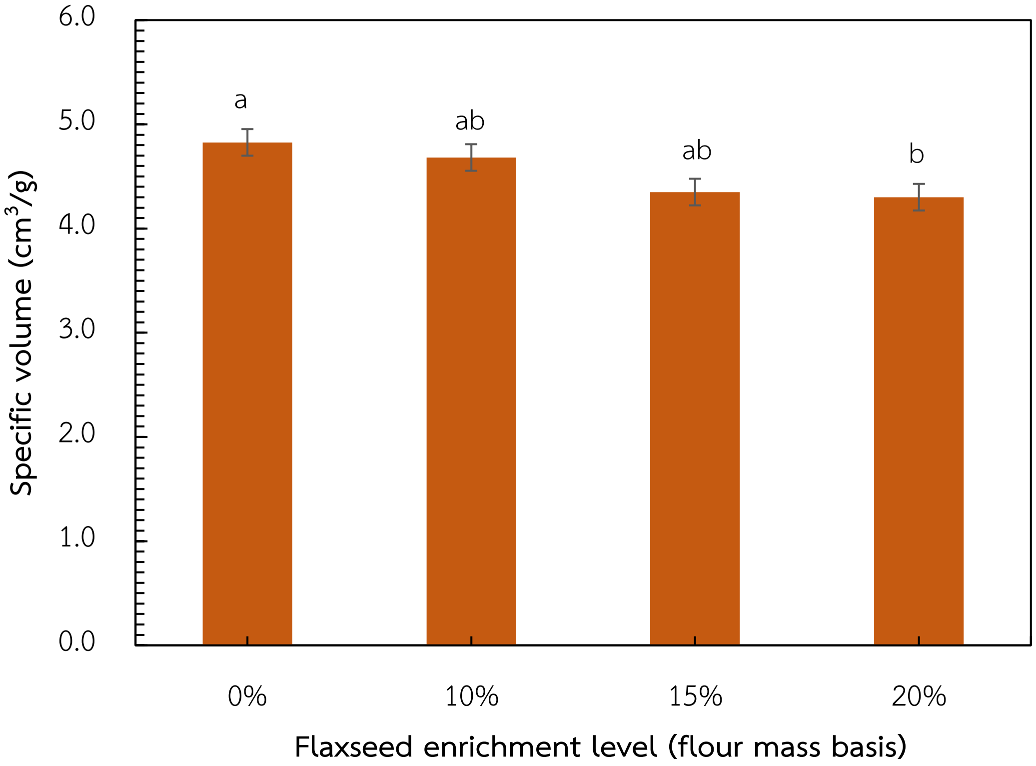

Figure 4.5 Specific volume of bread loaf at different flaxseed enrichment levels. Data are treatment means and the error bars are standard deviation (n=2). Means with different letters differ significantly ($p<0.05$).

There have been a great deal of research study about the effects of flaxseed fortification on physical characteristic of the bread. However, from many studies, the effect of flaxseed fortification on the specific volume of bread loaf seemed to be unclear [9], [38]. There was proposed that the dilution of gluten might account for the reduction in bread loaf specific volume [8]. Furthermore, the dietary fiber was also reported to have fungistatic activity which could hinder the growth rate of yeast which led to the lowering of carbon dioxide production and finally the lesser expansion of the dough [39], [40]. In contrast, there was also a report on the increase of bread loaf specific volume upon flaxseed enrichment [9]. The explanation was that dietary fiber particularly the soluble one which has a great water binding capacity could retain more water during mixing. This helps promote the rising of dough and later could create the higher pressure, by evaporation process, inside the dough during baking. As a result, the specific volume of bread product would be enhanced [41].

Again, the findings from this study evidenced that the addition of ground flaxseed resulted in the reduction of specific volume of bread loaf. It should be however noted that the magnitude of specific volume reduction was considerably small and might be practically insignificant. In other literature that studied on the effects of flax marc and flax flour fortification reported similar results [42]. It was also proposed that the dilution of gluten network by dietary fiber as well as lignan would be responsible for the decrease in specific volume of bread loaf [43]. Additionally, the reduction of the specific volume could be due to the high water binding capacity of soluble fiber that might limit the amount of steam generated during baking process [44].

4.1.3 Correlation between Rheological Characteristic of Dough and Specific Volume of Bread Product

The strength of bread dough is presumed to be an important property in breadmaking process. Other than process ability, dough strength also contributes to the final quality of bread product. In this study the correlation between the large strain rheological parameter of dough and the specific volume of bread product was investigated. The D-rupture parameter—a measure of extensibility of dough was selected. Figure 4.6 shows the plot between D-rupture of dough and the specific volume of bread loaf.

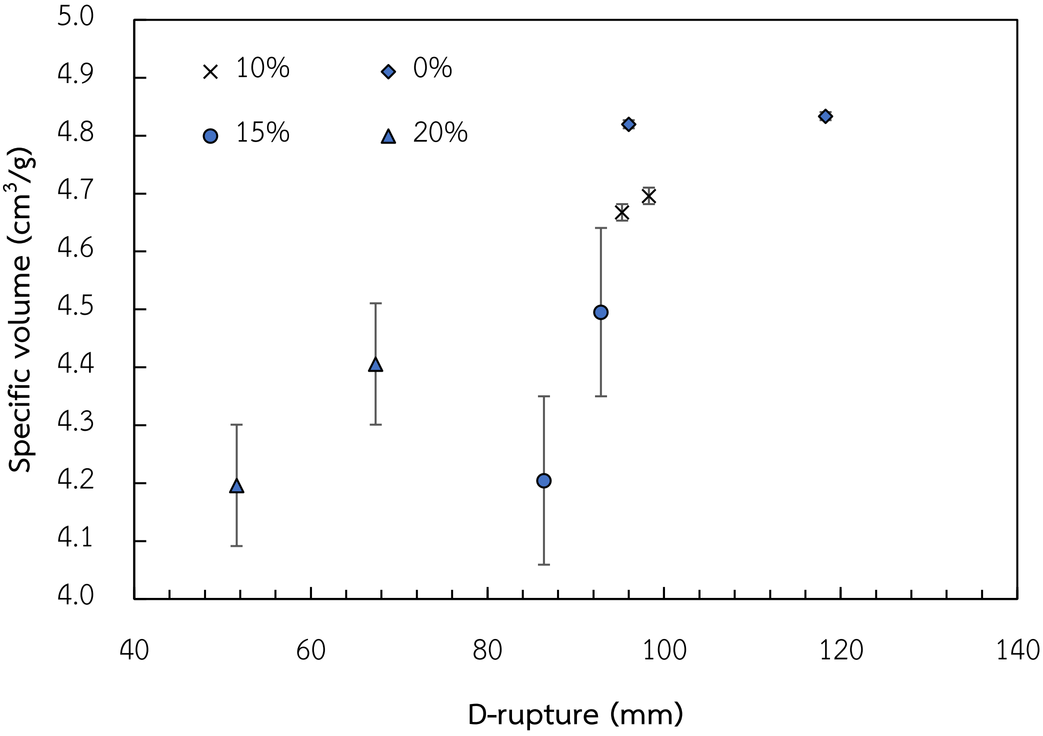

Figure 4.6 A correlation plot between the D-rupture of dough and specific volume of the obtained bread loaf. Data are treatment means and the error bars are standard deviation (n=2).

It could be seen from that the D-rupture apparently well correlated with the specific volume of bread loaf. From statistical analysis, the pearson correlation coefficient value was approximately 0.80 confirming a high level of correlation between dough extensibility and the specific volume of bread product.

4.1.4 Moisture Content of Bread Product

There was a report about the relationship between the moisture content and the firmness of bread. It was found that moisture content was inversely proportional to firming rate. Like in many other kinds of foods, water exhibits an important role as a plasticizer in bread. The decrease in moisture content could accelerate the formation of cross-links between starch and protein which led to the increasing firming rate of bread [45].

In this experiment, there was apparently no trend of change in moisture content of bread crumb upon the addition of ground flaxseed up to 20% which was the highest enrichment level in this study (Figure 4.7). Statistical analysis confirmed that there was no significant difference of moisture content among all of the treatments. The moisture content of bread crumb varied within a range of 41.15% – 42.21% (wb). In contrast, one of prior studies reported the increase of moisture content as the level of flaxseed enrichment increased from 0% to 15% [37].

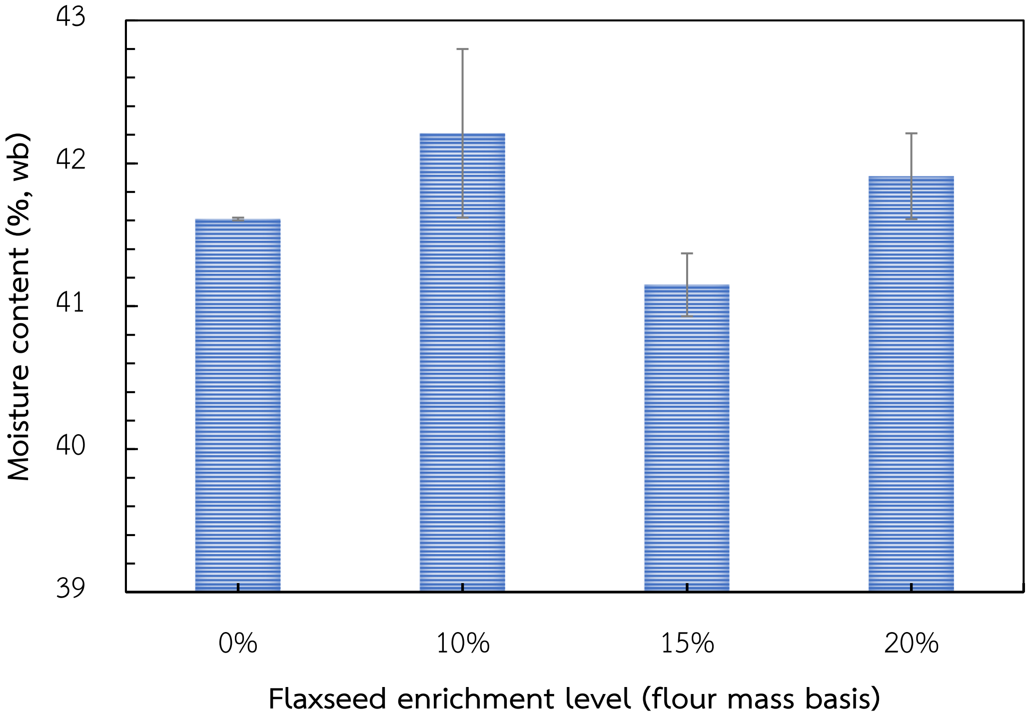

Figure 4.7 Moisture content of bread crumb at different flaxseed enrichment levels. Data are treatment means and the error bars are standard deviation (n=2). Means with different letters differ significantly ($p<0.05$).

4.1.5 Instrumental Textural Characteristics of Bread Crumb

The texture profile analysys (TPA) test allowed several textural characteristics of bread to be inferred from. The instrumental textural parameters including hardness, cohesiveness, springiness and chewiness of bread crumb was investigated in this study. The example of typical TPA graphic for each treatment showed in Figure. 4.8. By the visual observation, the maximum point of the plot at the first compression is gradually decreasing from the graph of the control sample to the sample with 15% of flaxseed addition and the greatest value found in the graph of 20% of flaxseed enrichment sample. As this parameter indicats the hardness of bread suggesting the effects of flaxseed on bread's hardness happened upon the addion of flaxseed.

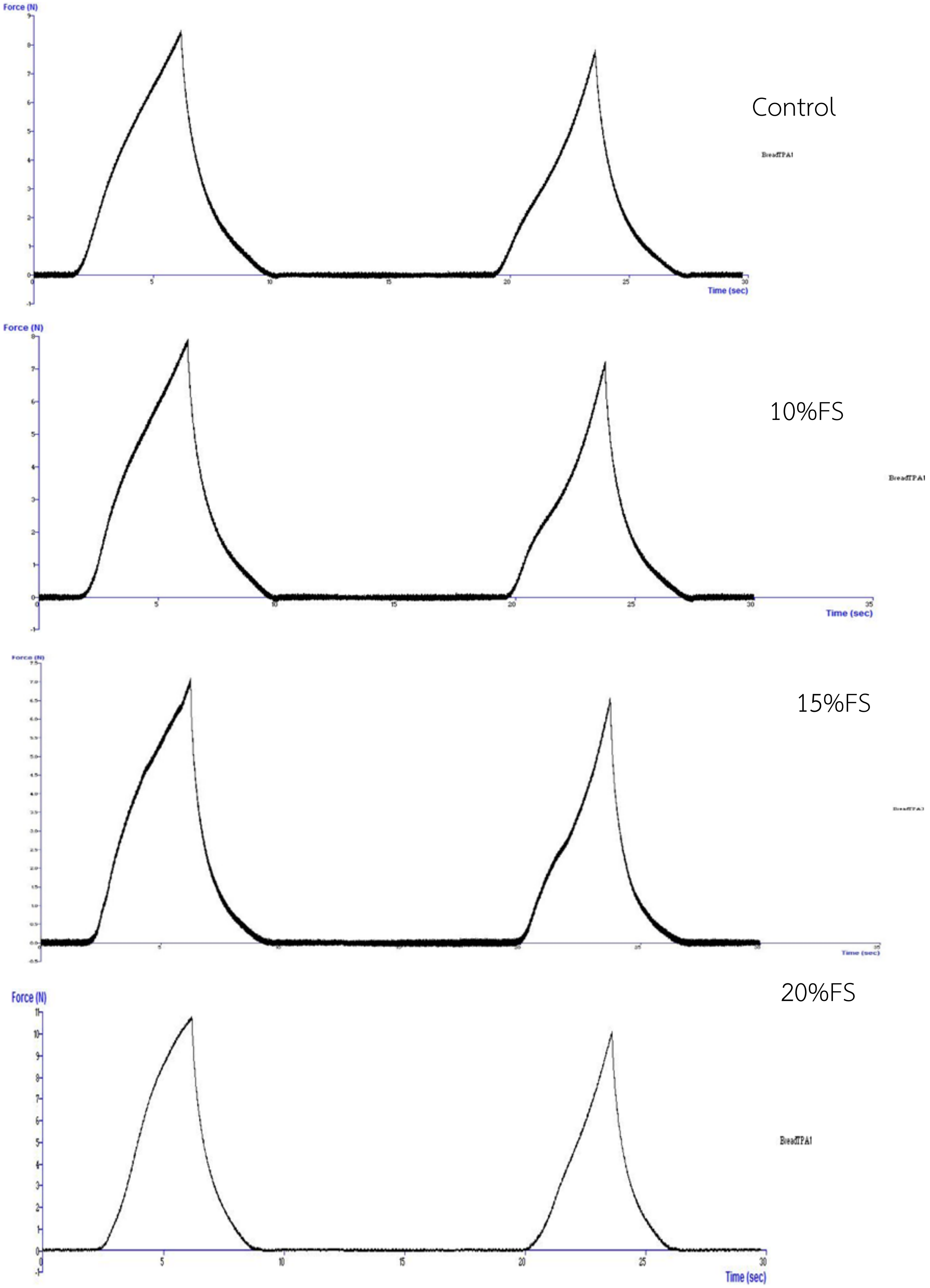

Figure 4.8 A typical force-time plot obtained from texture profile analysis (TPA) test of bread sample using the TA.XT*plus* texture analyzer for control (0%), 10%, 15% and 20% of flaxseed enriched bread samples.

From the data analysis, it was found that the addition of flaxseed up to 15% did not cause any significant change in the and hardness (Figures 4.9). By adding flaxseed for 20%, the hardness significantly increased to 11.48 N, or increasing by 41% as compared to those for the control treatment. The effect of flaxseed enrichement of hardness was in accordance with previous study. It was reported that 15% flaxseed enrichement could make the hardness rise by 40% [46].

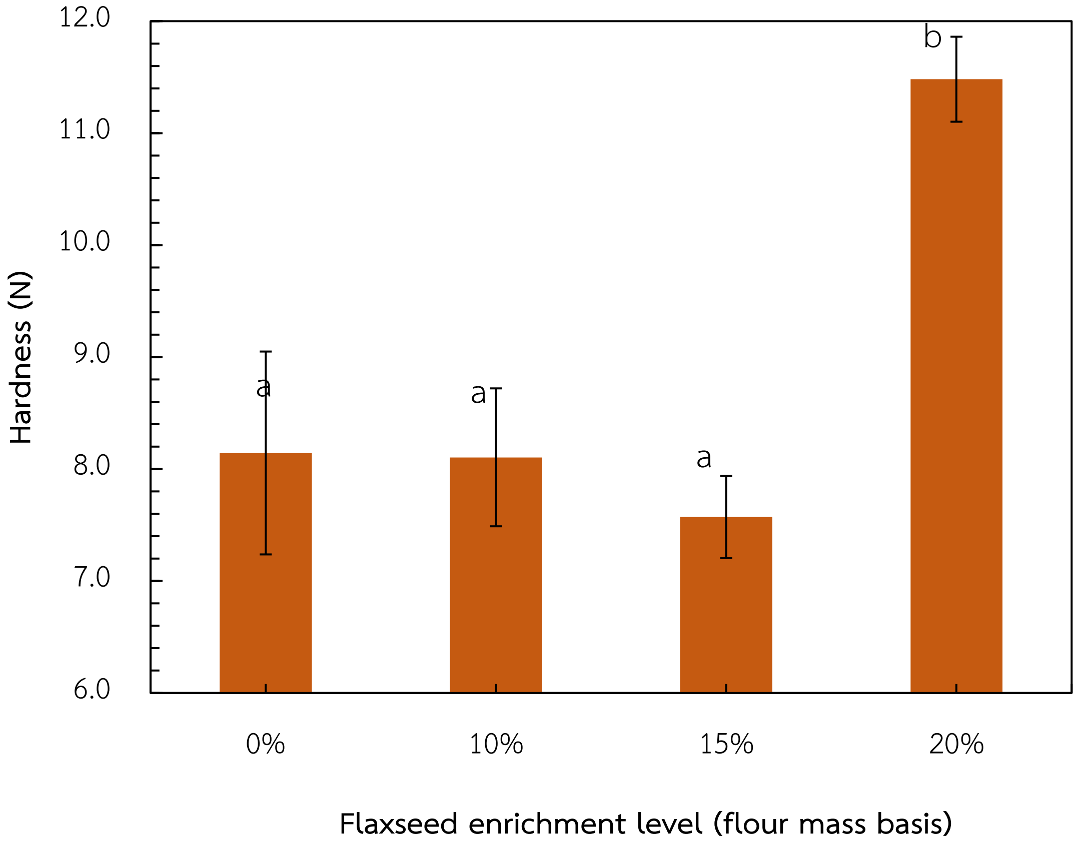

Figure 4.9 Experimental data for the hardness of bread samples baked from freshly prepared dough with different flaxseed enrichment levels. Data are treatment means and error bars are standard deviation (n=2). Means with different letters differ significantly ($p<0.05$).

While the hardness tended to increase upon the addition of flaxseed to bread recipe, in contrast, the cohesiveness and springiness showed a decreasing trend. Again these parameters did not significantly change when flaxseed was added up to 15% (Figures 4.10 and 4.11). When the addition of flaxseed was raised to 20%, cohesiveness and springiness significantly decreased to 0.69 N, and 0.92 or decreasing by 11.5% and 2.1%, respectively, as compared to those for the control treatment.

The decrease in springiness indicated that the addition of flaxseed could impare the elasticity of bread. Depending on the source of dietary fiber used, it could affect the firmness and springiness of bread. The reduction of gluten content could also be the cause for the decrease of elasticity [7]. It was clearly evidenced from the inspection by electron microscopy that bread crumb was observed with a less fine structure. The sheets and filaments were coarser for the sample of bread with fibrous [8].

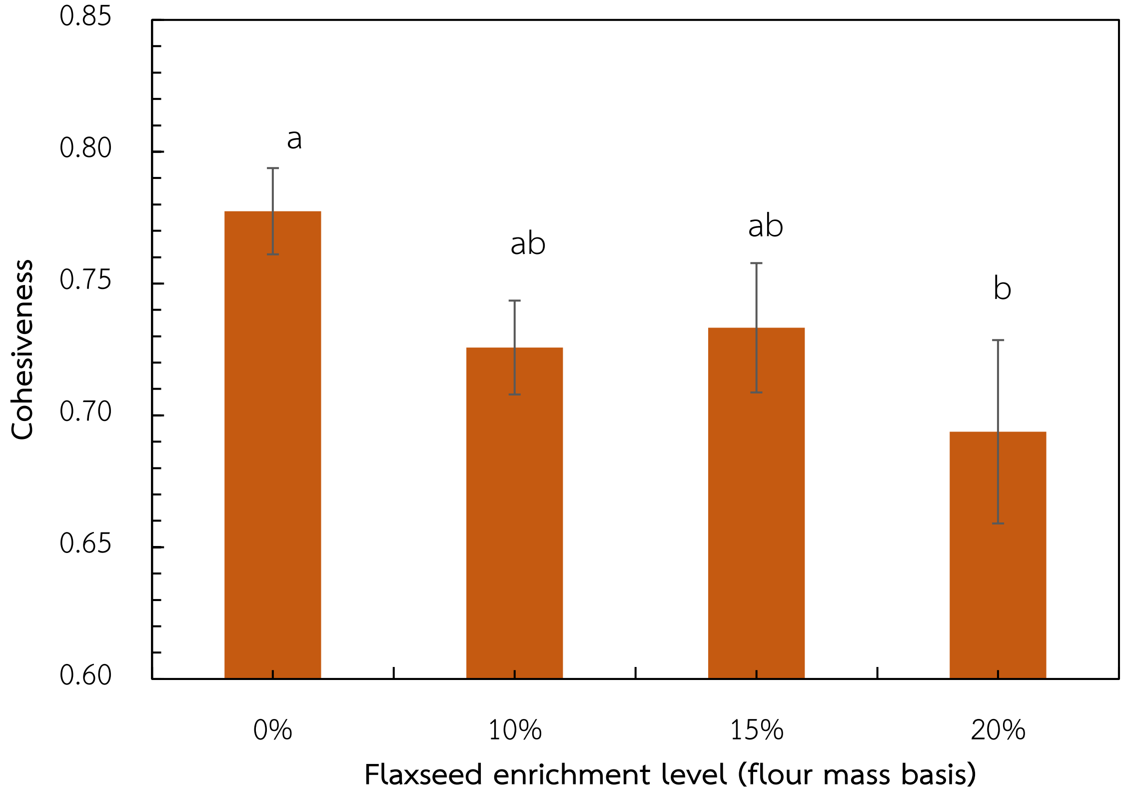

Figure 4.10 Experimental data for the cohesiveness of bread samples baked from freshly prepared dough with different flaxseed enrichment levels. Data are treatment means and error bars are standard deviation (n=2). Means with different letters differ significantly ($p<0.05$).

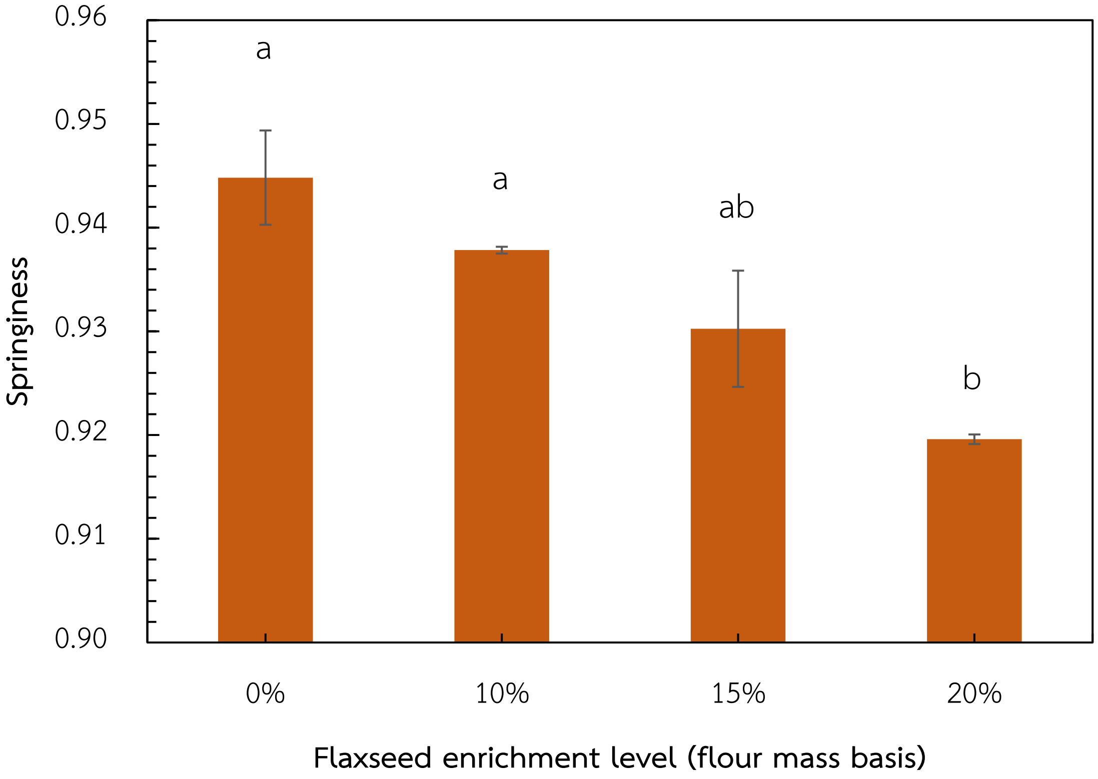

Figure 4.11 Experimental data for the cohesiveness of bread samples baked from freshly prepared dough with different flaxseed enrichment levels. Data are treatment means and error bars are standard deviation (n=2). Means with different letters differ significantly (p<0.05).

Similar to the case of hardness, the chewiness of bread was found to increase with the addition of flaxseed (Figure 4.12). By adding flaxseed for 20%, the chewiness significantly increased to 7.22, or increasing by approximately 21% as compared to those for the control treatment. The reason could simply be that the chewiness value was calculated using the values of hardness, cohesiveness, and springiness. Among these parameters, the most substantial change upon the addition of flaxseed was found in the value of hardness.

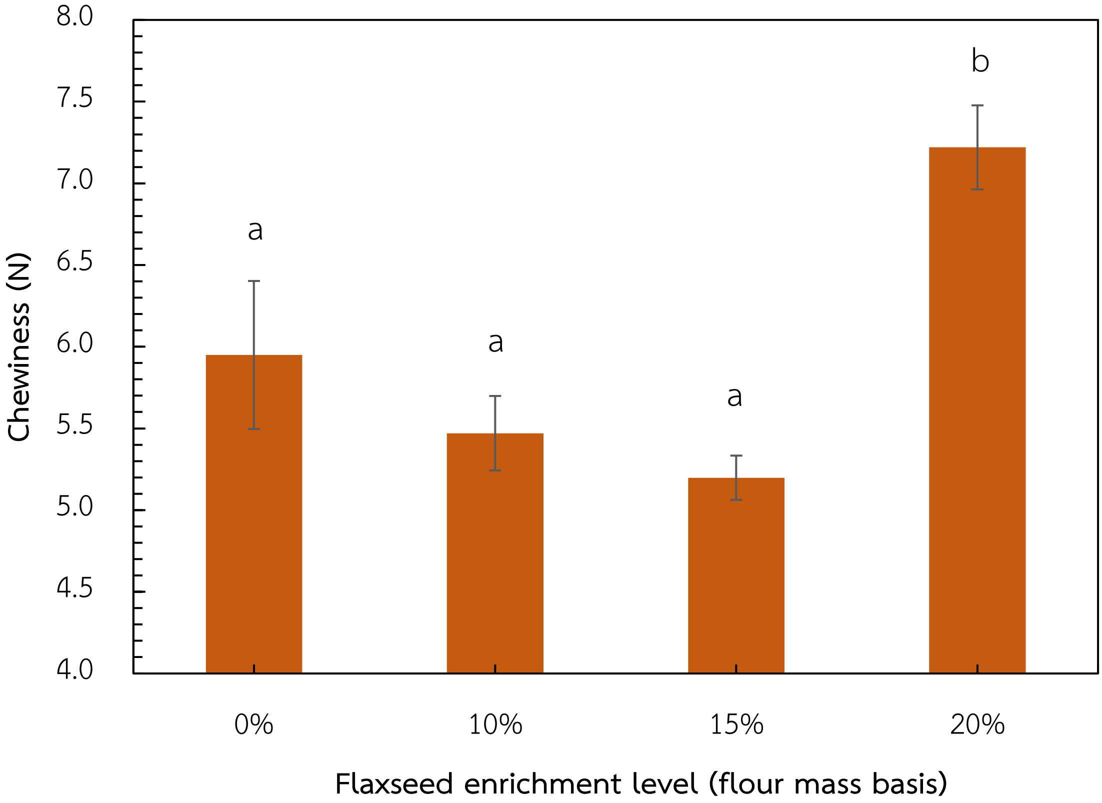

Figure 4.12 Experimental data for the chewiness of bread samples baked from freshly prepared dough with different flaxseed enrichment levels. Data are treatment means and error bars are standard deviation (n=2). Means with different letters differ significantly (p<0.05).

4.1.6 Evolution of Bread Firmness During Storage

Staling is a phenomenon that affect the shelf life of baked products in terms of consumer acceptability. The texture of foods get harder as staling is taking place. In this study, bread hardening process was investigated at two different storage temperatrues, 4°C and 18°C for up to 7 days. The process was observed from the evolution of the hardness values during storage. The staling was found to be a function of time, processing, temperature, as well as the formulation of bread [47]. The experimental data on the evolution bread hardness during the storage at the two different temperatures studied, 4°C and 18°C, are illustrated in Figures 4.13 and 4.14 respectively. Regression lines are also given along on the plots. These regression lines were generated based on the Avrami equation using the parameters shown in Table

4.1. It was found that experimental data could be well fitted with the Avrami equation showing coefficient of determination (R^2) in a range of 0.97 to 0.99.

In general, the hardening rate of bread was faster when stored at 4°C compared to that at 18°C. It was also visible from Figures 4.11 and 4.12 that the hardening rate of the treatment with out flaxseed or control treament was higher than that of the treatments with flaxseed added. This was true fot both levels of storage temperature. After one day of storage, the hardness of the control treatment increased from 8.14 N to 25.90 N, and to 20.96 N when stored at 4°C and 18°C, respectively. The hardening rate could be numerialcally justified by considering the constant rate (k) and the half-life ($t_{1/2}$) parameters. From regression analysis, the value of k was 0.47 and the value of $t_{1/2}$ was 1.83 days when bread samples were stored at at 4°C, whereas these values for bread samples were 0.30 and 2.29 days when stored at at 18°C. The study on the gluten-free bread storage at two different temperatures, 4°C and 20°C found a similar result on the hardening rate of bread product [33]. However, the differences of Avrami parameters and $t_{1/2}$ were not obvious when comparing between the control sample and treated samples. It was probably due to a limited number of data obtained in this study was.

From the experimental data, the initial hardness values of flaxseed enriched treatments were higher than that of the control treatment. However, the hardness of the control treatment increased rapidly and turned to be higher than that of the treatments with flaxseed, particularly after the 4th and 7th days of storage. The same trend was found for the samples stored at both levels of storage temperatrues, 4°C and 18°C. It might be due to the fact that the added flaxseed helped improve moisture retention in bread which could suppress the hardening rate. In flaxseed, mucilage presents about 8% of the seed weight [48]. Muciage is a soluble fiber making up of polysaccharides and is known for its great water binding capacity (WBC). It was reported that the mucilage of flaxseed exhibits a water binding capacity in the range of 1600—3000 $g_{water}/100\ g_{solid}$ [49].

When considering the two storage temperatures studied, it was found that bread samples exhibited a higher firming rate when stored at 4°C compared to that when stored at 18°C. The average value of the rate constant (*k*) and the half-life for the bread stored at 4°C were 0.44, and 1.86 days, respectively, while these values were respectively 0.33 and 2.28 days for the sample stored at 18°C. In previous study, the similar finding was also reported in that starch retrogradation rate was higher at low temperature ranges [33], [50], [51].

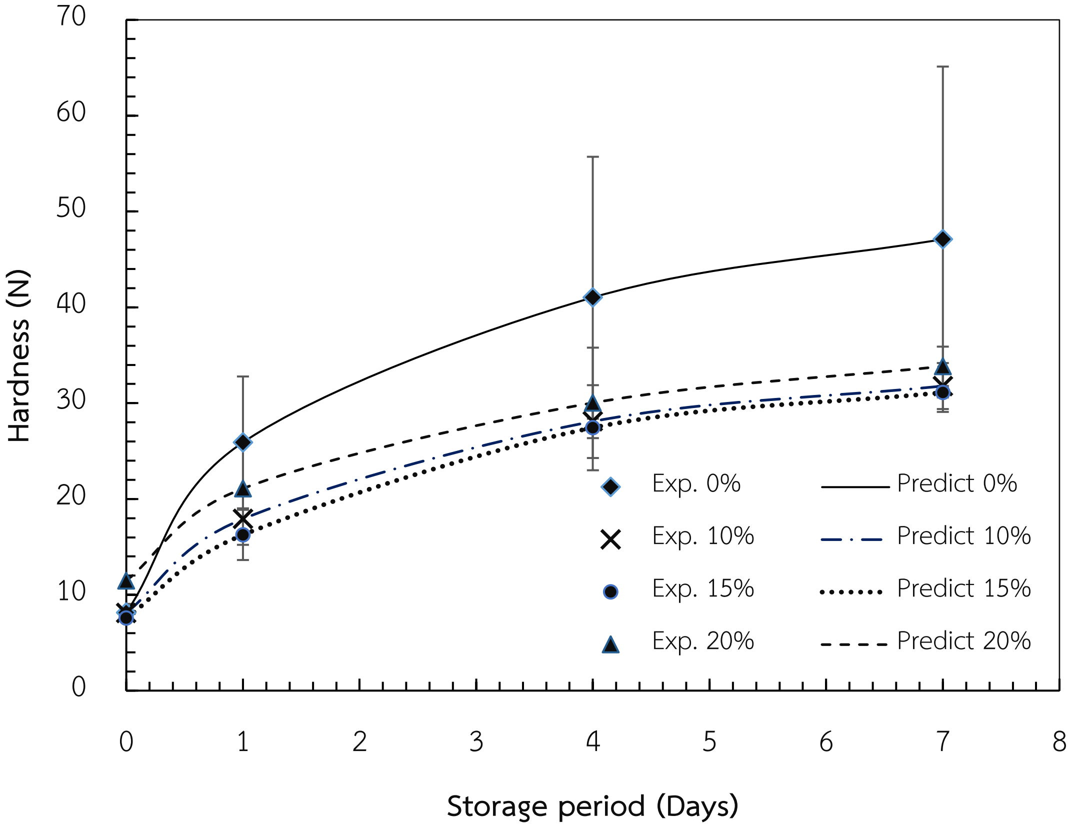

Figure 4.13 Evolution of the hardness of bread crumb during storage at 4±2°C for up to 7 days. Error bars are standard deviation (n=2). The prediction lines were generated using the Avrami equation with the parameters given in Table 4.1.

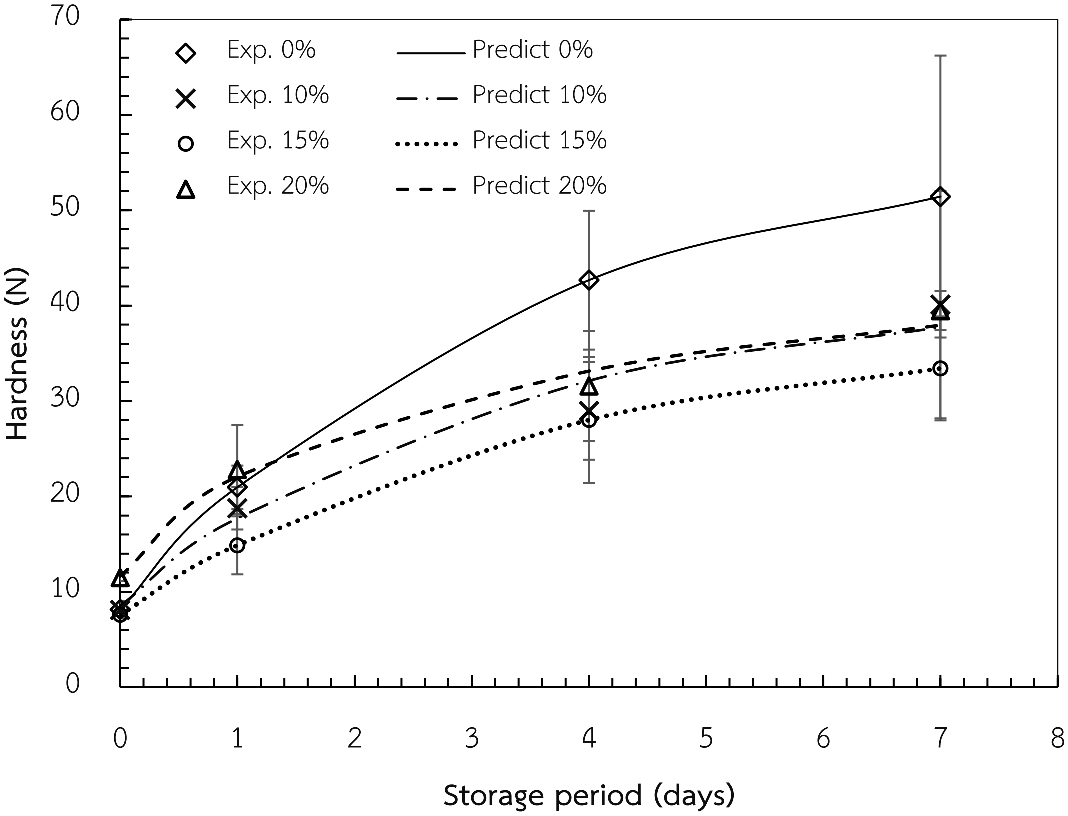

Figure 4.14 Evolution of the hardness of bread crumb during storage at 18±2°C for up to 7 days. Error bars are standard deviation (n=2). The prediction lines were generated using the Avrami equation with the parameters given in Table 4.1.

Table 4.1 Hardening kinetic parameters of bread samples based on the Avrami model, the corresponding determination coefficient (R^2), and the half-life of bread samples stored at two different temperatures (4°C and 8°C) for up to 7 days.

Storage temperature	Treatments	H_0 (N)	H_∞ (N)	k (day^{-n})	n	R^2	Half-life (days)
4°C	Control	8.14	55.92	0.47	0.66	0.999	1.83
	10%FS	8.10	35.10	0.45	0.79	0.999	1.72
	15%FS	7.57	33.22	0.41	0.93	0.999	1.75
	20%FS	11.48	39.89	0.41	0.68	0.999	2.14
18°C	Control	8.14	57.36	0.30	1.00	0.999	2.29
	10%FS	8.52	41.53	0.33	0.97	0.970	2.17
	15%FS	7.57	36.98	0.29	1.03	0.999	2.37
	20%FS	11.48	44.80	0.38	0.74	0.988	2.29

4.2 Characteristics of Refrigerated Dough and Bread Product

4.2.1 Syruping Behavior of Refrigerated Dough

Exerimental data for the evolution of dough syruping when refrigerated at 4°C as a function of time were given in Figure 4.15. In this experiment, when freshly prepared dough was centrifuged, it was found the appearance of brownish liquid adhering on the centrifuge tube. This meant that dough syruping already took place for some extent even before refrigeration. The degree of dough syruping (DDS) then slightly increased until the 3rd day of refrigeration and continued at a limited rate until the 7th day except for the control treatment which syruping rate started to increase. The control treatment showed an increasing syruping rate so that the DDS increased from approximately 4% on the 7th day of refrigeration to around 8%, 11%, and 13% on the 14th, 21st, and 35th day, respectively. The result suggested that flaxseed enrichment could retard dough syruping. The most retarding effect was observed in the 20% flaxseed enriched sample.

The similar result was also reported in prior studies. It was found the increase of syruping in a control treatment from the 8th day of refrigeration until reaching the maximum level at the 40th day of observation [21]. In another study on Jopoom wheat dough, the samples were refrigreated at 5°C. Dough syruping occurred since day 3 of refrigeration with the value of approximately 1.73% (w/w, dough weight basis) and reached the maximum value of 17.2% at day 35 of refrigreation [52].

Arabinoxylans (AXs)─ non-starch polysaccharides, which usually present in the amount of 1.5% to 2.5% in wheat flour, was found to be responsible for the syruping phenomena of dough. AX plays significantly role on dough characteristic and the quality of baked product since it is capable of binding to water at almost ten times as much as its own weight and this accounts for almost 30% of the water binding capacity of wheat flour [53]. The degradation of AX by xylanase enzyme presenting in wheat flour causes the dough to lose its water-holding capacity resulting in the syruping of refrigerated dough [21].

There was no significant difference of DDS among the flaxseed enriched treatments until the 21st day of refrigeration. After 35 days of refrigeration, the DDS of the treatments with 10% and 15% flaxseed significantly increased from approximately 4% to 6% and 5%, respectively.

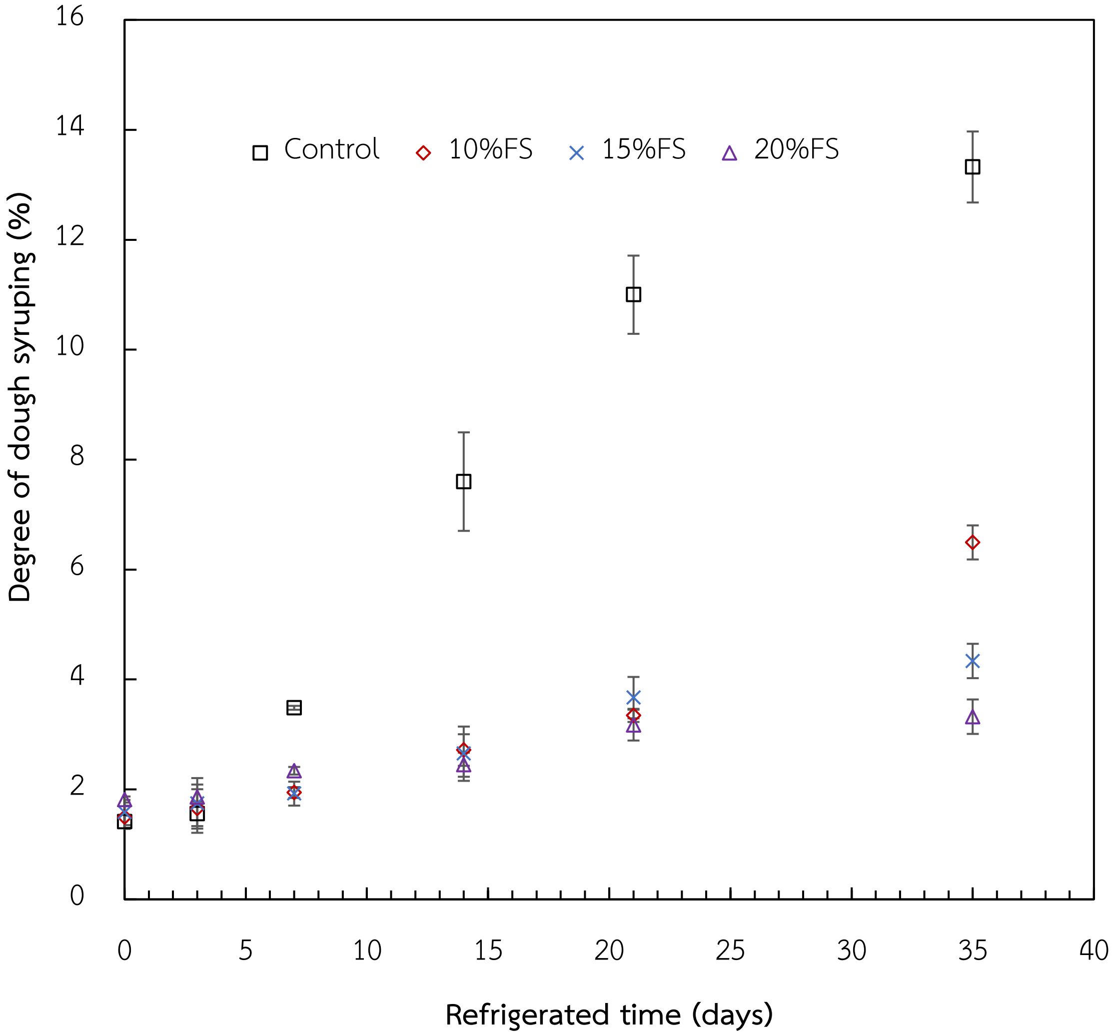

Figure 4.15 The evolution of dough syruping as a function of refrigerarted time (at 4°C for up to 35 days). Data are mean and the error bars represent standard deviation (n=3).

4.2.2 Effect of Dough Refrigeration on Specific Volume of Bread Product

From the fact that characterisitcs of dough are well correlated with the qualities of final product, it is therefore interesting how refrigeration process could affect the dough and finally the quality of bread. The specific volume of bread loaf was selected since it is among the quality parameters that could greatly affect comsumer acceptance. In this experiment, the evolution of specific volume of bread product as a function of refrigeration time of dough at 4°C was observed for up to 35 days. Experimental data are given in Figure 4.16.

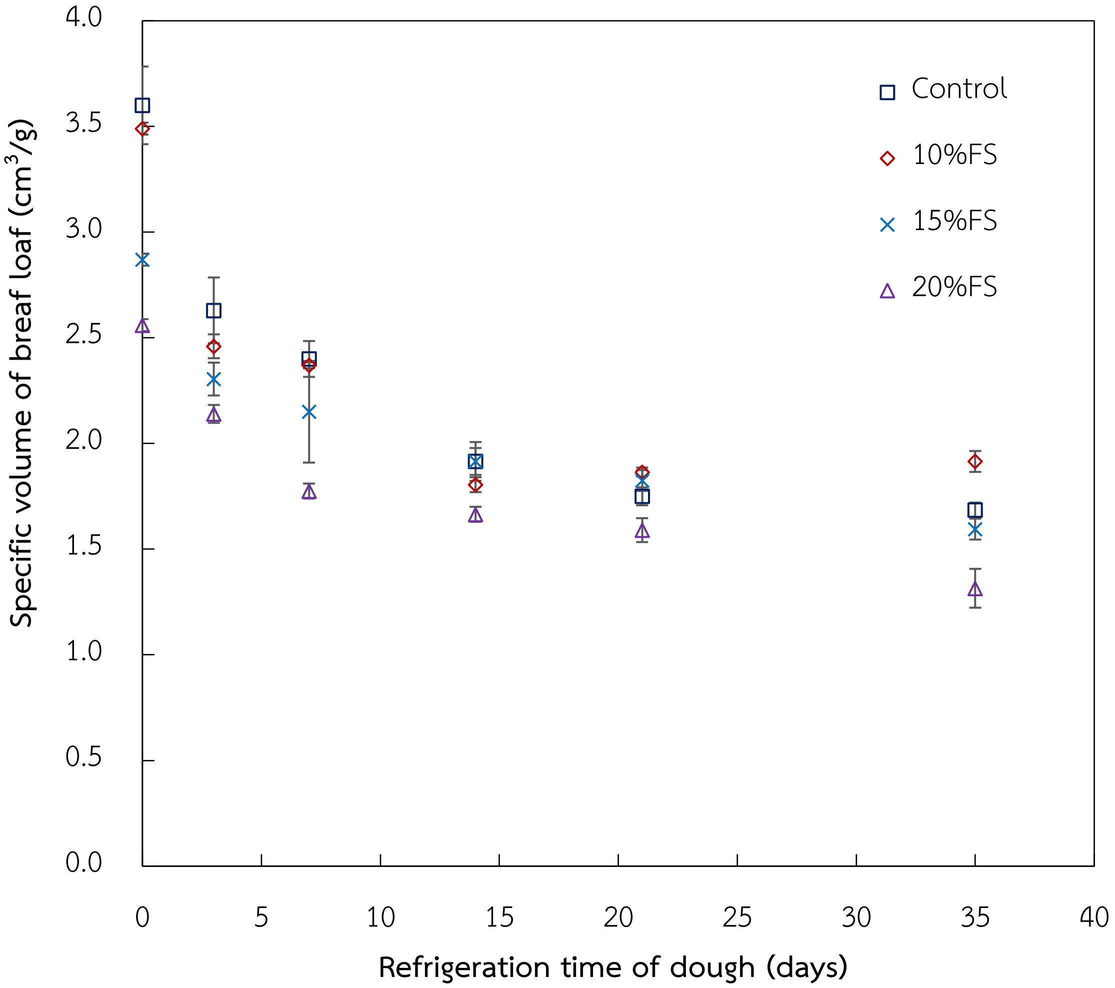

Figure 4.16 Specific volume of bread loaves baked from freshly prepared dough and refrigerated dough (at 4°C for up to 35 days) samples. Data are means and the error bars are standard deviation (n=3).

In all of the treatments studied, the specific volume of bread product tended to decrease as dough refrigeration time got longer. For the bread sample baked with freshly prepared dough, the specific volume of the flaxseed fortified treatments were generally lower than that of the control treatment which was 3.6 cm^3/g. However only the specific volume of the treatment with 15% and 20% flaxseed that were significantly lower that that of the control treatment. After 3 days of dough refrigeration, there was no significant difference of specific volume among all of flaxseed fortified bread samples. The decreasing trend kept going on until the 35th days of refrigeration. Interestingly, the bread sample with 10% flaxseed enriched could retain the specific volume well with the highest value even when compared to that of the control treatment. The similar findings of the reduction in specific volume of bread product were also reported in other studies. It was found that the specific volume of bread decreased upon the addition of fibers from different sources such as hazelnut fiber [54], sugar beet [55] fiber, and apple fiber [56]. It was postulated that the integrity of dough structure might be compromised with the presence of fibers leading to the reduction in CO_2 retention. Furthermore, fiber which is known to have excellent water binding capacity would reduce the available water for the development of starch-gluten network, causing some under-developed gluten network and finally resulting in the decrease of specific volume of bread product [8]. It was suggested in litureature that adding hydrophilic gum into the frozen dough could help retaining the specific volume of bread product [57].

4.2.3 Effects of Dough Refrigeration on Instrumental Textural Property of Bread Product

The textural property of bread product baked from refrigerated dough was studied since it is logically believed that changes on dough during refrigeration would also affect the baked product. In this experiment, dough samples were refrigerated at 4°C for up to 35 days. Bread products were baked with refrigerated dough samples after the 3rd, 7th, 14th, 21st, and 35th day of refrigeration. As for comparison purpose, bread samples were also obtained with freshly prepared dough. The textural parameters studied included the hardness, cohesiveness, and chewiness and results are shown in Figures 4.17, 4.18, and 4.19, respectively.

Among all of the treatments, the hardness of bread baked from freshly prepared dough were viuaully comparable. For every treatment, in general, the hardness of bread increased as a function of refrigeration time of the dough up to the 21 days. The hardness of every flaxseed enriched treatment was lower than that of the control treatment. When considered over the whole refrigeration period studied, it appeared that the 10% flaxseed enrichment could yield a product with the lowest hardness value. The increasing bread firmness upon dough refrigeration was also reported in prior study. The addition of hydrophilic gum to frozen dough resulted in a lower firmness of bread product as compared to the sample without gum [57]. A softer texture of bread might be due to an increased moisture content since hydrophilic gum posses a great water-holding capacity. The same would be true for the addition of flaxseed to bread recipe since the mucilage in flaxseed could bind with water at around 1600—3000 g_{water}/100 g_{solid} [49].

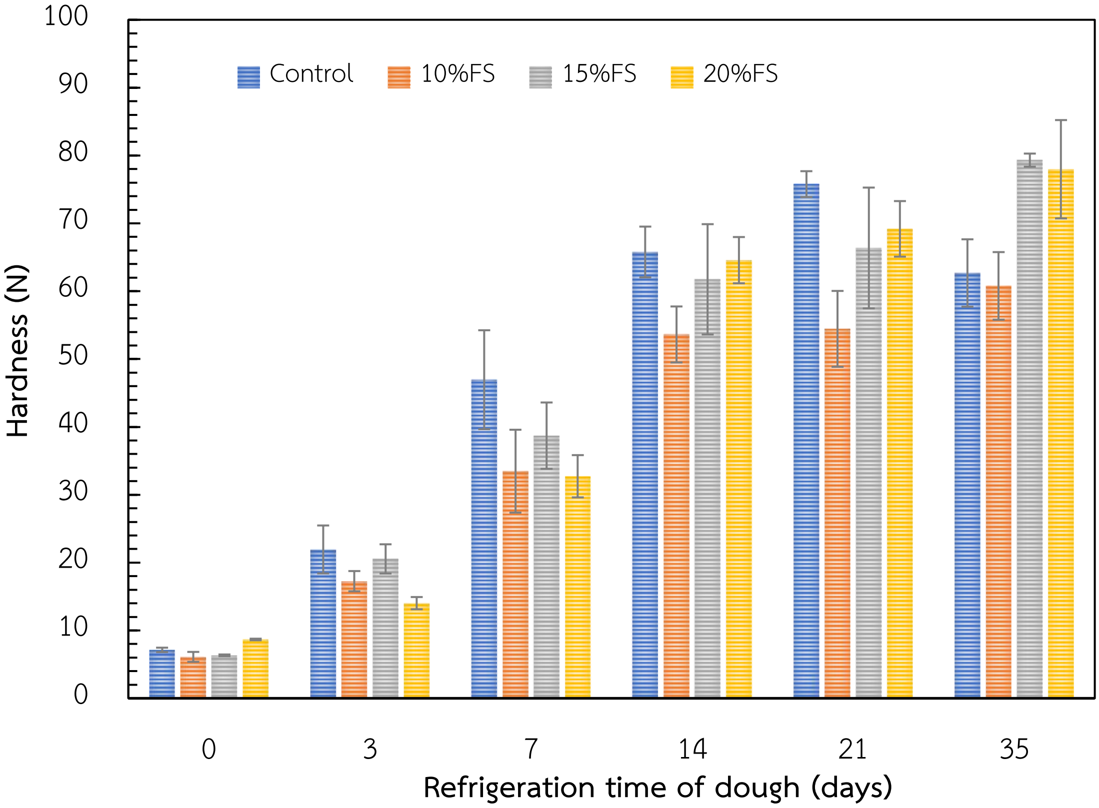

Figure 4.17 Evolution of hardness of bread baked from freshly prepared dough (day 0) and refrigerated dough at 4°C for up to 35 days. Data are means and the error bars are standard deviation (n=3).

In contrast to the hardness, the cohesiveness of bread product gradually decreased with the increased refrigeration period of dough. However, only a subtle decrease of cohesiveness was observed when the refrigeration period was 3 days. In general, for every treatment, much decrease in cohesiveness value was observed when the refrigeration period of dough was 7 days and longer. Apparently, the treatment with 10% flaxseed retain the cohesiveness well over different durations of dough refrigeration and this was comparable to that of the control treatment.

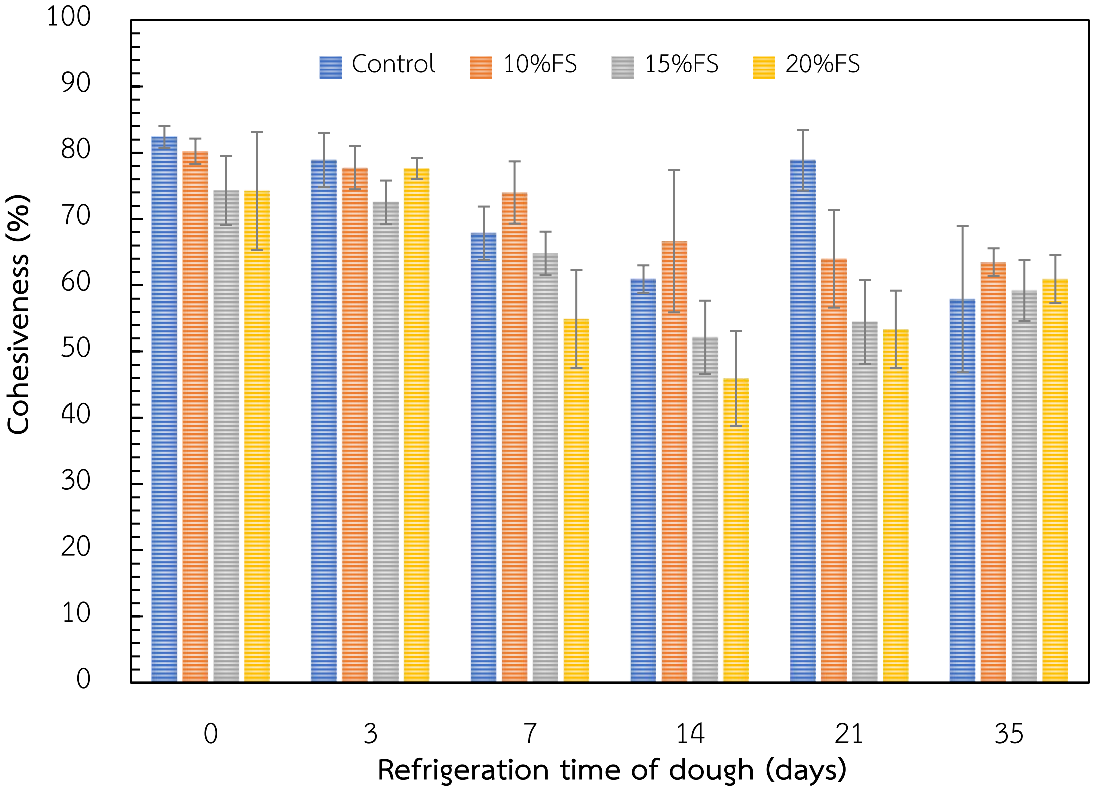

Figure 4.18 Evolution of cohesiveness of bread baked from freshly prepared dough (day 0) and refrigerated dough at 4°C for up to 35 days. Data are means and the error bars are standard deviation (n=3).

From the experimental data on the chewiness of bread products, it was observed that this textural parameter generally kept increasing with the length of refrigeration period of dough. However, the chewiness of flaxseed enriched bread baked from refrigerated dough were lower than that of the control treatment, except the case of 35-days refrigeration. The chewiness is a measure of effort to chew foods. The lower the chewiness value, the less effort needed to break down food by chewing. Hence, the effect of flaxseed enrichment on keeping the chewiness of bread, baked from refrigerated dough, lower than that of the control treatment would be on a positive side.

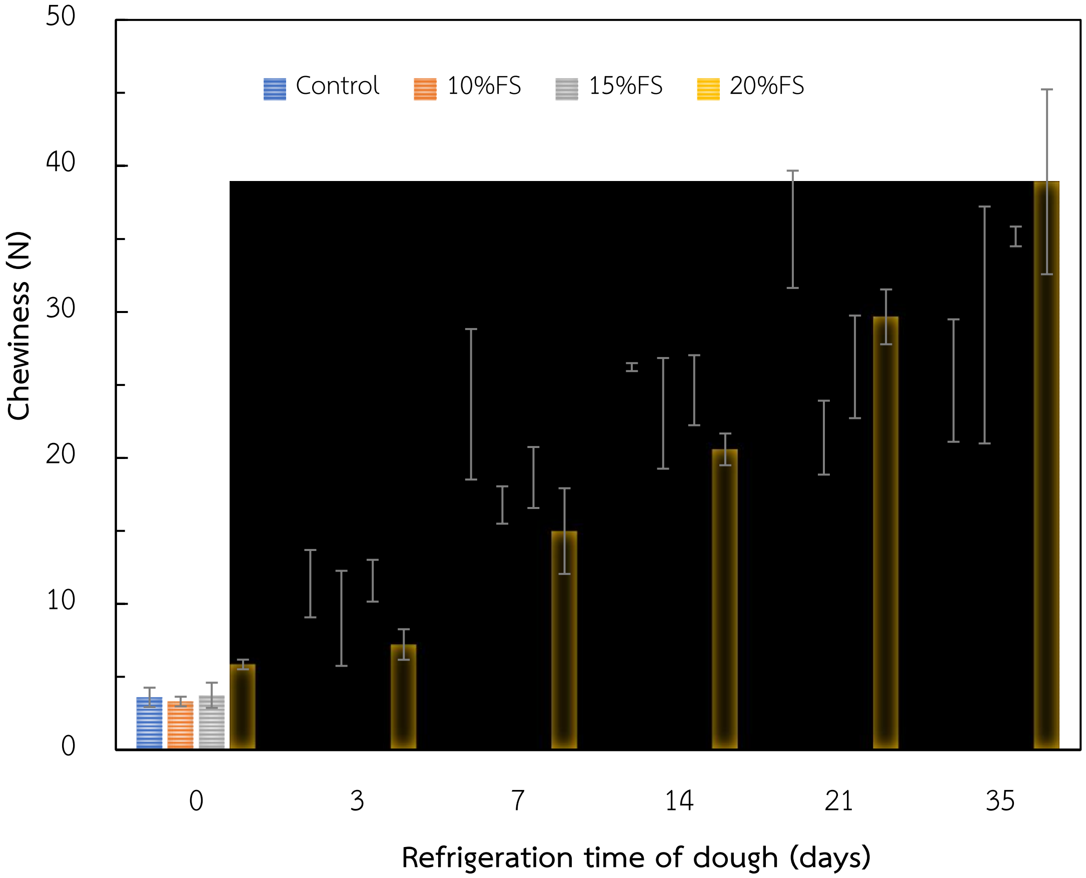

Figure 4.19 Evolution of chewiness of bread baked from freshly prepared dough (day 0) and refrigerated dough at 4°C for up to 35 days. Data are means and the error bars are standard deviation (n=3).

4.3 Step-Change Baking Temperature Scheme and Emissivity of Bread

4.3.1 Settings for the Step-Change Temperature Scheme

According to preliminary tests, the applicable temperature settings for the step-change temperature scheme were obtaind as given in Table 4.2. as well as the experimental data for bread weight loss corresponding to each temperature setting.

For zone 1 of baking, the baking temperarue of 180°C was chosen. This setting allowed the core and the surface temperatures of dough sample to gradually increase to 40°C and 90°C - 95°C, respectively, at the end of the stage. At these temperature levels, enzymatic activity inside the bread is initiated and the growth activity of yeast releases carbon dioxide causing the volume of bread to expend. Though, water vapor might be able to diffuse through the surface of dough sample, the vapor pressure at the surface was still low and so the evaporation was hardly detectable. Accordingly, weight loss was negligible. The baking period of this zone was approximately 20% of the total baking time. With higher baking temperatures, it was found that crust formed up rapidly and the surface of the sample got burned slightly at the end of this baking zone preventing further water evaporation in subsequent stages of baking.

Table 4.2 Experimental data on bread weight loss after baking with different temperature settings.

Baking schemes (°C)	Bread weight loss (%)
180-120-170	10.81 ± 0.34^{a}
180-120-180	12.56 ± 0.47^{c}
180-120-190	11.85 ± 0.78^{b}

Data are mean±SD (n=3). Means with different letters differ significantly ($p<0.05$).

In zone 2 of baking where the core temperature increased from 40°C - 60°C, some enzymatic activities and the growing of yeast would still proceeding. The volume expansion was observable. When fixing the baking temperature of zone 1 at 180°C, adjusting three different levels of baking temperature for zone 2 (90°C, 110°C, and 120°C) did not cause any significant different in bread weight loss. It was mentioned in literature that varying the baking temperature in a considerable narrow range would only slightly affect the surface temperature and so the evaporation of water would not be differenciable [4], [58]. Besides, the length of this baking zone was only around 7% of the total baking time. As a result, the baking temperature of this zone was solely chosen based the cooking level of the sample. It turned out that the sample was properly cooked only when the baking temperature of this zone was set as 120°C.

Baking with the temperature of this zone lower than 120°C resulted in the presence of undercooked portion inside the samples.

In zone 3, the core temperature was increased from 60°C to 98°C and the baking was continued for 10 more minutes so that the crust turned brown at proper level and the desirable aromatic profile was developed. All activities would occur at the highest rate in this baking zone [5]. Water evaporation contributed to the largest portion of bread weight loss since this stage was the longest period from the total baking time of approximately 30 min. There was no visual difference of crust color when setting the temperatures of this zone as 170°C, 180°C, and 190°C. So, all of these temperature settings were selected for the last baking zone. The resulting step-change temperature baking schemes for this experiment were presented in Table 4.2.

4.3.2 Bread Weight Loss

When conducting the baking experiment with a traditional constant baking temperature scheme, bread weight loss was found to be approximately 11.5%. From Table 4.2, it could be seen that bread weight loss varied in the range of approximately 10.8% – 12.6% and all of these three baking schemes yielded baked products with significant difference values of weight loss ($p<0.05$). In terms of temperature, the three chosen baking schemes were set with the same temperature of 180°C and 120°C, respectively for the first and the second zones. Accordingly, the difference in bread weight loss would be due to the temperature setting in the last baking zone together with the fact that the last zone was longest period covering approximately 73% of the total baking time. Other than water evaporation, the volatilization of organic compounds commonly known as bake-out-loss [4], [59] would be a also responsible for the weight loss. In this study, the step-change temperature baking scheme with the setting of 180°C, 120°C, and 170°C for Zones 1, 2, and 3, respectively, could yield bread product with the lowest weight loss of around 10.8%, and most importantly this was lower than the weight loss of bread product obtained with a conventional baking process with a fixed temperature of 180°C. As a result, this step-change temperature setting was selected for the experiment in subsequent section of this study as to determine the emissivity of the product during baking. It was also found that experimental data on bread weight loss in this experiment were comparable to literature values [60], [61].

4.3.3 Emissivity of Bread Obtained with a Thermal Image Camera

Following the study in previous section, the emissivity of bread during baking with two different schemes — a step-change temperature with the setting of 180°C-120°C-170°C and a fixed temperature of 180°C, was investigated. It was found that the emissivity of bread tended to decrease with the increasing temperature. The values of emissivity obtained with a fixed temperature scheme was in a range of approximately 0.55 -0.95, and those obtained with the step-change temperature varied from approximately 0.63 to 0.90. Experimental data of emissivity values according to the three baking zones were given in Table 4.3. The emissivity values found in this study were in the same range with literature values [62]. Apparently, it could be also observed that was no obvious difference in the emissivity values observed from the two baking schemes.

Table 4.3 Experimental data on emissivity values of bread during baking with two different temperature schemes.

Core temperature during baking (°C)	Emissivity values	
	Fixed Temperatrue (a)	Step-change Temperature (b)
25-40	0.770-0.950	0.793-0.903
40-60	0.720-0.770	0.793-0.797
60-98	0.545-0.720	0.630-0.800

(a) baking with a fixed temperature of 180°C, (b) baking with a step-change temperature of 180°C -120°C -170°C.

4.3.4 Emissivity of Bread Obtained with an Infrared Sensor

Table 4.4 shows the experimental data on emissivity values of bread measured with an infrared (IR) sensor at three different baking zones along with the core and surface temperatures measured with thermocouples and the surface temperature inferred from the IR measurent. The results showed that emissivity value of bread varied in a narrow range and so, in this study, it was conveniently assumed to be constant over a 10°C interval, as presented in Table 4.4.

During zones 1 amd 2 of baking, the emissivity remained constant at 0.95. The reasons could be that in these baking zones, the surface temperature and water evaporation were still low. In zone 3 of baking, where the surface temperature increased from around 125°C to 140°C, emissivity value gradually decreased from 0.95 to 0.87. According to weight loss data in 4.3.2 which suggested that much of water evaporation occurred during zone 3 of baking. This would lead to certain changes of surface characteristic and therefore the emissivity of the bread.

It was also found that the surface temperature inferred from the IR measurement in zone 3 was very close (not more than 1°C difference) to that measured with a thermocouple. This was not the case for zones 1 and 2. It should be noted that zone 3 was the longest baking period where bread weight loss in this sudy was almost entirely observed. Since weight loss is one of major concerns in bread processing, it would be applicable to use IR sensor as a non-contact measurement device for monitoring or as part of a control system for bread baking process.

Table 4.4 Experimental data of emissivity ($\mathcal{E}$) value obtained at three different stages of baking and of temperatures of bread measured with the IR sensor and a thermocouple.

Baking Zone	Emissivity values	Temperature measured with thermocouple (°C)		Temperature inferred from IR sensor (°C)
		Core temperature	Surface temperature	
1	0.95	31-40	98.0	110.8
2	0.95	41-50	99.5	113.9
	0.95	51-60	113.0	124.2
3	0.95	61-70	125.3	125.2
	0.94	71-80	126.0	126.1
	0.93	81-90	137.0	136.4
	0.87	91-100	140.0	139.0

4.3.5 Correlation Between Surface and Core Temperatures of Bread Loaf

Theoretically, the application of IR technique to measure a temperature of an object allows only the measurement of temperature at the surface, not that inside the object. However, the core temperature of bread is indeeded the more important process parameter that is needed to consider. Accordingly, the utilization of IR technique for bread baking process would only be applicable only if there is a correlation between the surface and the core temperatures of bread. The correlation between the these temperatures of bread sample during baking was investigated in this study. It was found that the surface and the core temperatures of bread were highly correlated showing the Pearson correlation coefficient (*r*) of 0.99. A simple linear regression was carried out to obtained the relationship between these two temperaures for each baking zone and the results were provided in Table 4.5. It can be seen that both temperarues could be fitted with a high determination coefficient (R^2) suggesting the core temperature of bread during baking could be obtained in a contactless manner. The finding revealed the potential of IR technique as a real-time, non-contact temperature measurement in bread baking process for the purpose of monitoring and process control.

Table 4.5 Relationship between the surface and the core temperatures of bread in each baking zone.

Baking zone	Core Temperature (°C)	Fitted Equation	R^2
1	Start-40	$y = 0.152x + 19.55$	0.926
2	40-60	$y = -3.020x + 330.48$	0.992
3	60-98	$y = 0.887x - 19.09$	0.818

Remark: x and y are the surface and the core temperatures, respectively.

CHAPTER 5

CONCLUSION

The effects of flaxseed addition for 10%, 15% and 20% flour weight basis (fwb) on wheat dough and baking product were studied. It was found that, the addition of ground flaxseed up to 15% did not significantly affect the rheological property of wheat dough samples. The decrease of these rheological parameters was significant only when the addition of flaxseed was 20% of which the peak load, D-Peak, and D-Rupture were found to decrease by 29.5%, 25.6%, and 47.7%, respectively. Also for the bread product, the instrumental textural parameters including hardness, cohesiveness, springiness, and chewiness and the specific volume of bread loaf were not found significantly affected when the addition of flaxseed was not higher than 15%. At 20% flaxseed enrichment, the hardness and chewiness significantly increased by 41.0%, and 21.34%, respectively, while the cohesiveness, springiness, and specific volume decreased by 10.4%, 2.1%, and 11.0%, respectively compared to those of bread without flaxseed. It was found that, flaxseed enrichment could retard bread staling as evidenced by the slower hardening rate during a week long storage period at 4°C and 18°C. In general, the hardening rate of breadcrumbs was faster when stored at 4°C than that when stored at 18°C. Based on the Avrami model, the hardening rate constant (k) and the half-life ($t_{1/2}$) for the treatment without flaxseed at 4°C were 0.47 and 1.83 days, respectively, and these parameters were found to be 0.30 and 2.29 days at 18°C. For flaxseed enriched treatments, the average hardening rate constant (k) and the half-life ($t_{1/2}$) at 4°C were 0.42 and 1.87 days, respectively, and these parameters were found to be 0.33 and 2.28 days at 18°C.

For bread samples obtained from freshly prepared dough, the addition of flaxseed tended to cause the specific volume of bread product to decrease. However, a significant reduction of specific volume was detectable only when flaxseed enrichment were 15% and 20%. For refrigerated dough, it was found that the addition of flaxseed particularly at 20% could suppress the degree of dough syruping. The specific volume of bread generally decrease with the refrigerated time of dough. The treatment with 10% of flaxseed enrichment showed the lowest reduction of specific volume of bread and the lowest hardness as compared to all other treatments.

The process of baking with step-change temperature setting could help minimize bread weight loss compared to that obtained by baking with a fixed temperature setting. The optimum baking temperature setting was found to be 180°C, 120°C, and 170°C for stages 1, 2 and 3, respectively. This baking temperature schemes allowed the bread loaf samples to be cooked properly throughout. The emissivity ($\mathcal{E}$) value of bread tended to linearly decrease from 0.95 to 0.87 with the increasing surface temperature from 98°C to 140°C. A high correlation between the surface and core temperatures of bread loaf was found (r=0.99) and a linear relationship could well established with R^2 values in range of 0.82 - 0.99. The finding suggests that a real-time, non-contact temperature measurement using IR sensor could applicable for monitoring and control of bread baking process.

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APPENDIX

APPENDIX A

Experimental setting for dough and bread tests on the TA.XT*plus* textural analyzer

A.1 Dough Extensibility Test

Mode:	Kieffer rig extension
Pre-Test Speed:	2.0 mm/s
Test Speed:	5.0 mm/s
Post-Test Speed:	10.0 mm/s

A.2 Texture Profile Analysis Test

Mode:	Texture Profile Analysis (TPA)
Pre – test Speed:	2.0 mm/s
Test Speed:	2.0 mm/s
Post – Test Speed:	10.0 mm/s
Strain:	50%
Time:	5 sec
Force Trigger:	5 g

APPENDIX B

Experimental data

B.1 Peak load

Table B.1 Results of dough’s peak load from the dough extensibility test for each replication

Treatment	R1	R2	Avg	STD
0%FS	0.42	0.46	0.44	0.03
10%FS	0.36	0.33	0.34	0.02
15%FS	0.39	0.35	0.37	0.03
20%FS	0.34	0.28	0.31	0.04

B.2 Deformation at peak load (D-peak)

Table B.2 Results of deformation of peak load from the dough extensibility test for each replication

Treatment	R1	R2	Avg	STD
0%FS	76.87	73.29	75.08	2.53
10%FS	72.36	75.78	74.07	2.42
15%FS	59.85	67.25	63.55	5.23
20%FS	35.42	45.21	40.32	6.92

B.3 Rupture point (D-rupture)

Table B.3 Results of rupture point from the dough extensibility test for each replication

Treatment	R1	R2	Avg	STD
0%FS	96.00	118.29	107.15	15.76
10%FS	95.25	98.28	96.77	2.14
15%FS	86.40	92.86	89.63	4.57
20%FS	51.59	67.35	59.47	11.14

B.4 Specific volume

Table B.4 Results of bread's specific volume from test of bread loaf for each replication

Treatments	R1	R2	Average	STD
0	4.82	4.83	4.83	0.01
10	4.70	4.67	4.68	0.02
15	4.20	4.50	4.35	0.21
20	4.41	4.20	4.30	0.15

B.5 Hardness

Table B.5 Results of hardness of bread from TPA test for each replication

Treatment	R1	R2	Avg	STD
0%FS	8.78	7.50	8.14	0.91
10%FS	7.67	8.54	8.10	0.62
15%FS	7.31	7.83	7.57	0.37
20%FS	11.21	11.75	11.48	0.38

B.6 Cohesiveness

Table B.6 Results of cohesiveness of bread from TPA test for each replication

Treatment	R1	R2	Avg	STD
0%FS	0.77	0.79	0.78	0.02
10%FS	0.74	0.71	0.73	0.02
15%FS	0.75	0.72	0.73	0.02
20%FS	0.72	0.67	0.69	0.03

B.7 Springiness

Table B.7 Results of springiness of bread from TPA test for each replication

Treatment	R1	R2	Avg	STD
0%FS	0.94	0.95	0.94	0.01
10%FS	0.94	0.94	0.94	0.00
15%FS	0.93	0.93	0.93	0.01
20%FS	0.92	0.92	0.92	0.00

B.8 Chewiness

Table B.8 Results of chewiness of bread from TPA test for each replication

Treatment	R1	R2	Avg	STD
0%FS	6.27	5.63	5.95	0.45
10%FS	5.31	5.63	5.47	0.23
15%FS	5.10	5.29	5.20	0.14
20%FS	7.40	7.04	7.22	0.26

B.9 Firmness Evolution of Bread Samples During Storage

Table B.9 Data on hardness evolution of bread samples during storing at 4°C observations for 7 days

Day 1

Treatments	R1	R2	R3	Average	STD
0%FS	33.39	19.85	24.48	25.90	6.88
10%FS	15.07	20.43	18.26	17.92	2.70
15%FS	15.56	19.15	14.04	16.25	2.62
20%FS	25.42	16.70	21.16	21.09	4.36

Day 4

Treatments	R1	R2	R3	Average	STD
0%FS	57.95	33.49	31.66	41.03	14.68
10%FS	28.41	27.99	27.89	28.09	0.28
15%FS	25.15	32.55	24.61	27.44	4.44
20%FS	33.84	30.03	26.22	30.03	3.81

Day 7

Treatments	R1	R2	R3	Average	STD
0%FS	40.74	59.85	34.37	47.11	13.26
10%FS	30.87	29.98	34.51	31.79	2.40
15%FS	30.75	31.48	31.12	31.12	0.37
20%FS	35.67	34.08	31.80	33.85	1.95

Table B.10 Data on hardness evolution of bread samples during storing at 18°C observations for 7 days

Day 1

Treatments	R1	R2	R3	Average	STD
0%	23.56	19.35	19.98	20.96	2.27
10%	16.22	20.37	19.68	18.76	2.23
15%	16.93	16.29	11.37	14.86	3.04
20%	28.00	18.92	21.52	22.81	4.67

Day 4

Treatments	R1	R2	R3	Average	STD
0%	44.62	34.61	48.78	42.67	7.28
10%	23.99	28.69	34.23	28.97	5.12
15%	28.45	34.39	21.17	28.01	6.62
20%	38.20	28.75	27.77	31.57	5.76

Day 7

Treatments	R1	R2	R3	Average	STD
0%	68.456	41.751	44.109	51.44	14.78
10%	38.671	28.962	52.689	40.11	11.93
15%	39.076	32.971	28.206	33.42	5.45
20%	38.566	40.371	39.469	39.47	0.90

B.10 Syruping of dough observation

Table B.10 Results of dough syruping degree of bread baking from refrigerated dough stored at 4°C (%)

Storage (Days)	Treatments							
	0%FS		10%FS		15%FS		20%FS	
	Average	STD	Average	STD	Average	STD	Average	STD
0	1.41	0.11	1.49	0.21	1.58	0.23	1.82	0.06
3	1.56	0.22	1.65	0.44	1.75	0.46	1.86	0.14
7	3.49	0.04	1.94	0.10	1.92	0.22	2.34	0.07
14	7.60	0.90	2.72	0.29	2.65	0.49	2.45	0.22
21	11.00	0.71	3.35	0.12	3.67	0.38	3.17	0.28
35	13.32	0.65	6.49	0.31	4.34	0.31	3.32	0.31

B.11 Specific volume reduction from storage dough baking

Table B.11 Experimental data for specific volume of bread baked from dough that was refrigerated at 4°C (cm^3/g)

Storage (Days)	Treatments							
	0%FS		10%FS		15%FS		20%FS	
	Average	STD	Average	STD	Average	STD	Average	STD
0	3.60	0.18	3.49	0.03	2.87	0.03	2.56	0.03
3	2.63	0.16	2.46	0.06	2.31	0.08	2.14	0.04
7	2.40	0.08	2.37	0.01	2.15	0.24	1.78	0.04
14	1.92	0.06	1.81	0.04	1.92	0.09	1.67	0.04
21	1.75	0.04	1.87	0.02	1.83	0.05	1.59	0.06
35	1.69	0.04	1.92	0.05	1.60	0.05	1.32	0.09

B.12 TPA of bread results from storage dough baking

Table B.12 Results of bread's hardness baking from the refrigerated dough (N)

Storage (Days)	Treatments							
	0%FS		10%FS		15%FS		20%FS	
	Average	STD	Average	STD	Average	STD	Average	STD
0	7.14	0.33	6.11	0.73	6.33	0.13	8.67	0.12
3	21.94	3.53	17.26	1.49	20.55	2.15	14.03	0.90
7	46.95	7.29	33.48	6.11	38.71	4.89	32.73	3.12
14	65.78	3.74	53.62	4.13	61.75	8.13	64.58	3.41
21	75.78	1.91	54.45	5.59	66.37	8.90	69.19	4.09
35	62.68	4.97	60.78	4.98	79.32	0.97	77.98	7.25

Table B.13 Results of bread's cohesiveness baking from the refrigerated dough (%)

Storage (Days)	Treatments							
	0%FS		10%FS		15%FS		20%FS	
	Average	STD	Average	STD	Average	STD	Average	STD
0	82.37	1.65	80.23	1.90	74.30	5.24	74.23	8.92
3	78.87	4.08	77.73	3.26	72.50	3.30	77.63	1.58
7	67.87	4.01	74.00	4.69	64.80	3.29	54.90	7.37
14	60.90	2.10	66.67	10.76	52.13	5.54	45.93	7.14
21	78.87	4.57	64.00	7.37	54.47	6.31	53.33	5.85
35	57.90	11.05	63.50	2.07	59.20	4.57	60.93	3.62

Table B.14 Results of bread's chewiness baking from the refrigerated dough (N)

Storage (Days)	Treatments							
	0%FS		10%FS		15%FS		20%FS	
	Average	STD	Average	STD	Average	STD	Average	STD
0	3.60	0.66	3.31	0.33	3.74	0.86	5.85	0.33
3	11.38	2.31	9.01	3.26	11.58	1.43	7.22	1.05
7	23.67	5.15	16.77	1.28	18.65	2.09	14.98	2.93
14	26.22	0.27	23.05	3.79	24.63	2.40	20.58	1.09
21	35.66	4.02	21.39	2.53	26.23	3.51	29.66	1.88
35	25.29	4.19	29.10	8.11	35.17	0.68	38.91	6.33

B.12 Typical force-time plot from texture profile analyzer (TPA) test on bread sample

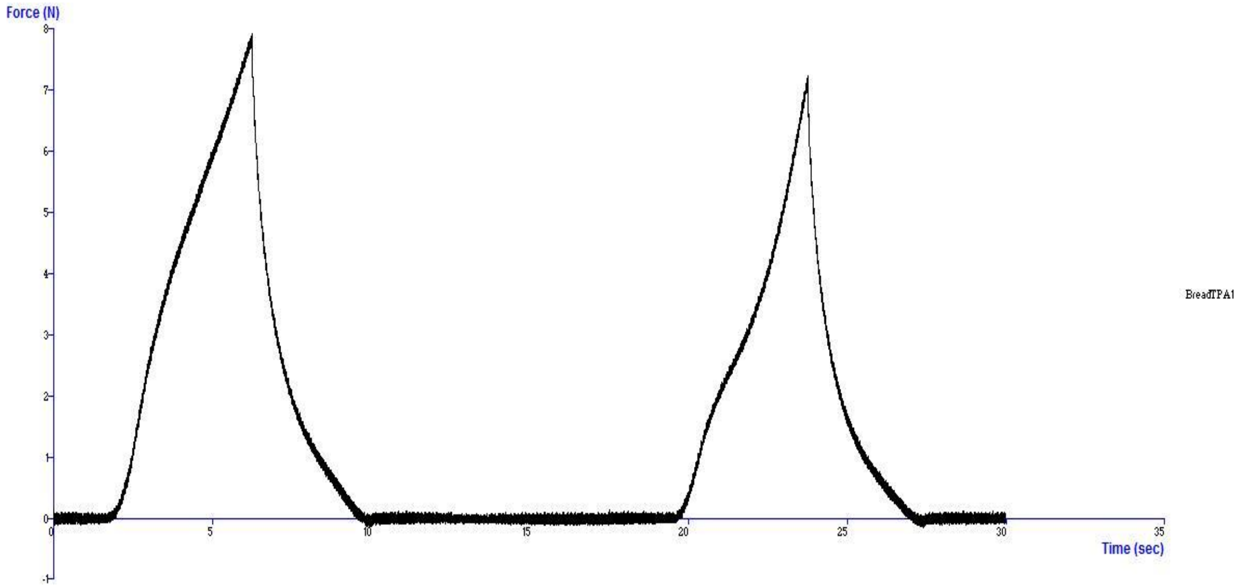

Figure B.1 A typical force-time plot obtained from texture profile analysis (TPA) test of bread sample using the TA.XT*plus* texture analyzer.

B.13 Typical force-time plot from Extensibility on dough sample using the Kieffer rig

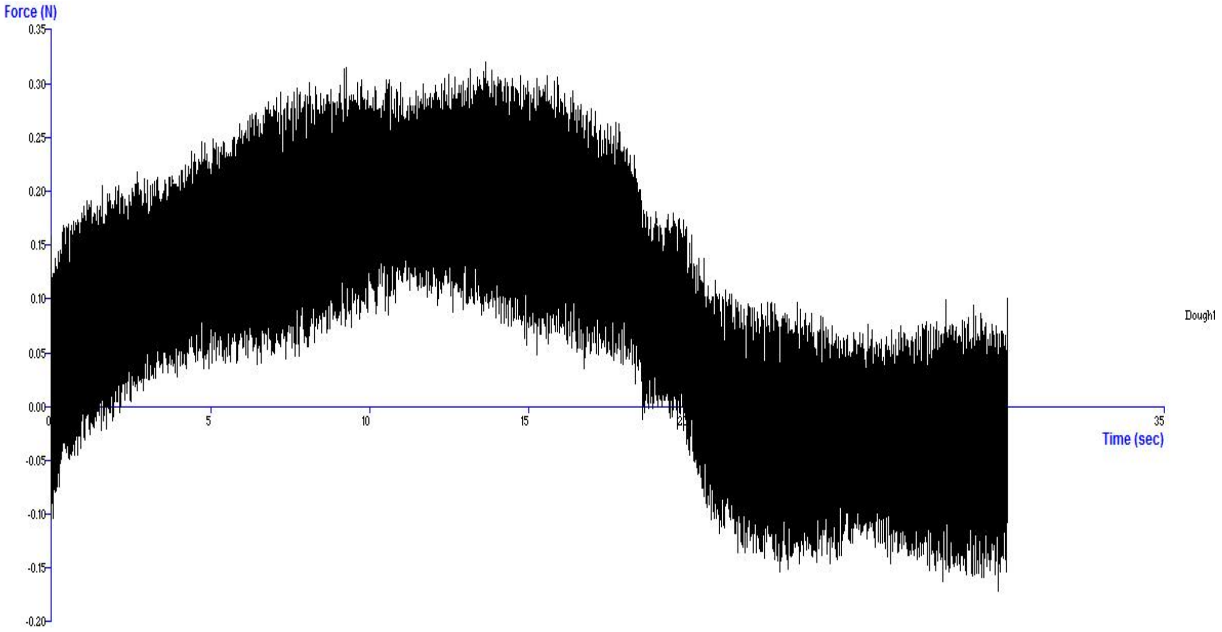

Figure B.2 A typical force-time plot obtained from extensibility test of dough sample using the Kieffer extensibility rig equipped on a TA.XT*plus* texture analyzer.

AUTHOR BIOGRHAPHY

Name	Mr. Tanundorn Veng
Date of birth	9 January 1995
Address	No.1, Chalongkrung1, Ladkrabang, Ladkrabang, Bangkok, 10520, Thailand
Education Record	2019 Bachelor of Chemical Engineering and Food Science, Institute of Technology of Cambodia
Scholarship	Thailand Scholarships (Year 2022) by Ministry of Higher Education, Science, Research and Innovation (MHESI), Thailand supported for the expense and tuition fee for 2 years of master’s degree
Publication	Sritham, E., Nunak, N., Veng, T., Chaishome, J., Tuppadung, Y., Nunak, T., Suesut, T. 2024. ” NONCONTACT TEMPERATURE MEASUREMENT BASED ON INFRARED RADIATION FOR BREAD BAKING PROCESS”. **Journal of Hygienic Engineering and Design.**
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