KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

GHANA

COLLEGE OF SCIENCE

SENSORY AND TEXTURAL PROPERTIES OF PIE CRUST PREPARED FROM SOFT WHEAT FLOUR INCORPORATED WITH LEMON PEEL-DERIVED FAT REPLACER

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A THESIS SUBMITTED TO THE DEPARTMENT OF BIOCHEMISTRY AND BIOTECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOOD SCIENCE AND TECHNOLOGY

BY

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DECLARATION

I hereby declare that this submission is my own original research towards the award of an MSc and that, no part of it has been published in part or in whole for another certificate in this University or elsewhere, except where due acknowledgement has been made in the text.

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ABSTRACT

The main objective of this research was to study the effect lemon peel has on the sensory and textural properties of pie crust using both sensory panelists and the Texture Profile Analyzer. Proximate composition, dietary fiber content, water holding capacity and pectin content of lemon peel were analyzed and data showed that lemon peel had high amount of dietary fiber (14 %) and high water holding capacity (86 %). The pectin content of the lemon peel was found to be 21.26 % which is very high. Pie crusts prepared with different proportions (0, 5, 10, 20, 30 and 40 %) of lemon peel as a substitute for fat revealed that the incorporation of lemon peel in pie crust formula increased the moisture content with decreasing fat content. Sensory evaluation showed that pie crusts prepared with 0 % and 5 % lemon peel fat replacer had the highest level of acceptance for all sensory attributes. Texture Profile Analysis on the pie crust treatments showed that hardness and fracturability decreased with increase in the level of fat replacement. However, springiness, cohesiveness, gumminess, chewiness and resilience increased with increase in lemon peel fat replacer. Highly acceptable pie crusts could be obtained by incorporating 5-10 % lemon peel fat-replacer in the formulation.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Fat consists basically of triacylglyceride which is made up of one glycerol molecule esterified with three fatty acid molecules and sometimes smaller amounts of phospholipids and sterols. These fatty acids are hydrocarbon chains which contain methyl (CH_3-) and carboxyl (-COOH) groups. The fatty acids differ in the number of carbon atoms in the chain and the degree of unsaturation. Fatty acids can therefore be classified into saturated, unsaturated and Trans fatty acids (Jump and Clarke, 1999; Sessler and Ntambi, 1998). Saturated fatty acids contain single bonds between the carbon chains while unsaturated fatty acids have one or more double bonds between the carbon chains. Most animal fats are highly saturated, for example, milk, cheese, and butter. Monounsaturated fatty acids (MUFAs) on the other hand contain only one double bond and polyunsaturated fatty acids (PUFAs) have more than one double bond (Piper, 1999).

Generally, animal fats are solid at room temperature and have higher melting points which is due to their high content of saturated fatty acids. Plant fats usually called oils on the other hand tend to have lower melting points and are liquid at room temperature because of their high content of unsaturated fatty acids (Jump and Clarke, 1999; Sessler and Ntambi, 1998).

Fats form a major part of the body and serve as a major source of energy in foods. Fats that are obtained from foods are called dietary fat and help the body to perform well.

Dietary fats provide essential fatty acids which the body cannot synthesize but can only be obtained from food (Lichtenstein *et al.,* 2006). Dietary fats also serve as insulators and lubricants and help protect very important organs and jointed tissues in the body (Mosca *et al*., 2007).

There are three types of nutrients that supply calories to the body and they are dietary fats, proteins and carbohydrates. Fat supplies nine (9) kilo calories per gram to the body and this is more than twice the amount produced by carbohydrates or proteins (Lichtenstein *et al.,* 2006). Fat also helps maintain healthy skin and hair and helps the body to absorb and transport the fat-soluble vitamins A, D, E and K through the bloodstream (Mosca *et al.,* 2007). Although fat has lots of benefits to human, its intake in higher amount is associated with many diseases affecting the society today. These diseases include obesity, type-2 diabetes, gall bladder diseases, some types of cancer and coronary heart diseases (Weber and Clavein, 2006). There are also many reports on the relation between total dietary fat and cancers (Lichtenstein *et al*., 1998).

The chronic diseases that are associated with the intake of high amount of fat pose a serious threat especially to developing countries (Johns and Eyzaguirre, 2006) because the cure for these diseases are expensive and indirectly they affect productivity thereby affecting the economy of a country (May and Buckman, 2007). Due to this, consumers now show interest in foods that contain lower amounts of fat. According to a survey by the US Calorie Council, about 65 % of adults will go for ingredients that can replace the fat in food products, and most of these adults find the reduction in both calories and fat a better option (Calorie Control Council, 2000). This has led to the use of fat replacers as

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alternative sources for fat. Fat replacers are therefore gaining public attention especially among consumers and producers. Low fat and fat free food are possible due to the existence of food technologies used to replace most of the fat in food without affecting texture, taste and aroma. In the production of ice cream, skimmed milk has been used to replace whole milk, baking is now preferred to frying and use of water or air to replace fat in some products (Calorie Control Council, 2006).

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Pastries are baked products made from ingredients such as flour, milk, sugar, shortening, baking powder and eggs. They are normally eaten as snacks. However, they contain very high quantities of fat. There is therefore the need to develop ingredients which can substitute or replace some of the fat to produce low fat pastries with similar qualities as the full fat products.

1.2 Problem statement and justification

One of the major causes of obesity is the intake of fatty foods. Other causes include physical inactivity, genetics and socio-cultural factors. Obesity is becoming a major problem in some regions and among certain group of people in Ghana. Amoah (2003) conducted a research in some urban and rural areas in Accra and found that the rate at which overweight and obesity occur was 23.4 and 14.1 % respectively among adults aged 35 years and above. He also found that, obesity increased with age up to 64 years and that there were more people who were overweight and obese in the urban high-class residents compared with the low-class residents. People with tertiary education had the highest prevalence of obesity compared with less literate and the illiterate.

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1.3 Main Objective

To develop a lemon peel-fat replacer and study its effect on the sensory and textural properties of pie crusts.

1.3.1 Specific objectives

1. To determine proximate composition of lemon peels (powder) to ascertain its fat replacing viability.
2. To determine water holding capacity, pectin and dietary fibre contents of the lemon peel-derived fat replacer.
3. To evaluate the sensory and textural properties of the reduced-fat pie crusts developed from the fat replacer.
4. To evaluate the colorimetric properties of the reduced-fat pie crusts.

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CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Fats

Fats are a heterogeneous group of substances made up of nonpolar groups and because of their nonpolar nature fats have low solubility in water and high solubility in nonpolar solvents. The common lipids normally found in diets are classified into fats or oils and this depends on the state in which they exist at room temperature (Dreon, 1990).

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Fats in food consist of triglycerides, glycerol and fatty acids and are classified according to their chemical structure as saturated and unsaturated fats. The proportion of fatty acids in a fat determines its physical properties and differentiates one fat from the other (Ospina-E *et al*., 2012). The saturated fats are mostly found in animal products such as cheese, butter and meat and may raise the levels of blood cholesterol more than any other component in the diet, even more than dietary cholesterol (Dreon, 1990).

2.1.1 Functions of fat in food systems

The main sources of fat in diets are cooking oils, butter, margarine, meat and dairy products. Dietary fats have been classified as visible and invisible fats. The visible fats are those that have been isolated from the tissues of animals, oilseeds or vegetables and are used in products such as margarine, shortening and salad oil. The invisible fats are those consumed as part of the tissues of the animal or the vegetable products (Institute of Shortening and Edible Oils, 1999).

Recent data from the Economic Research Service of the U.S Department of Agriculture indicated that the use of fats and oils have increased from 29.3 kg per capita to 29.66 kg per capita during 1991 through 1995 to 29.12 kg per capita to 33.79 kg per capita during 1996 through 2000 (Economic Research Service, 2003). In Ghana, most meals are prepared using lots of fats.

2.1.2 Roles of dietary fat

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The fat consumed in the diet performs many functions such as providing energy and essential fatty acids, protecting vital organs, maintaining the temperature of the body and facilitating the absorption of fat soluble vitamins A, D, E, and K (Pinheiro and Penna, 2004). Fats are the only source of essential fatty acids (EFAs) such as linoleic and linolenic acids which play a functional role in all the tissues of the body (Anonymous, 1998).

Fat contributes to flavour or the combined perception of mouthfeel, taste and aroma in foods (Lucca and Tepper, 1994; Mistry, 2001; Sampaio, 2004). It also contributes to creaminess, appearance, palatability, texture and lubricity of foods and increases the feeling of satiety during meals (Romanchik-Cerpovicz, 2002; Sipahioglu *et al.*, 1999). From a physiological point of view, fat acts as precursors for prostaglandins and a carrier for lipophilic drugs (Trudell *et al.*, 1996; Cooper *et al.*, 1997; Harrigan and Breene, 1989). Fats can also carry some flavor compounds and act as a precursor for developing and stabilizing flavour (Romeih, 2002; Tamime, 1999).

2.1.3 Functions of fat in baked products

Fat helps to produce quality baked products (Bennion, 1995 a). When fat is added to dough, it increases the volume and the cell walls of the product become more uniform resulting in softness and better bite. In puff pastries for example, fat is used to separate the thin layers of dough to produce a uniform flaky texture and an increased volume (Robert, 2007). When fat is reduced in a product, the product becomes coarse and the crumb darkens. In many baked goods, too much fat decreases the quality of the product.

Another important function of fat in baked goods is to improve the eating quality. When fat is included in a recipe, it disperses throughout the mix in the form of irregularly sized droplets and coats some of the surfaces of the particles of the flour. Thus reducing the gluten structure network and resulting in a soft product. However, when too much fat is used, the product becomes more crumbly. A recipe without fat will allow the gluten to develop, resulting in a pastry that is hard and tough when it should be soft and crumbly (Gallagher and Dwyer, 2001).

Fat therefore imparts moistness, tenderness, colour, lubricity, flavour, structure and volume and antistaling quality in baked products. Although fat plays an important role in foods, it is suggested that it should be reduced to 30 % or even less of the amount taken in a day. These recommendations have been provided in order to help reduce the risk of heart disease, obesity and certain types of cancers and possibly gall bladder disease which is associated with high fat intakes (Glueck *et al.*, 1994).

Consumers are now becoming aware of the need to reduce fat in diet and therefore the need for developing healthy and low-fat foods. The food industry has reduced the fat in various food products using fat substitutes and each fat substitute has its own functions, advantages and disadvantages which food processors must understand in order to help select the most effective fat substitutes for specific food applications.

Fig. 2.1 Functions of fat in food

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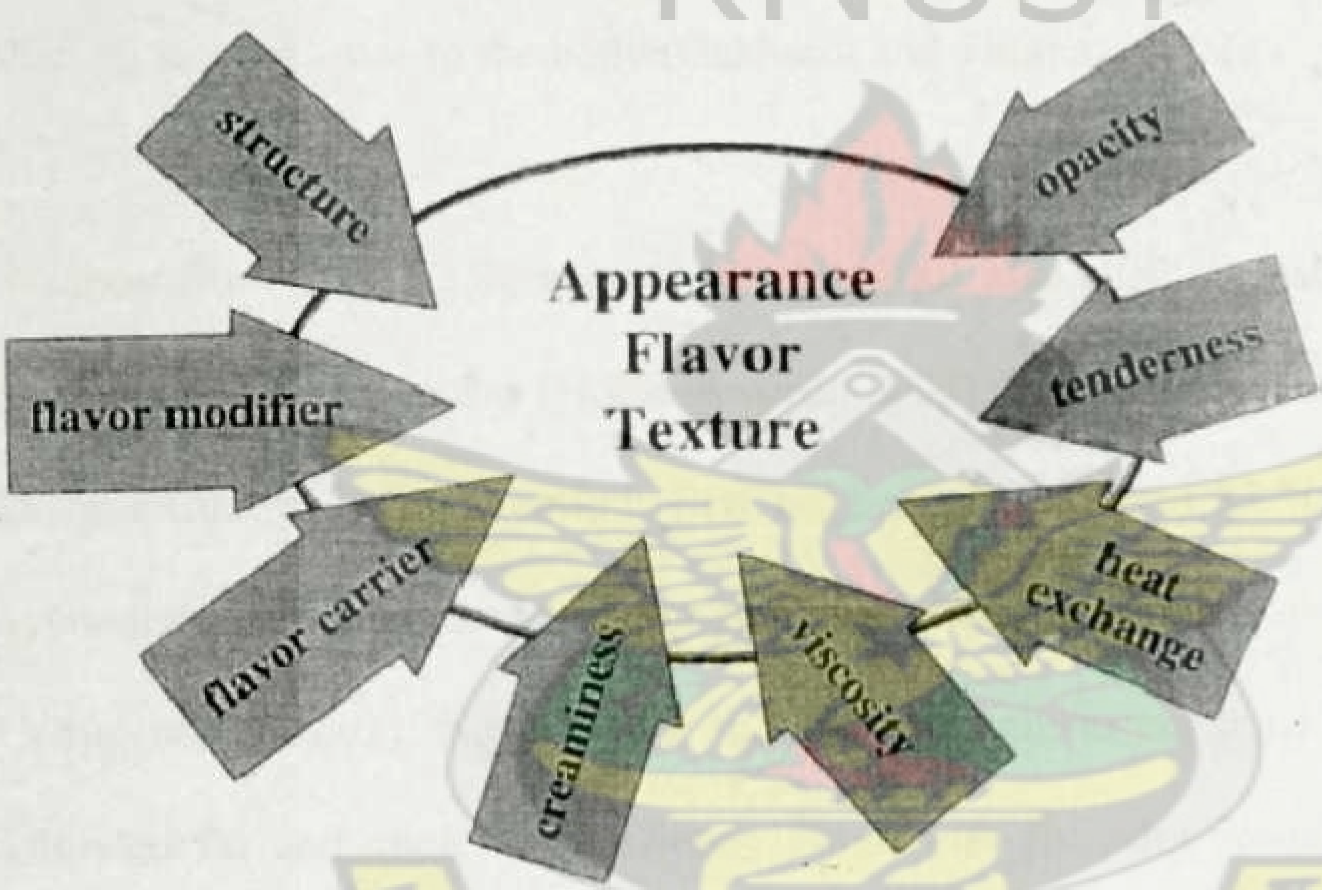

(Source: Miraglio, 1995)

2.2 Rationale for fat replacers

The intake of high amounts of fats and oils in the diet of most people in developing countries such as Ghana has led to an increase in health risks among the people. These diets include fast foods, deep-fried foods, desserts and pastries. Excessive intake of fat may lead to unnecessary gain in weight. In 1999, 61 % of adults in the U.S. were estimated to be overweight and it is still on the rise in recent years. Figures for obesity have doubled among adults since 1980 and statistics on overweight among adolescents has tripled (Anonymous, 2002). The American Heart Association, American Cancer Society, National Academy of Sciences, U.S. Surgeon General, National Cholesterol Education Program, American Dietetic Association, National Institutes of Health, USDA and the Department of Health and Human Services are among the various health and government authorities that support the reduction of dietary fat for most consumers. These scientific groups recommend the limitation of fat to levels that provide not more than 30 % of calories to the body (Gebhardt and Thomas, 2002).

A report from the U.S. Surgeon General in 2001 also attributed 300,000 deaths annually to fat-related health issues (Hollingsworth, 2003). Further statistics from U.S. Centre for Disease Control and Prevention (CDC) indicated that about 87 % of obese and 80 % of overweight individuals are trying to lose or maintain their weight (Calorie Control Commentary, 2002). Nutritionists encourage people to consume diets low in total fat, saturated fat and cholesterol. Dietary Guidelines for Americans also recommend that saturated fat should be limited to not more than 10 % of what they consume. Cholesterol also should be reduced to not more than 300 mg/day (Kurtzweil, 1996). Saturated fat and cholesterol are the substances in fat that contribute to the formation of plaque which clogs the arteries leading to heart diseases. In order to attain the recommended levels of 30 % of calories from total fat and 10 % of calories from saturated fats, many people must cut out one-fifth of the fat taken (Wylie-Rosett, 2002). The advice to reduce fat and energy consumption has led to the production of foods with a lower amount of fat and the development of fat substitutes which is the main focus of this research project.

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Recent research suggests that individuals who consume diet low in fat and calories and use fat-modified products have a better nutrient profile than people who do not use any fat-modified products (Wylie-Rosett, 2002). A survey also conducted in 2000 by the Calorie Control Council indicated that low-fat, reduced-fat and fat-free products remained popular among the general public (Calorie Control Commentary, 2002). Another Council survey showed that two-thirds of adults support fat substitutes and fat-modified products making them an important part of the diet. Many people are also looking for ways to enjoy their favourite foods while maintaining a low-calorie diet.

2.2.1 Fat replacers

Food scientists are developing new food additives that will mimic the functions of fat in foods while keeping the calorie contents low. Dietary fat substitutes are therefore food constituents that are able to completely or partially replace the dietary fat in a way that some organoleptic and physical properties of the food products involved are not altered (Dreon *et al.*, 1990). There are different ways to replace fat in food products and one way is the traditional techniques which involves the replacement of water or air for fat and baking instead of deep-fat frying for preparing snack foods (CCC, 1992). Fat may also be replaced in foods by reformulating the foods with lipid-, protein- or carbohydrate-based ingredients.

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2.2.2 Carbohydrate-based fat replacers

Carbohydrate based fat replacers are derived from cereals, grains and plants that include both digestible and indigestible complex carbohydrates (Glicksman, 1991). Carbohydrate-based fat mimetics are used to replace fat in foods because of their textural and organoleptic properties. In general, carbohydrates mimic fat by binding water, thus providing slipperiness, lubrications, body and mouth-feel. There are a lot of carbohydrate-based fat replacers available for use in foods (Segal, 1990). Some carbohydrate-based fat replacers are used as bulking agents to replace some of the volume lost when fat is absent. Most of the carbohydrate based substitutes are modified starch products produced by hydrolysis or substitution. When finely ground micro particles of cellulose are added to food, they disperse throughout the food to provide a non-caloric network with smoothness and flow properties similar to that of fat (Syed *et al*., 2011).

A research by Jun *et al*. (2006) reported that pumpkin is a good source of carotene, pectin, mineral salts, vitamins and other substances that are beneficial to health. These facts lead to the processing of pumpkin into various food products. Another research by Vergara-Valencia *et al*. (2006) reported that unripe mango pulp has high starch content and high levels of hemicellulose, lignin, cellulose and carotenoids. Mango peel on the other hand has been found to contain high proportion of soluble dietary fibre, which is similar to citrus fruits and also a substantial amount of pectin and polyphenols (Larrauri *et al*., 1996). Therefore, these fruit peels and pulp could be used as fat replacers.

Maltodextrin and starch-based ingredients upon hydration form a smooth, viscous solution or soft gel. Carbohydrate-based fat replacers can be used successfully to reduce fat in a low moisture food but cannot totally replace the fat (Segal, 1990). Practically, fibre-based ingredients such as locusts bean gum, guar gum, xanthum gum, pectin, gum arabic and carrageenan have no calories. They provide a gelling effect and modifier or bulking agent in dairy products, salad dressings, spreads, sauces, baked goods, processed meat and frozen desserts (Syed *et al.*, 2011). Some examples of fat replacers that are used in various food categories are summarized in table 2.1.

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Table 2.1: Examples of types of fat replacers used in various food categories

Food category	Fat replacer	
	Carbohydrate-based	**Protein-based**
Baked foods	Fibers, gums, inulin, maltodextrins, polydextrose, starches	Microparticulated protein, modified whey protein concentrate, protein blends
Cereal and grain products	Fibers, gums, insulin, maltodextrins, polydextrose, starches	Microparticulated protein
Confectionery and candies	Cellulose, gums, inulin maltodextrins, Oatrim, polydextrose, starches	Microparticulated protein
Cooking and salad oils	NA[b]	Microparticulated protein

Dairy products	Cellulose, gums, inulin maltodextrins, Oatrim, polydextrose, starches	Microparticulated protein, modified whey protein concentrate, protein blends
Dairy products, refrigerated and frozen desserts	Cellulose, gums, inulin maltodextrins, Oatrim, polydextrose, starches	Microparticulated protein, modified whey protein concentrate, protein blends
Meat and poultry products	Gums, inulin maltodextrins, Oatrim, starches	NA
Other fats and oils	Cellulose, gelatin, gums, inulin, maltodextrins, Oatrim, polydextrose, starches	Microparticulated protein, protein blends
Prepared entrees	Cellulose, gums, inulin maltodextrins, Oatrim, polydextrose, starches	Microparticulated protein, modified whey protein concentrate
Soups, sauces, gravies	Cellulose, gums, inulin maltodextrins, Oatrim, starches	Microparticulated protein, modified whey protein concentrate
Savory snacks	Cellulose, fiber, gums, maltodextrins, starches	NA

Source: ADA (2005) **NA = not applicable**

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2.2.3 Protein-based fat replacers

The ability of proteins to be used as fat replacers is usually determined by the extent of denaturation, temperature stability, gelling properties and solubility. Various fat mimetics can be derived from protein sources such as egg, milk, whey and soy. One simple protein-based fat replacement method is to add milk protein and milk solids to reduced-fat products such as skim or low-fat milk. Other ingredients used to increase milk solids are whey protein concentrates and whey protein isolates (White, 1993).

Microparticulated protein is usually based on whey protein concentrate but there are several sources of protein that can also be used (Singer and Moser, 1993). Microparticulated protein has a clean flavor base and good flavor-releasing qualities (Hatchwell, 1994 a). Some other protein-based fat replacers are isolated soy protein, gelatin and protein blends that may contain gums and modified starches. Most of these ingredients contain small quantities of carbohydrate, fat and ash. However, they have energy values which are almost the same as that of protein and range from 13.0 to 17.2 kJ. Although protein-based fat replacers provide similar characteristics as carbohydrate-based fat replacers, protein-based fat replacers provide added functionality to food systems including opacity and emulsification (Harrigan and Breene, 1993).

Protein-based fat mimetics are normally used in butter, margarines, dairy products, salad dressings, baked goods, soups, sauces and frozen desserts. These substances give a better mouthfeel than carbohydrates-based replacers. However, similar to carbohydrate-based substances, protein-based fat mimetics cannot be used for frying. Whey protein concentrate is used to prepare simplesse which is a low-calorie and cholesterol-free fat substitute. The caloric value of simplesse is 4.18kj/g and provides creaminess like fat, however, it tends to mask flavor similar to other proteins. Because it is made from proteins, it cannot be used in foods that involve the use of high-temperatures such as frying or baking.

Modified whey proteins for example are not suitable for use in fried foods but can be used in dairy products, sour cream, coffee creamers and in sauces (Cheung *et al*., 2002).

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2.2.4 Fat-based replacers

Fat based replacers are either triacylgylcerols whose configurations have been modified to produce low amount of calories or they have similar chemical structures of triacylgylcerols with reduced or no calories (Owusu-apenten, 2005). These include Caprenin and Olestra. Caprenin has the characteristics of cocoa butter which is used in many confectioneries such as candy bars. Caprenin provides 20.92 kJ/g of food. Mono and diglyceride emulsifiers can be used in addition to water to replace all or some of the shortening content in cake, cookies, icings and many other products. Although, emulsifiers supply 37.66 kJ/g of food, little amount is used and thus the product contains less fat and calories. Many products that are being developed use a mixture of fat and oil which contribute little or no calories, cholesterol and fat. These products look, taste and feel like fat but they are metabolized like a carbohydrate. Due to their ability to withstand heat, they will be used in high-temperature products such as chips, snack foods and baked goods as well as for frying (Sobczynska and Setser, 1991).

Olestra is a polyester consisting of a mixture of haxa, hepta and octa esters of sucrose, esterified with long-chain fatty acids normally from edible oils. Olestra is either liquid or solid at room temperature depending on the source of fat present in the sucrose polyester. It has some thermal and organoleptic properties similar to that of fat but it is too large to be absorbed in the gastrointestinal tract and thus cannot be metabolised for energy (Burns *et al.*, 2000).

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2.3 Potential effects of fat replacers on health

The effects of fat substitutes on health vary and literature indicates that little or no health issues have been raised about the impact of protein-based or carbohydrate-based fat substitutes. Carbohydrate-based or protein-based fat substitutes seem to have little or no effect on absorption, digestion or metabolism of other nutrients (Position of American Dietetic Association, 1998; American Diabetes Association Position Statement, 2002).

In a study conducted over a 24-week period on overweight people who added diacylglycerol (DAG), a fat substitute, in their diet revealed a decrease in body weight and body fat mass by 3.6 % and 8.3 % respectively. This showed an appreciable decrease in body weight and body fat mass when compared with diets containing the usual fats. Furthermore, diacylglycerol can help reduce post meal serum TAGs by 30 –50 % (Pszczola, 2003).

A lot of studies have indicated that the intake of olestra, a fat replacer, affects the composition and softness of stool (McRorie *et al.*, 2000; Freston *et al.*, 1997). Evidence from a case study of three people suggested that olestra could double the removal of lipophilic contaminants such as hexochlorobenzene (HCB) and polychlorinated biphenyls

(PCBs) from the body (Moser and McLachlan, 1999). This fat substitute (Olestra) also has the ability to hinder the absorption of other components of the diet, especially lipophilic substances eaten at the same time since olestra is lipophilic, nondigestible and nonabsorbable. This interference occurs because part of those components can separate into the olestra in the gastrointestinal tract and excreted with the olestra itself (O Hill *et al.*, 1998; Peters *et al.*, 1997; Cooper *et al.*, 1997).

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2.4 Fruits which have been used as fat replacers

Different fruits and fruit purees have been used successfully as fat replacers. Purees of pear, bananas, plums and apples and fruit peels such as that of lemon can perform numerous functions of fat due to their pectin and fibre contents. Particularly, the complexes of fibre and pectin provide texture and body to foods. Some of the health benefits of these fruits and peels include antioxidant activity. These replacers may be able to partially or completely replace fat in pie crusts, cookies, cakes and other bakery products. Since these fat-replacers are not modified as compared to other fat-replacers, adding them to food must be managed carefully (Michaelides and Cooper, 2004). Lemon peel powder could also be used as a fat replacer since it has a high fibre and pectin content.

Some fat replacers have also been derived from fruits and include avocado, kiwi, mango and citrus and the water retaining property of the fibre they contain which is pectin makes them better choice of fat replacers (Vaclavik and Christian, 2003). Pectin has the ability to absorb water and slow the movement of food through the digestive system and so considered a natural and non-toxic diet supplement. In addition, pectin slows down the

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absorption of food by covering the food molecules making them less susceptible to digestive enzymes, since only the enzymes in the colon can break down the pectin molecules. Pectin also makes the coating on the intestinal walls thick resulting in difficulty for the small intestines to absorb the food molecules that have been broken-down (Sriamornsak, 2003).

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2.5 Dietary fibre

Dietary fibre is made up of different non-starch polysaccharides and includes hemicelluloses, cellulose, pectin, β-glucans, lignin and gums (Gallaher and Schneeman, 2001; Lamghari *et al*., 2000). The cell walls of fruits, vegetables and cereals make up most of the dietary fibre taken into the body. Fibre is often classified as soluble dietary fibre (SDF) and insoluble dietary fibre (IDF) (Gorinstein *et al*., 2001). Initially, the classification was thought to provide a simple way to predict physiological function, but has not been the case in most times. It is generally accepted that those fibre sources that are suitable for use as food ingredient should have an SDF/IDF ratio close to 1:2 (Jaime *et al*., 2002; Schneeman, 1987). Dietary fibre concentrates can be used in different applications in the food industry to obtain remarkable results. Fibres with 15 % of SDF are able to bind and retain several times their weight of water (Herbafood, 2002).

Dietary fibre therefore plays an important role in health and diets containing high dietary fibre are associated with the reduction, prevention and treatment of some diseases such as coronary heart diseases (Anderson *et al*., 1994). It is also known that dietary fibre obtained by different methods and from different sources behave differently during their movements through the intestines and this depends on their chemical composition and physicochemical characteristics and also on the process that the food undergo (Chau and Huang, 2003; Jim-Enez *et al.*, 2000).

Fibre derived from fruits and vegetables have been found to contain a higher amount of soluble dietary fibre, whereas cereal fibres contain more insoluble cellulose and hemicellulose (Herbafood, 2002). Plant fibre is known to show some functional properties such as water-holding capacity and cation-exchange capacity which have been very useful in appreciating the physiological effect of dietary fibre rather than the chemical composition alone (Gallaher and Schneeman 2001). The functional properties of plant fibre depend on the SDF/IDF ratio, extraction condition, particle size and source of vegetable (Jaime *et al.*, 2002). According to Kethireddipalli *et al.* (2002) grinding the dry fibrous material to fine powder may influence both its water holding capacity (WHC) and water swelling capacity (WSC). The effect is attributed not only to the reduction in particle size, but also to alteration in the structure of the fibre. Nowadays, there are many raw materials, mainly processing by-products from which dietary fibre powders can be obtained (Femenia *et al.*, 1997).

When plant fibres are added to food, they affect the water holding properties and viscosity of the product (Kethireddipalli *et al.*, 2002). The viscosity of the soluble dietary fibre fraction is more important than the amount of soluble fibre in a food. Addition of water to soluble dietary fibre increases its viscosity (Gorinstein *et al.*, 2001).

Citrus and apple fibres have better quality than other dietary fibres because of the presence of bioactive compounds such as flavonoids, polyphenols and carotenes (Wolfe and Liu, 2003). An increase in the level of dietary fibre in the diet has been recommended (25-30 g/day) and therefore it is necessary to increase the intake of foods that can supply fibre. The addition of fibre in foods that are mostly consumed could help overcome the fibre deficit (Fernandez- Gines *et al.*, 2003).

2.6 Pectin

2.6.1 Source

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Pectins are complex polysaccharides which contain 1, 4-α-D-galacturonic acid residues (Visser and Voragen, 1996) and are a major component of plant cell walls. The main sources of pectin are by-products from the fruit juice and sugar industries, mainly fruit peels, apple pomade and sugar beet pulp.

2.6.2 Pectin Gelation

The ability of pectin to form gels is related to its ability to hold onto water, to thicken and to stabilize foods. The ability of pectin to form gel accounts for its use in food industry and pharmaceuticals (Kelco, 2001). Pectin gels are hydrocolloid mixtures involving water in which one substance is suspended in another.

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In pectin, there are two important interactions that are considered and these are the polymer-polymer interactions and the polymer-water interactions. The most important one is the polymer-polymer interactions because these interactions create the bonds between pectin chains. The polymer-water interactions are also important because the level of hydrophobicity of pectin is determined by the degree of esterification (DE)

(Agoub *et al.*, 2009), since the ester substituent is quite hydrophobic whereas the polar carboxylic acid substituent is hydrophilic.

Molecular weight and degree of esterification play major roles in gelling. Pectin can have a large number of galacturonic acid units when polymerized and these numbers range from a few hundred units to about one thousand units (Sriamornsak, 2003). The longer the chain and the higher the molecular weight of the pectin, the greater the strength of the intermolecular bonding that occurs. This increase in the intermolecular force leads to a more viscous product and thus stronger gels (Fernandez, 2001).

Unlike HM pectin, LM pectin can be dissolved after it has completed gelation and this is due to the fact that its intermolecular bonding occurs through the use of divalent cations such as Ca^{2+} instead of hydrogen-bonding (May, 2000).

2.7 Citrus Fruits

The genus citrus belongs to the family Rutaceae and consists of different species which are found in many countries such as China, India, Malaysia and Australia. Citrus is one of the most important fruit crops and is consumed as fresh fruit or in the form of juice because of its nutritional value it adds to food (Dugo and Giacomo, 2002). The world's citrus fruit production and consumption have grown steadily since the middle of 1980. The citrus fruit production after two decades reached about 100 million tonnes in 2005. The increase in citrus production is due to increasing income, increase in plantation areas and consumers' preference through the consumption of more healthy food (UNCTAD, 2005).

Table 2.2: The world's citrus fruit production (1,000 Mt).

	Orange		Tangerines		Lemon		Grapefruit	
Years	**Production**	**Index**	**Production**	**Index**	**Production**	**Index**	**Production**	**Index**
1990	49.654	100	12.497	100	7.273	100	4.059	100
1995	59.283	119	16.003	128	8.667	119	5.140	126
2000	64.147	129	18.262	146	11.135	153	5.333	131
2005	59.858	121	23.312	187	12.554	173	3.667	90

Source: www.fao.org, 2005

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The production of citrus fruits is expected to increase in the years ahead. Orange producing countries in Asia are expected to continue expanding their production, though most of their produce is consumed in their local markets. Argentina, Mexico and Spain have been able to maintain their production of lemons and so they remain the leading producers (AEU, 2001). The U.S.A ranks first in the production of citrus followed by Brazil, Spain and Japan. However, Spain ranks first in exporting citrus (FAO, 2001). The citrus fruit industry in Africa is growing rapidly and is due to the increase in population and improved economic conditions together with advance in agricultural sciences and technology of by-products and the increased awareness of the nutritious value of the fruits.

In Ghana, citrus is consumed locally and exported throughout the sub regions. Citrus is the second largest exported horticultural crop after pineapple and the fastest growing tree crop. Pineapple and citrus are driving the growth of Ghana's fruit exports. However, this performance is not recognized because citrus is processed locally or exported within the sub regions, that is Togo, Burkina, Senegal and Cote d'Ivoire.

For some time now, citrus fruits have been considered as an important part of a nutritious and healthy diet and it is well established that some of the nutrients in citrus promote health and provide protection against diseases. Many biologically active substances can be found in citrus fruits and they include both nutrients and non-nutrients which protect health. The active substances in citrus fruits include folic acid, carotenoids, vitamin C, dietary fibre, potassium and other phytochemicals (WHO, 2003). Some other health promoting substances found in citrus are ferulic acid, hydrocinnamic acid, hesperidin and naringin (Abeysinghe *et al.*, 2007; Kelebek *et al.*, 2008).

Table 2.3: Summary of the export sector from Ghana for some fruits (fresh and processed)

Crop	Est. 2002 Prod. (tons)	2002 Exports (tons)	FOB value (US$)	No. of Exporters	Principal Destination	Local Processing
Citrus (Orange/lemon/lime	330,000	16,500	868,000	5	Germany	Juice
Papaya	5,000	1,500	865,000	28	Germany Togo UK	Slicing for street sales
Banana	10,000	3,230	3,250,000	1	Netherlands UK	No
Mango	4,000	126	70,000	33	Belgium UK South Africa	Fresh cut
Passion Fruit	5	2	2,700	2	Switzerland Belgium	Juice

Source: Voisard and Jaeger, (2003).

In the last two to three decades there has been increase in awareness concerning the role diet plays in the cause of the chronic diseases that are the main causes of death in

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developing countries such as Ghana. A lot of work has been summarized in a major World Health Organization study on "Diet, Nutrition and the Prevention of Chronic Disease" (WHO, 2003).

Majority of the diseases of concern now in most countries are associated with a dietary component. These diseases include cardiovascular conditions such as stroke and coronary heart disease, cancers of various types, dental caries, obesity, anaemia, type 2 diabetes, cataracts, gall bladder disease and depression. The World Health Organization in their recent report on "Diet, Nutrition and the Prevention of Chronic Diseases" revealed that fruits and vegetables have a positive effect on cardiovascular diseases, obesity and possibly cancer and type II diabetes (WHO, 2003). Recently, WHO (2003) conducted a study and concluded that "nutrition is coming to the fore as a major modifiable determinant of chronic disease" and it was concluded based on the effects fruits and vegetables have on chronic diseases. The conclusions include a convincing evidence of positive effects of dietary fibre and energy-dilute foods, such as fruit and vegetables on obesity. Secondly, a convincing evidence of the positive effects of fruit and vegetables on cardiovascular diseases and probable evidence of the positive effects of fruit and vegetables on cancers of the oral cavity, oesophagus, stomach and colon-rectum.

2.8 Lemon (*citrus×limon*)

Lemon fruit has the scientific name *citrus×limon*. It is an important medicinal plant of the family Rutaceae and cultivated mainly for its alkaloids which have anticancer activities (Kawaii *et al.*, 2000). Lemon is native to south-east Asia and is widely cultivated in the tropical and subtropical humid regions of the world (Thaman and Whistler, 1996).

2.8.1 Description

Lemon is a small evergreen tree that grows from 9 to 19 feet tall with oval leaves, fragrant flowers and green fruits turning to yellow. Lemon bears fruits all year round and each tree can yield as much as 1500 lemon fruits in a year. Suitable climates for lemons are the tropical and subtropical humid climates or the drier regions with irrigation. Lemons can tolerate different types of soils, from pure sand to organic mucks to heavy clay soils (Reiger, 2002).

Fig. 2.2 – Cross-section diagram of lemon fruit

2.8.2 Varieties of lemon

Lemon varieties include eureka, meyer, lisbon and the variegated pink lemon. Eureka variety produces large crops of lemons and bears fruits throughout the year. It is also

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known as the standard market variety with its tree bearing fewer thorns than other traditional lemons. Meyer is an improved genetic dwarf, very hard and sweeter than the other lemon varieties. It is very juicy and not as tart as eureka lemons. It also bears fruits throughout the year and its mature fruit takes on a golden color. Lisbon lemon fruit is quite similar to eureka type but with more thorns and dense foliage. Lisbon grows well in inland regions and is somehow more resistant to cold than eureka variety. The variegated pink lemon on the other hand is a distinctive green and yellow spotted plant. These lemons have pink flesh, clear juice and acidic lemon flavor. It is an excellent landscape tree that is valued more for its interesting variegated foliage than for fruit quality and quantity (http://fourwindsgrowers.com/our-citrus-trees/lemon/principal-lemon-varieties.html).

2.8.3 Uses of lemon

The main uses of lemon is for food, refreshing drinks, tasty desserts and also for seasoning vegetables, meats, sauces, salads and casseroles (Ehler, 2002; Katzer, 2002). The wild type of lemon has a better flavor than the improved varieties because of its higher acid content (Ehler, 2002). The fresh fruits and bottled juice are also excellent sources of vitamin C and are used to prevent scurvy (Bruneton, 1999).

Lemons also contain special flavonoid compounds that have antioxidant and anti-cancer properties and within these flavonoids are d-limonene which has been shown to inhibit mammary tumours in rats. The interesting property of flavonoids in lime juices maybe their antibiotic effects, for example against *Vibrio cholera* (Mata *et al.*, 1994).

2.8.4 Food uses of lemon

Lemons are purposely grown for use as preserves especially in marmalade and syrup due to their tart flavour. The essential oil in the cortex of the peels is used to add fragrance to beverages and liqueurs, sweet foods like candies and cakes, soaps, detergents, cosmetics and perfumes. Specifically, the oil from the leaves and zest is used as a flavouring agent as well as in sauces for meats and poultry (Quintero *et al.*, 2003). Lemon is also an expectorant, laxative and diuretic. In the United States, some of its uses include prevention of cancer of the skin, breast, colon etc. (Raintree Nutrition In., 2002).

The powder extracted from the dried peel using water/alcohol has been used in many dietary supplements and herbal weight loss formulas (American Botanical Council, 2000). Synephrine is one of the active ingredients of lemons and functions as a stimulant (Brooks *et al.*, 2003). Thus, products that contain synephrine, octopamine or other alkaloids obtained from lemon peel have been manufactured to maintain weight loss, improve physical fitness and increase lean muscle mass (Jones, 2002). Moreover, one publication reported that the oil extracts of lemon peel may contain potential insecticides (Mwaiko, 1992).

Lemon albedo has an advantage over other sources of dietary fibre due to the presence of bioactive compounds with antioxidant properties. Such compounds include flavonoids and vitamin C which may add health promoting effects in addition to those of the dietary fibre itself (Benavante-Garcia *et al.*, 1997).

2.8.4.1 Limonin

Limonin is a bitter compound found in lemon peels. It exhibits a range of biological activities like antibacterial, antifungal, anticancer, antiviral and a number of other pharmacological activities on humans.

Limonoids are a group of chemical substances found in the rutaceae and meliaceae families and includes fruits like oranges, lemon and pumello. There are about 36 limonoid aglycones found in citrus and its hybrids of which only six are bitter. Limonin was the first compound to be characterized from this group and is the major limonoid found in most citrus fruits and also the major cause of bitterness. Nomilin is also involved in bitterness but its role is not as much (Hasegawa *et al.*, 1992).

2.8.4.2 Previous attempts for debittering citrus juices

Bitterness which is due to the presence of limonin in citrus fruits is one of the main problems in citrus industry. Therefore various physicochemical, chemical and biotechnological approaches have been employed to find out a solution to this problem. Some of the physicochemical approaches involve the use of polyamides to selectively adsorb significant quantities of the limonin. Various adsorbents such as cellulose acetate, nylon based matrices, porous polymers and ion exchangers have also been used to reduce bitterness (Johnson and Chandler, 1988). Chemical methods involve the treatment with ethylene to accelerate ripening in navel oranges, lemons and grapefruits with a continuous decrease in bitterness (Maier *et al.*, 1973). Also, the use of CO_2 at pressures of 21 to 41 MPA at 30 °C - 60 °C for 1hr resulted in an average removal of 25 % of limonin from navel orange juice. Biotechnological approaches involve the use of Immobilized Microbial Cells.

2.9 Fruits by-product utilization

Processed fruits and vegetables leave large amounts of wastes which are either sent into the field to act as soil conditioner or are left on the road side to pose great threat to the environment and human as a whole. If these wastes are treated with much attention, they may serve as good sources of nutrients (Wadhwa *et al.*, 2006). Recently, a number of studies have proposed some fruits and vegetable by-products being sources of natural antioxidants. Cauliflower by-product has been proposed as a cheap source of enriched polyphenol extract and the consumption of polyphenol-rich foods or beverages seems to be associated with the prevention of some types of diseases (Llorach *et al.*, 2005).

Lemon peel, a by-product from the citrus fruit industries is made up of the fresh or dried outer portion of the pericarp of the fruit of lemon. The main components of the lemon peel are the volatile oil and an amorphous, bitter glucoside called limonin. One other component is hesperidin ($C_{44}H_{28}O_{14}$), a colourless, tasteless, crystalline glucoside which occurs mainly in the white zest of the peel (American Botanical Council, 2000). Lemon peels have lots of health benefits as a result of its dietary fibre content and its antibiotic activity.

A lot of by-products from fruits may be useful as sources of nutrients and as potential functional ingredients to give food industries and consumers the chance to obtain products with added value (Domínguez-Perles *et al.*, 2010). The seed of jackfruit which is a waste from the fruit industry has commercial potential for application as a cheap source of fiber replacing the wholemeal. The flour of jackfruit seeds has been successfully incorporated into bread at 25% level and was accepted by sensory panellists (Hasidah and Noor Aziah, 2003).

2.10 Trends in the baking industry

The bakery industry in U.S is growing steadily at a rate of 2.0 – 3.0 % per year. Manufacturers of bakery products need to keep bringing novel products in order to sustain the industry and many efforts have therefore been made in the past few years to bringing in new food products.

Recently, the bakery industry has undergone significant changes as it responds to changes in consumer trends, especially the increasing preference for products that improve health and are convenient. As a result of the increasing risks of obesity and cardiac disorders, the cakes and pastries industry has displayed some level of innovation and differentiation in terms of novel healthy food products such as low, fat-free and sugar-free products by the use of fat replacers (Frost and sullivan market research, 2008).

The trend in the market for fat replacers over the years has been growing at a high rate. However, the market grew low recently because of economic hardship. Nonetheless, the market is aimed for growth as there is increase demand for low-fat and fat free-products. According to the new market research report on fat replacers, carbohydrate based fat replacers represent the largest as well as fastest growing product but in terms of sales, protein-based fat replacers constitutes the fastest growing product, exhibiting an annual growth rate of more than 5.0%. With obesity becoming a major concern among people in general, the trend in the use of fat replacers is expected to increase rapidly in developing countries as well (San Jose, 2011).

A lot of fat replacers are available but it has still been a challenge to develop fat replacers for a low-fat and low-calorie product in which the texture, flavor and appearance are not compromised. Therefore, it is necessary to develop fat replacers from various sources to assist the formulation of low-fat and fat-free foods with high quality. The purpose of this research was therefore to evaluate the feasibility of lemon peels as a fat-replacer in pie crusts and determine the effects of different levels of fat replacement on the sensory and textural properties on the pie crusts.

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2.11 Functions of pastry ingredients

The main ingredients used in the preparation of pie crust are flour, fat, eggs, liquid and leavening agents. Other ingredients such as salt, vanilla, spices, colouring agents, etc. can also be used in small amounts. Each ingredient has its own function in the preparation of pie. Therefore, a proper balance of ingredients needs to be obtained to produce a quality product (Penfield and Campbell, 1990 a).

2.11.1 Flour

Flour is the powder obtained by grinding wheat kernels or berries. The kernel consists of three different parts; bran which is the outer covering of the grain, germ and the endosperm and these make white flour. Soft wheat flour is the type of flour used in preparing pie. This flour improves the performance in high-ratio pastries (Bennion, 1995 b). Flour contributes structure to pie crusts. If too little flour is used, the structure of the resulting product will be weak and may fall. If too much flour is used, a compact, dry pie crust will be produced (Bennion, 1995 b).

2.11.2 Fat

Fat contributes to tenderness and helps retain air, flavour and a smooth moist mouth-feel in pie crust. Fat also interferes with the development of gluten thereby causing the pie structure to be weak (Bennion, 1995 b). Plastic fats helps incorporate and retain air in the form of small bubbles distributed in the product. These bubbles serve as gas cell nuclei into which carbon dioxide and steam diffuse during baking (Penfield and Campbell, 1990 b). Thus, the smaller the air cells, the lower the volume of the product.

2.11.3 Liquid

The liquid used in the preparation of pie crusts serves as a solvent for salt and leavening agent. It disperses the fat and flour particles, hydrates the flour proteins and gelatinizes starch. The liquid also provides steam which helps leaven the pie (Bennion, 1995 b). If milk is used in preparing pie crust, the carbonyl-amine reactants contribute to browning of the crust (Penfield and Campbell, 1990 b).

2.11.4 Leavening agents

The three main components of leavening agents are steam, air and carbon dioxide. Air can be incorporated into pie crusts by creaming fat or rubbing in fat to flour (Bennion, 1995 b). Carbon dioxide is generated from chemical leavening agents such as baking

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soda and baking powder. In the presence of an acid, sodium bicarbonate (baking soda) releases carbon dioxide on heating (Bennion, 1995 c). If too much leavening is added, the cell walls will expand beyond their limit and result in a coarse, irregular crumb. However, addition of too little leavening agent poorly expands the cell walls and leads in a compact and low volume product.

2.12 Food Texture

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The texture of a food product is an important factor that influences the pleasantness of the food and the amount that can be eaten. The texture of food can affect the acceptability (Bourne, 2002), and also its identification.

Texture evaluation is an important step when developing a new food product and often involves the use of sensory evaluation techniques and instrumental measurements. Generally, relationship between the instrumental measurement and sensory evaluation technique are determined using correlation to predict responses by consumers or evaluate quality control parameters (Szczezniak, 1987).

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Sensory analysis involves the use of the sense of smell, taste and touch. It is sometimes preferred to use instrumental methods to assess the texture of food rather than sensory analysis because instrumental methods can be carried out under more strictly defined and controlled conditions. Therefore, the main goal of any texture studies is to develop mechanical test as a tool to evaluate food texture with the ability to replace the human sensory evaluation (Peleg, 1983). A lot of instrumental tests both initiative and empirical have been designed for the evaluation of texture of foods. The most popular instrumental

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initiative test, Texture Profile Analysis (TPA), was first developed for the General Foods Textureometer (Szczesniak *et al.*, 1963) and later adapted to the Instron Universal Testing Machine (IUTM).

2.12.1 Texture profile analysis

Texture profile analysis was developed in the early 1960s to study the mechanical properties of foods and their relationship to the texture of foods. The original TPA was carried out using the General Foods (GF) Textureometer by Friedman *et al.* (1963). A new TPA was developed using the Instron Universal Testing Machine.

Texture Profile Analysis (TPA) is an imitative test and is designed to subject food to severe crushing and breaking similar to what occurs during chewing. The method is based on a system of classification and definition of different textural characteristics. Textural characteristics can be classified into two main groups: Geometrical attributes and Mechanical attributes (Szczesniak *et al.*, 1963).

The geometric characteristics are grouped into two: those related to particle size and shape such as gritty, grainy or coarse and those related to shape and orientation such as fibrous, cellular or crystalline (Szczesniak *et al.*, 1963). The mechanical characteristics are important in determining the manner in which the food behaves during mastication in the mouth. The mechanical characteristics are divided into five primary parameters and three secondary properties. The secondary properties are made up of two or more of the primary parameters (Szczesniak *et al.*, 1963).

The primary properties include hardness, cohesiveness, viscosity, springiness and adhesiveness. Hardness is the force required to compress a food between the molars of the force necessary to attain a given deformation ((Szczesniak *et al*., 1963).

Cohesiveness is the degree to which a substance is compressed between the teeth before it breaks or the measurement of how well the structure of a product withstands compression. Springiness on the other hand is the degree to which a product returns to its original shape once it has been compressed. It is measured as the rate at which a deformed material goes back to its original condition after the deforming force is removed and adhesiveness is the work necessary to overcome the attractive forces between the surface of the food and the surface of the other materials with which the food is in contact with (Szczesniak *et al*., 1963).

The secondary properties include fracturability which is the force required for a material to disintegrate. Chewiness: the energy required to chew a solid food to a point require for swallowing and Gumminess: the energy required to disintegrate a semi-solid food to a state ready for swallowing (Szczesniak *et al*., 1963).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Source of lemon

Lemon fruits (rough lemons) used in this study were obtained from a local farm at New Tafo-Akim in the Eastern region.

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3.2 Experimental design and statistical analysis

The experimental design used in this study was a one factor design with 6 fat replacement levels (0, 5, 10, 20, 30 and 40 %). The fixed treatment design was used to study the effect of fat replacement on the sensory and textural properties of pie crusts. Data obtained was analysed using the one-way Analysis of Variance (ANOVA) and Fisher's least significant test using the Microsoft Excel and Minitab software.

3.3 Preparation of fat replacers

Matured, green lemon fruits were harvested and washed with water to remove dirt. They were then sorted to remove undesirable ones and peeled with clean knife. The peels (albedo) were dried using solar dryer until constant moisture content was attained and the dried sample milled into a smooth powder. The fat replacer (powder) was packaged in high density polyethylene bags and stored. The flow diagram is shown in fig. 3.1.

Fig. 3.1: Flow diagram for the preparation of fat replacer

Lemon Fruits
↓
Washing
↓
Sorting/Grading
↓
Peeling
↓
Drying (solar)/Milling
↓
Fat Replacer
↓
Packaging
↓
Storage

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Table 3.1: Formulated composition for the substitution of fat replacers in pie crust

Sample Code	Mass Composition(g)			Percentage fat substitution
	Soft wheat flour	Shortening	Fat Replacer	
A	500	250.0	0.0	0%
B	500	237.5	12.5	5%
C	500	225.0	25.0	10%
D	500	200.0	50.0	20%
E	500	175.0	75.0	30%
F	500	150.0	100	40%

3.4 Proximate analyses of lemon peels

All proximate analyses were done in duplicates.

3.4.1 Moisture content determination

This was done by weighing two grams of sample into a previously weighed Petri dish and placed in a Gallenkamp oven (model XOV** Gallenkamp Co. Ltd., England) which was controlled at 105 °C for 2 hours. The petri dish was removed and immediately placed in a dessicator to cool after which it was reweighed. The dish and its content was placed in the oven for further drying, cooling and reweighing until a constant weight was obtained. Moisture content was calculated (AOAC, 1990). Calculations are shown in Appendix 1.

3.4.2 Total ash determination

This was done by weighing two grams of dried lemon peels into a weighed crucible and placed in a Gallenkamp muffle furnace (model AS 260D, Gallenkamp Co. Ltd., England) that had been preheated to 600 °C for 2 hours. The crucible was removed from the furnace and placed in a dessicator to cool and reweighed. The ash content was then calculated, (Kirk and Sawyer, 1991). Calculations are shown in Appendix 1.

3.4.3 Protein determination

About two grams of the sample was weighed and digested with 25 ml conc. H_2SO_4 in a Kjedahl digestion flask until a clear mixture was attained. The digested sample was transferred to a 100 ml volumetric flask and made to the mark after cooling.

Distillation/condensation apparatus was set up. About 25 ml of 2 % Boric acid was poured into a 250 ml conical flask and two drops of mixed indicator (4 ml of 0.1 % Methyl Red solution + 20 ml of 0.1 % alcohol Bromocresol Green solution) added and placed under the condenser with the tip of the condenser completely immersed in the Boric acid solution. About 10 ml of the digested sample and 20 ml of 40 % NaOH solution were poured into the decomposition tube and tightened. Distillation/condensation process was conducted and the ammonia liberated during the distillation process was collected into the Boric acid solution, turning it bluish-green. The distillate was titrated with 0.1 N HCl solution until the solution became pink. The titre values obtained were used to calculate the Nitrogen and hence the protein content (Kirk and Sawyer, 1991). Calculations are shown in Appendix 1.

3.4.4 Crude fat determination (Soxhlet method)

The dried sample from the moisture content determination was transferred into a thimble. About 150 ml Petroleum ether was weighed and poured into a round bottom flask. The thimble was fixed on the flask and the quick-fit condenser connected to the Soxhlet extractor on a steam bath and refluxed for 8 hrs. The flask containing the extracted fat was dried in a Gallenkamp oven at 103 °C for 30 minutes, after which it was cooled to room temperature in a dessicator and then weighed for the calculation of fat content (AOAC, 2000). Calculations are shown in Appendix 1.

3.4.5 Crude fibre determination

Residue from crude fat determination was transferred to a 750 ml Erlenmeyer flask and asbestos added. 200 ml of 1.25 % boiling H_2SO_4 solution was added and the flask connected to a condenser. After 30 minutes of digestion, the flask was removed and its contents filtered immediately through a cheese cloth and washed with boiling water until washings were no longer acidic. The procedure was repeated using 200 ml of 1.25 % NaOH solution. The residue was transferred to a weighed crucible and then washed with 15 ml ethanol. The crucible with its contents were dried for 1 hour at 100 °C in an oven, cooled in a desicator and reweighed. The sample was subjected to ignition in an electric furnace for 30 minutes, cooled and reweighed. The crude fibre content of the sample was then calculated (Kirk and Sawyer, 1991). Calculations are shown in Appendix 1.

3.5 Pectin determination

A modified method of the Nitric acid extraction was used by weighing 2g of dry peel powder into a 250 ml beaker and 130 ml of deionized water added. The content was acidified to pH 1.3 using 0.1 N Nitric acid solutions. The mixture was stirred vigorously for one hour at a temperature of 95 °C on a heating mantle and volume of the mixture maintained throughout the extraction. The mixture was then cooled in an ice bath to 55 °C, centrifuged and the supernatant decanted into a beaker. About 300 ml of 95 % ethanol was added to the supernatant to precipitate the pectin out of solution. The mixture was then stored for 24 hrs after which it was filtered and the precipitate washed three successive times with 95 % ethanol. The precipitated pectin was dried in an oven at 40 °C for 6 hrs. Dried pectin was weighed and the value recorded (Crandall and Rouse, 1976).

3.6 Water holding capacity

The water-holding capacity was determined according to a method by Anderson *et al.* (1969). One gram of lemon peel flour was weighed into a 50 mL centrifuge tube and 25 mL of water added and stirred for 30 minutes. The mixture was then centrifuged at 2500 rpm for 10 minutes and the supernatant removed. The weight of the pulp was recorded and water-holding capacity calculated.

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3.7 Dietary fibre determination

This was done by weighing 1g of lemon peel into a beaker and 40 ml MES-TRIS buffer solution (pH 8.2) added and stirred until the sample was completely dispersed in the solution. About 50 µl of heat stable α-amylase solution was added with continuous stirring at low speed. The beaker was covered with aluminium foil and incubated for 35 min in a water bath at a temperature of 95°C. It was then cooled to 60 °C and 100 µl of protease solution was then added, covered with aluminium foil and incubated in a water bath at 60 °C for 30 min with stirring. The sample was removed and 5 ml of 0.561 N HCl solution added. The pH of the sample was adjusted to 4.5 with 5 % NaOH solution. Amyloglucosidase (200 µl) was then added to the sample and covered with aluminium foil, placed in a water bath and heated for 30 min at 60 °C. About 225 ml of 95 % ethanol preheated to 60 °C was then added. The sample was left at room temperature for 60 min to precipitate. The precipitated enzymes digested were filtered through weighed fritted crucibles. The precipitates were soaked in 2 % cleaning solution for 1 hour and rinsed with deionized water. Finally, 15 ml acetone was used to rinse and then air-dried. One gram of celite acid was added to the crucible and dried at 130 °C overnight, cooled for 1

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hour and then weighed. The celite was wetted with 15 ml ethanol and suctioned to draw celite unto the crucible. The residue remained were then washed with 15 ml of 78 % ethanol and then with acetone. The crucible containing the residue was dried overnight in an oven at 103 °C, cooled for one hour and weighed. The same procedure was repeated for the blank determination to correct for protein and ash contents. Total dietary fibre was calculated as in appendix 1.

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3.8 Preparation of pie crusts

The dry ingredients were measured into a mixing bowl and the fat was rubbed onto the soft wheat flour. Salt solution was measured and added to the mixture to obtain the required dough. The dough was rolled on a board and cut into shapes and one-half of the cut dough folded on the other and sealed with a fork. They were arranged on a prepared baking sheet and baked in a preheated oven for 40 min and cooled. Subsequent pie crusts prepared had some of the fat substituted with fat replacer as shown in table 3.1.

3.9 Sensory analyses on reduced fat pie crusts

Fifty untrained panellists participated in the sensory evaluation and consisted of twenty-eighty (28) women and twenty-two (22) men, aged between 20 – 50 years. Panellists were given coded samples and asked to rate them on a scale (1 = dislike extremely 9 = like extremely). Attributes rated includes appearance, colour, taste, etc. Data obtained were analysed for ANOVA and Fishers LSD using MS Excel and Minitab software.

3.10 Colour measurements

Surface colour of the baked lemon pie crust samples were measured using the CIE colour scale. The CIE colour scale measured the degree of lightness L* (black [0] to light [100]), a* (red [60] to green [-60]), b* (yellow [60] to blue [-60]) using a Chroma Meter CR- 310 (Minolta Co. Ltd., Osaka, Japan). The Chroma Meter was standardized using a white (Y= 93.7, x= 0.3138 and y= 0.3194) standard plate. Three samples were used per experiment.

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3.11 Instrumental texture profile analyses

For instrumental texture analysis (TA) on the pie crusts, the dough was rolled out to the same thickness. Biscuit cutters were used to cut the dough into uniform sizes and shapes. Baked samples were cooled to room temperature prior to test. The TA.XT2 Texture analyser (Stable Microsystems, Godalming, UK) was used for the texture analysis. Optimized test conditions were; probe TA-2 mm; test speed, 1.0 mm/sec; pre-test and post-test speed, 5.0 mm/s; compression, 75 %; time pause, 2 sec; load cell, 5 kg. Data collection and calculations were done using Microsoft Texture Expert and Microsoft Excel software. Data reported were averages of 5 measurements for 2 replicates of each pie crust.

3.12 Water activity (a_w)

Water activity was determined using a Decagon Aqua Lab CX-2 water activity meter (Pullman, WA). Water activity determination was performed on freshly baked pie crusts and pie crusts stored at room temperature (25 °C) for 1, 24 and 72 hours after baking. The

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water activity meter was calibrated by filling a plastic disposable cup half-full with a saturated potassium chloride solution. The cup was placed into the sample holder and the knob turned to "READ" to take the a_w. Each sample was measured by covering the bottom of a plastic disposable cup with a portion from the pie, placing the cup into the sample holder and taking the reading.

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CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Nutritional composition of lemon peel-derived fat replacer

Proximate analyses on the lemon peel-derived fat replacer yielded 21.26 % pectin as shown in table 4.1, an indication that lemon peels contain high amount of pectin and therefore could be used as a fat replacer. A research conducted by Lerotholi (2009) reported pectin content of 22.22 % from dried lemon peels. The lemon peels also contained high amount of dietary fiber (14%) and carbohydrate (71.50 %), while it had low contents of fat (0.05 %), proteins (1.50 %) and ash (2.13 %). Marin *et al.* (2007) reported high amount of dietary fiber from the solid residue of *citrus limon*.

Table 4.1- Proximate, pectin and water holding capacity of lemon peel-derived fat replacer

Nutrient	Amount (%)
Pectin	21.26 ± 1.70
Crude fibre	20.19 ± 0.01
Moisture	4.59 ± 0.042
Fat	0.08 ± 0.014
Protein	1.50 ± 0.041
Ash	2.13 ± 0.014
Carbohydrate	71.50 ± 0.12
Dietary fibre	14.0 ± 0.03
Water holding capacity	86.0 ± 0.12

The value for water holding capacity of lemon peels was 86 %, an indication that the fiber in the lemon peels interacted and held water strongly to form gel and so this lemon peels could potentially be used as a functional ingredient to modify the texture of formulated foods.

4.2 Moisture content of reduced fat-pie crusts

Moisture content of a food indicates the food's stability and quality (Pomeranz and Meloan, 1994). Substances such as pectin, xanthan gum and maltodextrins are hydrophilic and therefore have high affinity for water and can also retain moisture in foods.

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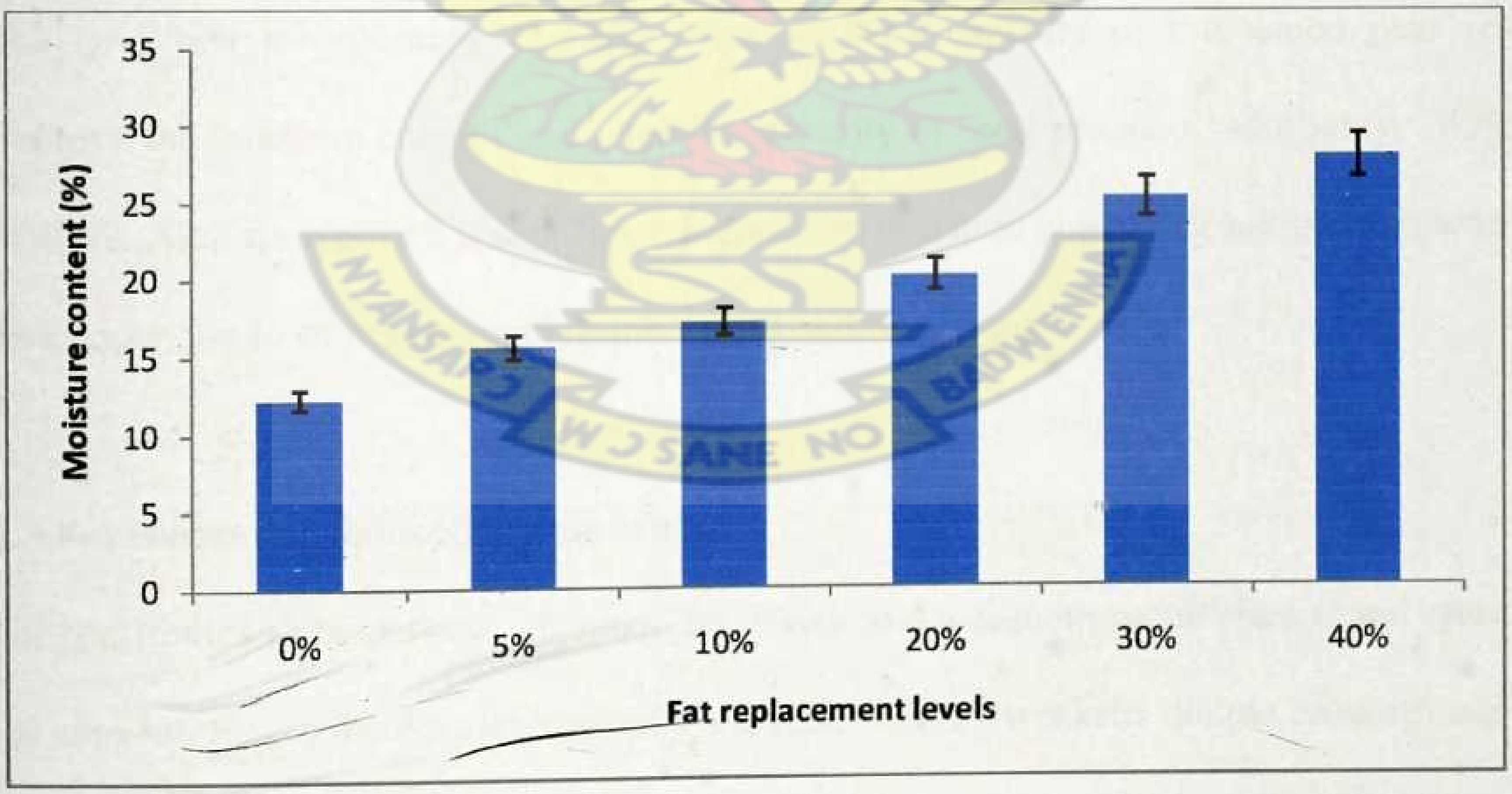
Fig.4.1- Moisture content of reduced fat pie crusts



Fat replacement has a significant effect on the moisture content of the products. Figure 4.1 revealed significant difference ($p \leq 0.05$) in moisture content of most of the products.

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Product A (0 %) had the least percent moisture of 12.25 % and product F (40 %) had the highest percent moisture of 25.35 %. No significant difference ($p \geq 0.05$) was observed between products B (5%) and C (10%). However, significant difference ($p \leq 0.05$) was observed when products B (5%) and C (10%) were compared with A (0%). Thus, the higher the fat replacement with lemon peels the greater the resulting moisture content. These results are consistent with the work of Conforti *et al.* (1996) in which the effect of three carbohydrate-based fat replacers in baking powder biscuits was studied. Comparing moisture content to hardness of pie crusts, it could be noted that hardness decreased with increasing moisture content of pie crusts. However, water activity increased with increase in moisture content. The increase in moisture content with increasing lemon peel fat replacer may be due to the higher number of hydroxyl group which exist in the fiber and allows more water interaction through hydrogen bonding as reported by Garau *et al.* (2007). When incorporated, the high water holding capacity of the lemon peel will improve the moisture content and retention capacity of food products (Moriartey, 2009). In 1999, Archilla reported a significant increase in moisture content of a high ratio white layer cake due to shortening replacement with maltodextrin gel.

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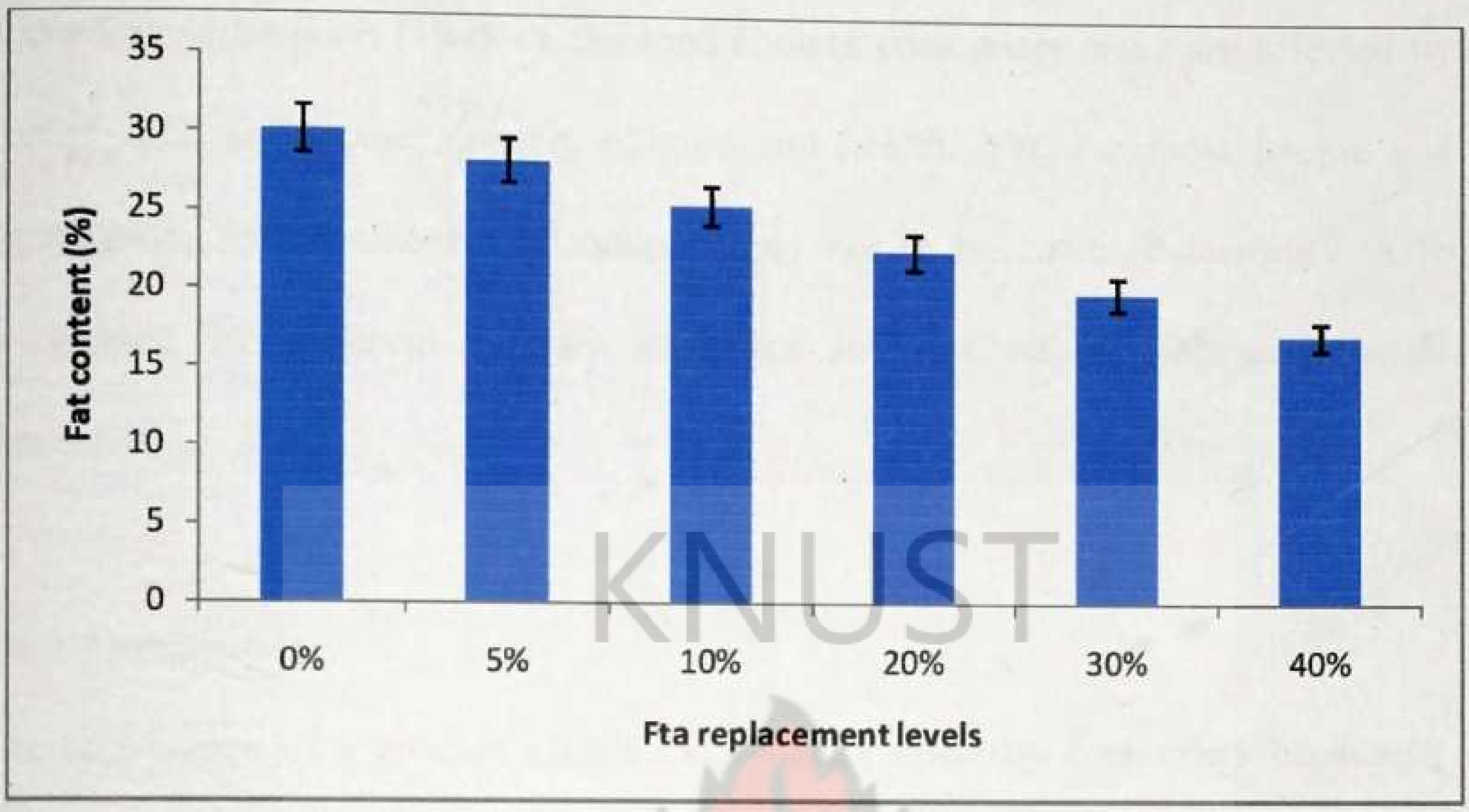
4.3 Fat content of reduced fat-pie crusts

Fat contributes to tenderness, air retention, flavor and a smooth mouth feel in pie crusts. Fat also influences the development of gluten and thereby weakens the pie crust structure (Bennion, 1995 a).

Fig 4.2- Fat contents of reduced fat pie crusts



The effect of fat replacement on the fat content of the products was quite significant. There were significant differences between the control A (0 %) and all the other products except product B with 5% fat replacement level (Fig. 4.2). This means that, the higher the percentage of fat replacement, the lower the level of fat in the product. This trend was however expected.

Product A (0 %) recorded the highest fat content of 30.11 % and product F(40 %) recorded the lowest fat content of 17.26 %. The other products B (5 %), C (10 %), D (20 %) and E (30 %) also recorded 28.21, 25.43, 22.59 and 19.96 % respectively. The decreasing trend conforms to one observed by Paintsil (2009) in which the sensory and rheological properties of reduced-fat rock buns and mango pie containing a papaya (*carica papaya*)-derived fat replacer were studied.

4.4 Sensory evaluation of pie crusts

According to Bennion (1995 c), the food choices consumers make are affected by many factors such as income, culture, religion and health. Yet, for most people and more importantly, foods must be palatable if they are to be eaten. Palatability of foods is determined by different sensory attributes such as odour, appearance, taste and mouthfeel.

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4.4.1 Appearance

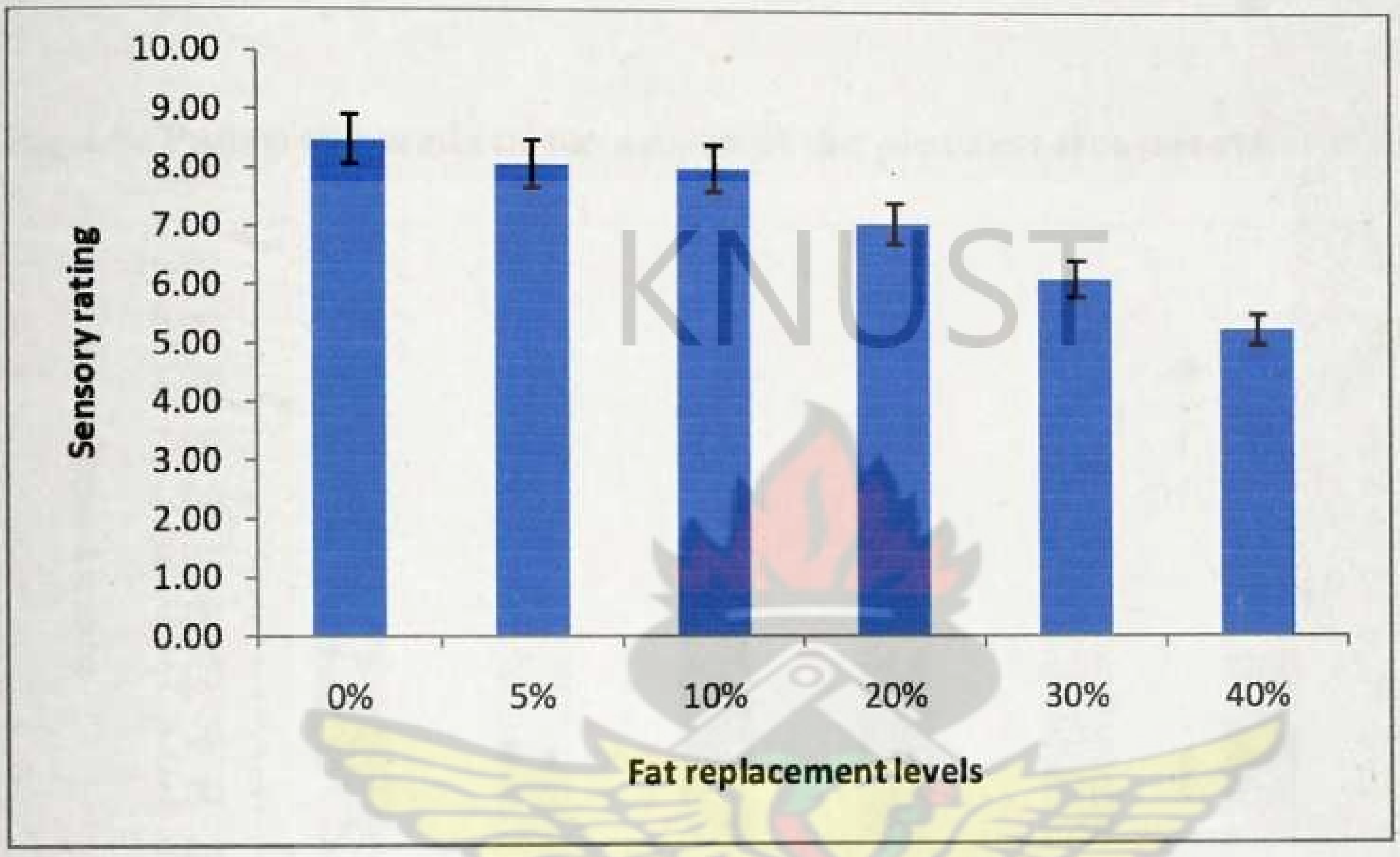
The appearance of a product affects the decision made by consumers because it is the only attribute consumers often base their purchasing decisions on (Meilgaard *et al*, 1991). Consequently, if the appearance of a food is not appealing to the consumer, the food may be rejected without being tasted at all (Bennion, 1995 c). Statistical analysis revealed no significant difference ($p \geq 0.05$) between products B (5 %) and C (10 %) when compared with the control A (0%) (Fig.4.3). Furthermore, no significant differences ($p \geq 0.05$) were found when products B (5 %) and C (10 %) were compared with product D (20 %). Dwyer and Eimean (2001) reported that, reducing the margarine content in Madeira cake recipe resulted in lower rating in appearance of the products when compared with the control. This may be due to incorporation of less air into the batter as a result of the decreased margarine content. Another report from Wang and Sullivan (2010) also showed lower ratings by panelists for appearance of brownies substituted with pumpkin puree as a fat replacer. The trends observed in both cases confirm how easily fat could affect the appearance of products and therefore decreasing the fat content affected the appearance of the pie crusts.

Fig 4.3- Panels response to the appearance of the pie crusts

4.4.2 Colour

Uniform golden brown crusts are most of the time preferred in bakery products (McWilliams, 1993 a). Browning of pie occurs in the crust and crumb, but it is more obvious in the crust and it is a result of Maillard reaction and some degree of caramelization (McWilliams, 1993 b). For colour, no significant differences ($p \geq 0.05$) were observed among products A (0 %), B (5 %) and product C (10%) whereas products D (20 %), E (30 %) and F (40 %) were significantly different ($p \leq 0.05$) from each other (Fig. 4.4). The general decline in colour rating from panelists could be due to the reduction in fat content since fat incorporates a uniform golden colour to baked products by interfering with the gluten formed when flour proteins are hydrated. Sudha *et al.* (2007) reported that cookies turned darker in colour with increasing levels of fat replacement leading to lower acceptance by panelists. The decrease in colour rating was possibly due to the high moisture content of the products and less fat. In addition, Masoodi and Bashir (2012) reported a decrease in colour rating in a study on the quality of biscuits when fortified with flaxseed.

Fig 4.4- Panels response to the colour of the pie crust



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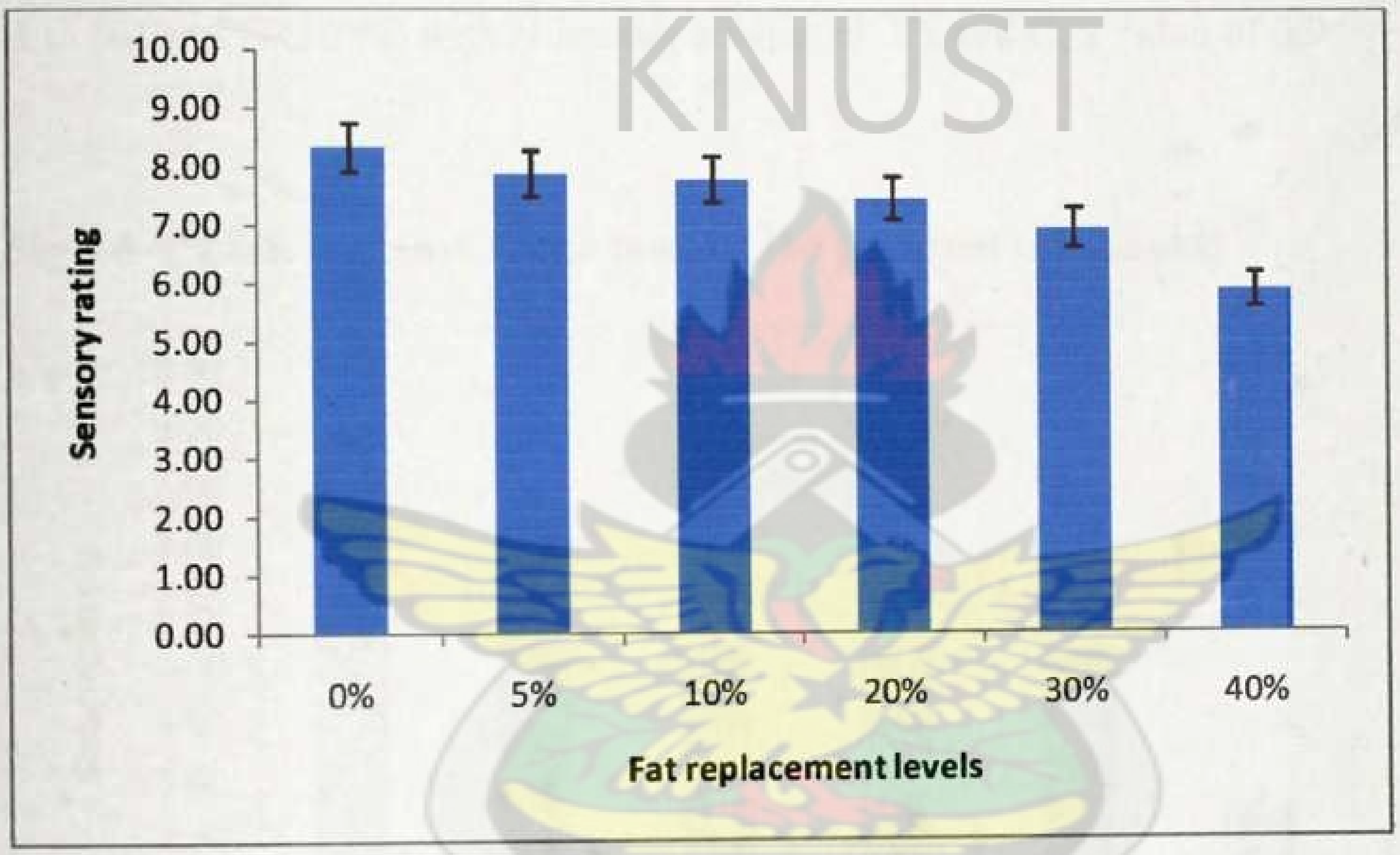
Furthermore, Siddiqui *et al.* (2003) observed that decreasing trend of color rating of biscuits by panelists could be due to high level of proteins present in the flour, since amino acids react with reducing sugars during baking and as a result Maillard reaction occurs and the color gets darker. Thus more darkness resulted in the reduction of quality scores for colour. Panelists' scores also agreed with Hunter L^*, a^* and b^* values.

4.4.3 Aroma

Aroma is one of the sensory attributes which helps to advertise food products. Significant differences ($p \leq 0.05$) were observed in aroma for most of the products with A (0 %) not being significantly different ($p \geq 0.05$) from B (5 %) and C (10 %). Hatchwell (1994 b) reported that the removal of a significant amount of fat from food products changed the flavour profile. In addition, the use of fat replacer in food products affected the flavour components and made a big difference in the perception of flavour (Schirle- Keller *et al.*, 1992).

Fig 4.5- Panels responds to the aroma of the pie crust treatments



Panelists' rating of 5.9 for product F (40 %) was an indication that they liked the aroma slightly whereas product A (0 %) had the highest rating of 8.33 which indicated that they liked the aroma very much (Fig. 4.5). Comparing products B (5 %), C (10 %) and D (20 %), no significant differences ($p \geq 0.05$) were observed amongst them for aroma. Masoodi and Bashir (2012) also reported a decrease in aroma during studies on the quality of biscuits fortified with flaxseed.

4.4.4 Taste

Generally for taste, there was a decrease in panelists rating as the level of fat replacement was increased. Product A (0 %) had the highest rating for taste with a value of 8.41; an indication that panelists liked the taste very much as compared with all the other products but no significant difference (p≥0.05) was observed between products A (0 %) and B (5 %) (Fig.4.6). Furthermore, there was no significant difference (p≥0.05) between products B (5 %) and C (10 %) with B having a value of 7.5 and C, a value of 6.9.

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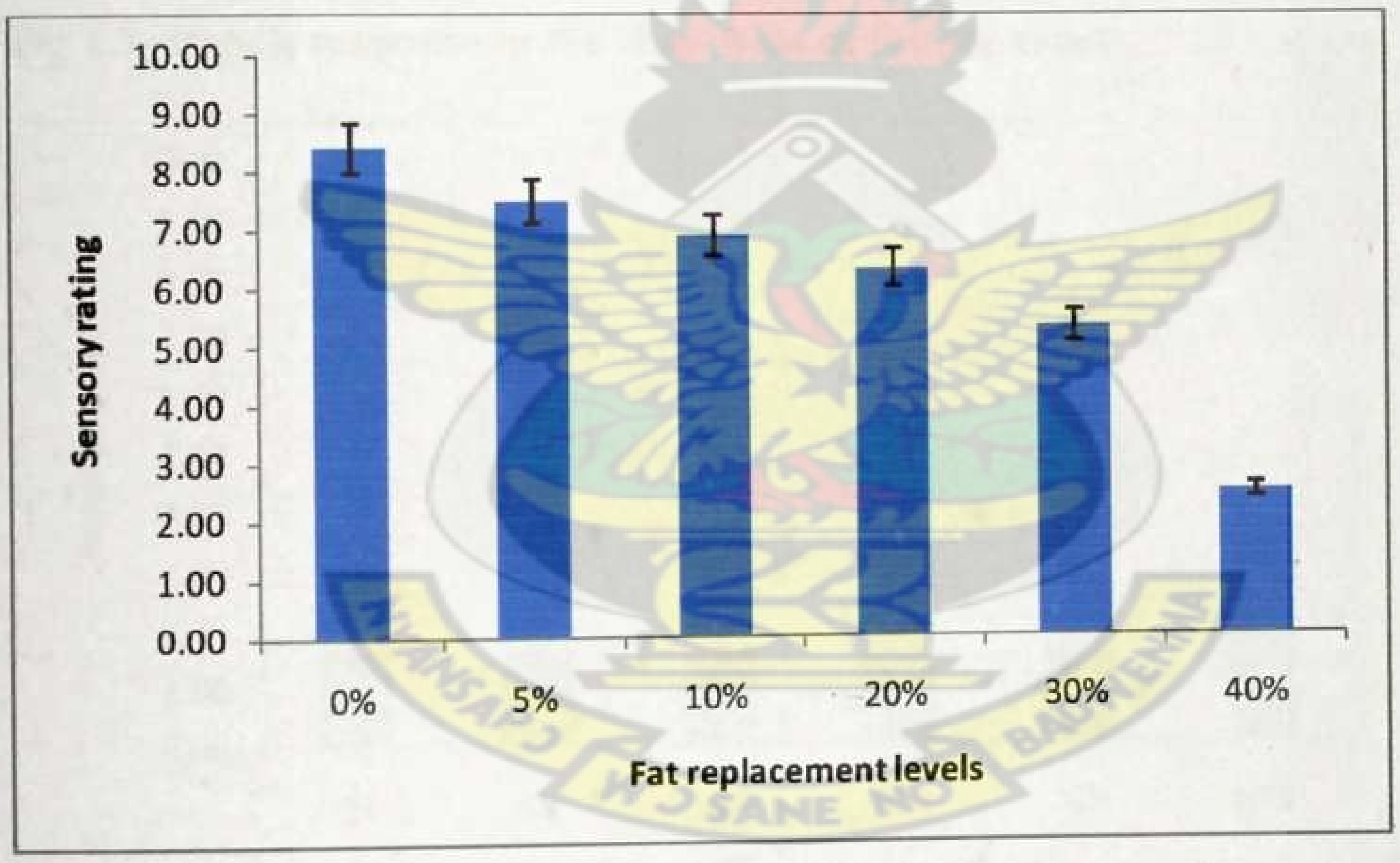
Fig 4.6- Panels response to the taste of the pie crust treatments

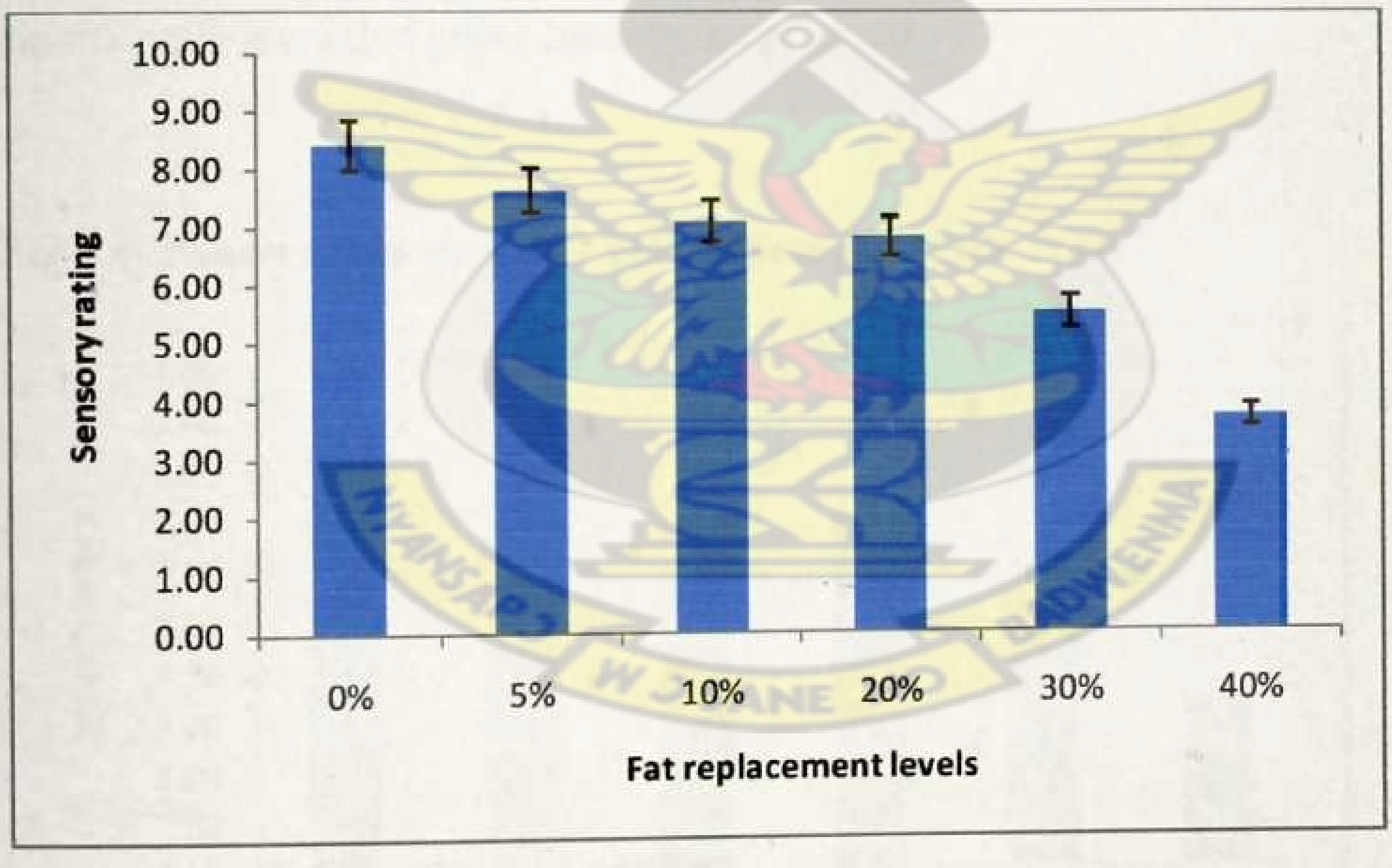


Products E (30 %) and F (40 %) had the least rating for taste and this could be due to the bitter principle (limonin) associated with the lemon peel. Product B (5%) was liked slightly by panelists because it contained 5% fat replacer compared with the products C (10 %), D (20 %), E (30 %) and F (40 %). Panelists commented that if consumers are educated on the health benefits of limonin they might prefer the reduced fat products to the control.

4.4.5 Chewiness

Statistical analysis showed significant differences among most of the products. Although no significant difference ($p \geq 0.05$) was observed between products A (0 %) and B (5 %), products D (20 %), E (30 %) and F (40 %) were found to be significantly different ($p \leq 0.05$) from each other (Fig. 4.7).

Fig 4.7- Panels response to the chewiness of the pie crust



There was a general decline in chewiness as the fat content was decreased and fat replacement increased with product A(0%) being most chewy. Panelists preferred the chewiness of the control with a rating value of 8.41 to the chewiness of the other products. The results are in agreement with research conducted by Akesowan, (2007) in

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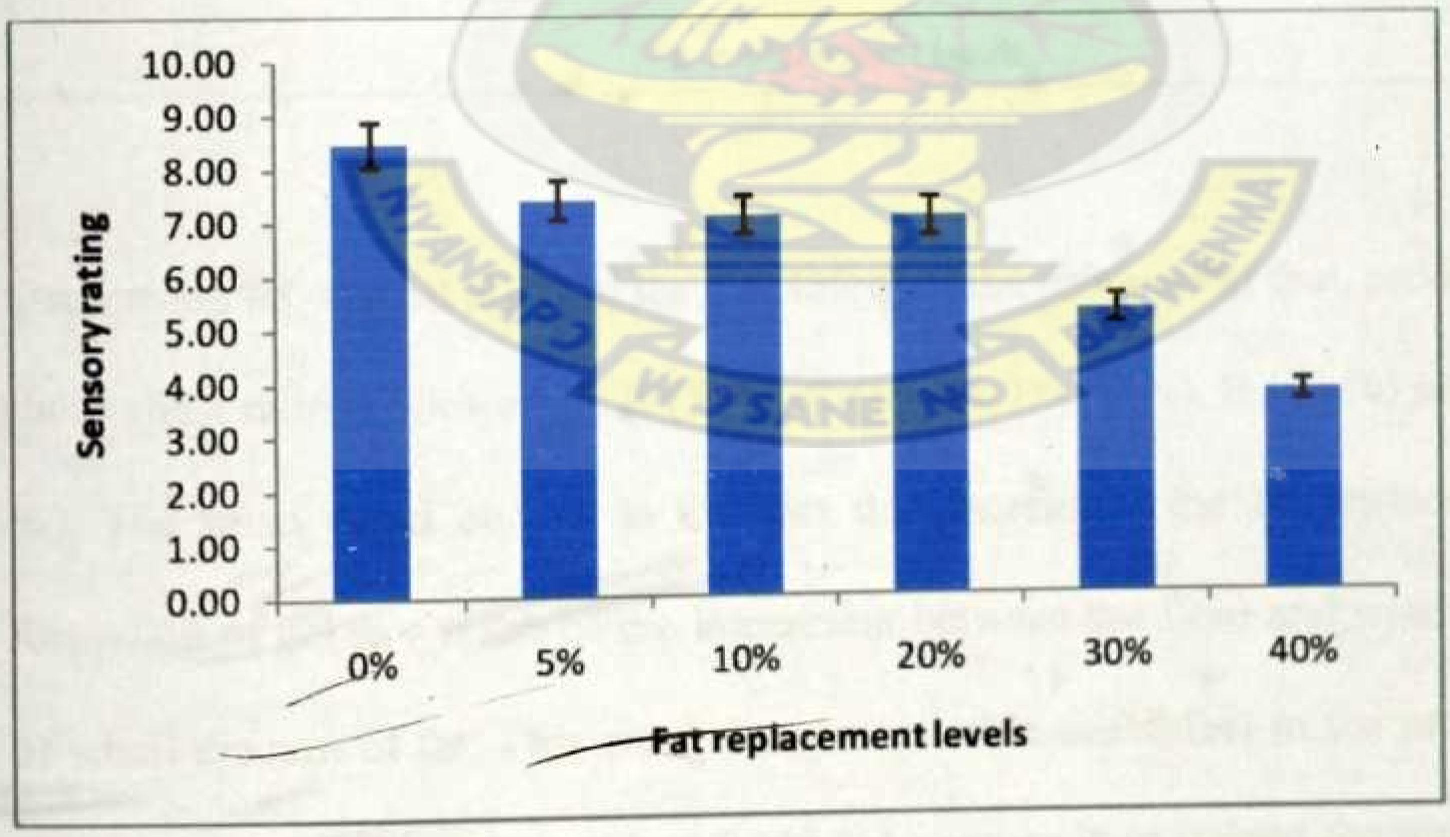
which was reported lower ratings from panelists for chewiness of water chiffon cakes when konjac flour and soy protein isolate mixture was added to replace fat in the cakes.

4.4.6 Gumminess

Gumminess is defined as the energy needed to disintegrate a semisolid food until it can easily be swallowed (Szczesniak, 1963). Sensory rating for gumminess was in the order A > B > C > D > E > F (Fig. 4.8). From the statistical data obtained for gumminess, no significant difference ($p \geq 0.05$) was observed between products A (0 %) and B (5 %) but there were significant differences ($p \leq 0.05$) when A (0 %) was compared with the rest of the products. Awad *et al.* (2005) showed that the reduction of fat content in cheese significantly increased gumminess in the products.

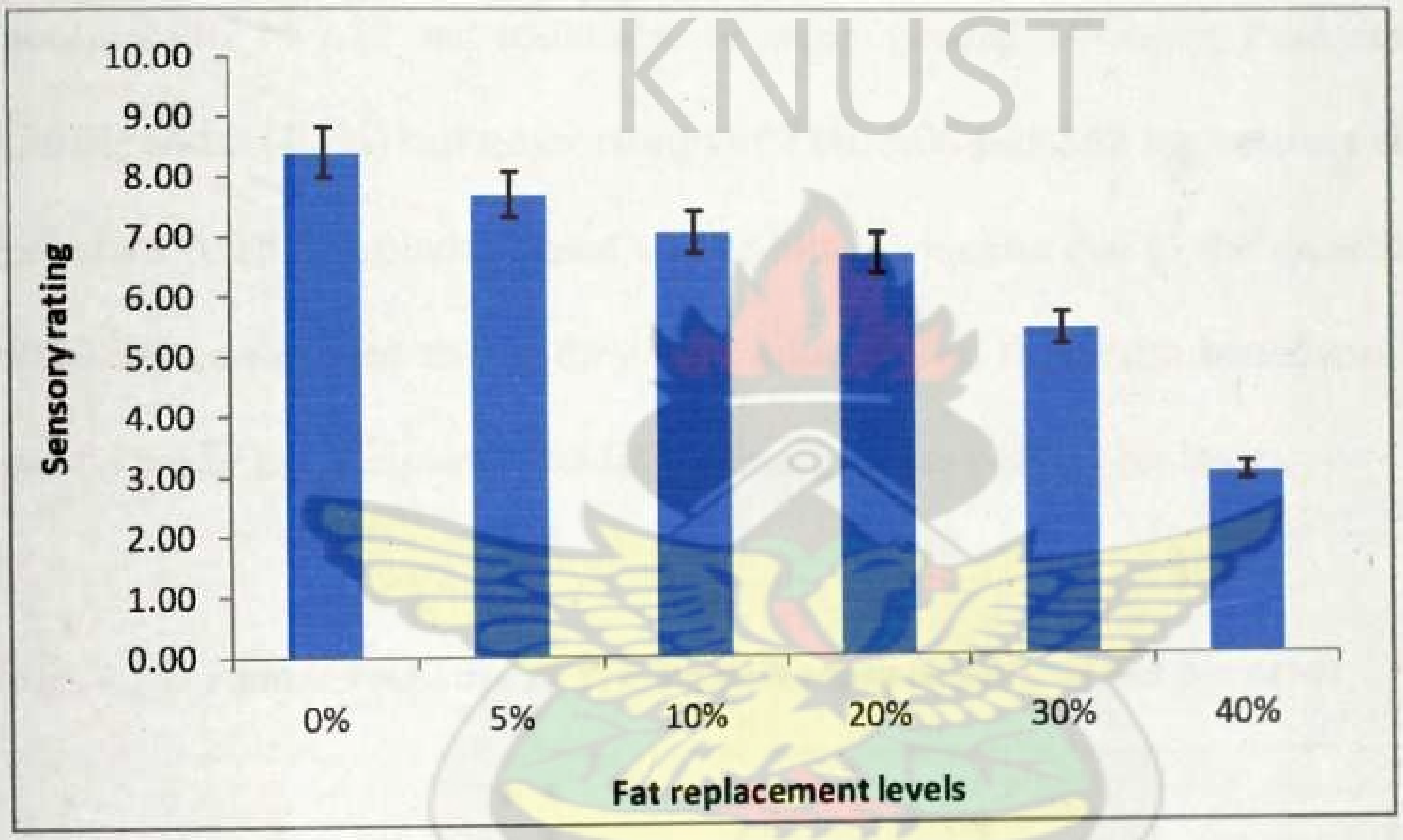
Fig 4.8- Panels response to the gumminess of the pie crust



4.4.7 Mouthfeel

No significant difference (p≤ 0.05) in mouthfeel was observed between products A (0 %) and B (5 %), and also products B (5 %) and C (10 %). The trend observed for panelists' rating of mouthfeel was in the order A > B > C > D > E > F (Fig. 4.9).

Fig 4.9- Panels response to the mouthfeel of the pie crust

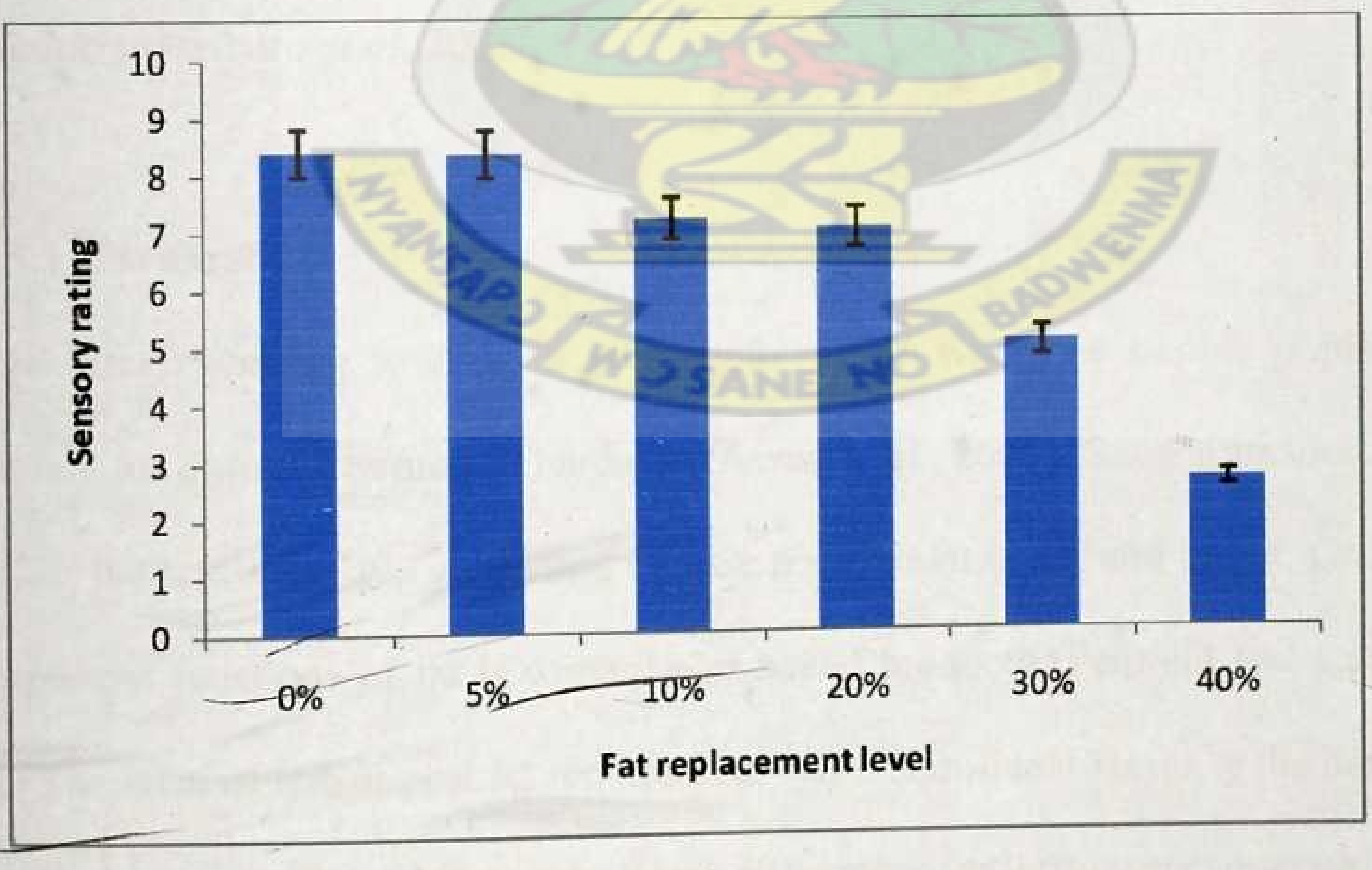


Decreasing fat content affected the mouthfeel of the products in that, product A (0 %) had the highest rating followed by B (5 %), C (10 %), D (20 %), E (30 %) and product F (40 %). The trend could be due to the fact that increasing the fat replacer increased the formation of gel as a result of the interaction between the flour and water in the presence of small amount of fat. This created an undesirable mouthfeel in the products. Panelists disliked the mouthfeel for product F (40 %) because it contained the highest level of fat replacer.

4.4.8 Overall acceptability

Generally, panelists preferred product A (0 %), which had no fat replacement and product B, with 5% fat replacement. There was no significant difference ($p \geq 0.05$) between the two products (A and B) and these products had the highest ratings for overall acceptability (8.40 and 8.36 respectively). Thus, 5% replacement with lemon peel was desirable by the panelists. From fig. 4.10, product C with 10% replacement had overall acceptability of 7.22 and could also be recommended. However, Products D (20 %), E (30 %) and F (40 %) had lesser ratings of 7.06, 5.06 and 2.62 respectively and most of the panelists rated acceptance based on the bitter principle due to the presence of limonin. Panelists commented that if they were educated on the health benefits of limonin they would prefer products with less fat and more lemon peel fat-replacer.

Fig. 4.10- Panels response to the overall acceptability of the pie crust



Often times, substituting fat in a recipe decreases the acceptability of the final product as shown by Swanson and Munsayae (2003), in a study that examined the effects of partially substituting fat in different types of cookies with applesauce and prune puree. The research found that substituting fat in the cookies affected the consumer preference, in that, cookies made with fruit substitute tend to be less liked by panelists. Similar results were found by work done by Wiese and Duffrin (2003), in which pawpaw fruit was used as fat replacer in plain shortened cake. As the fat replacer was increased, preference also decreased.

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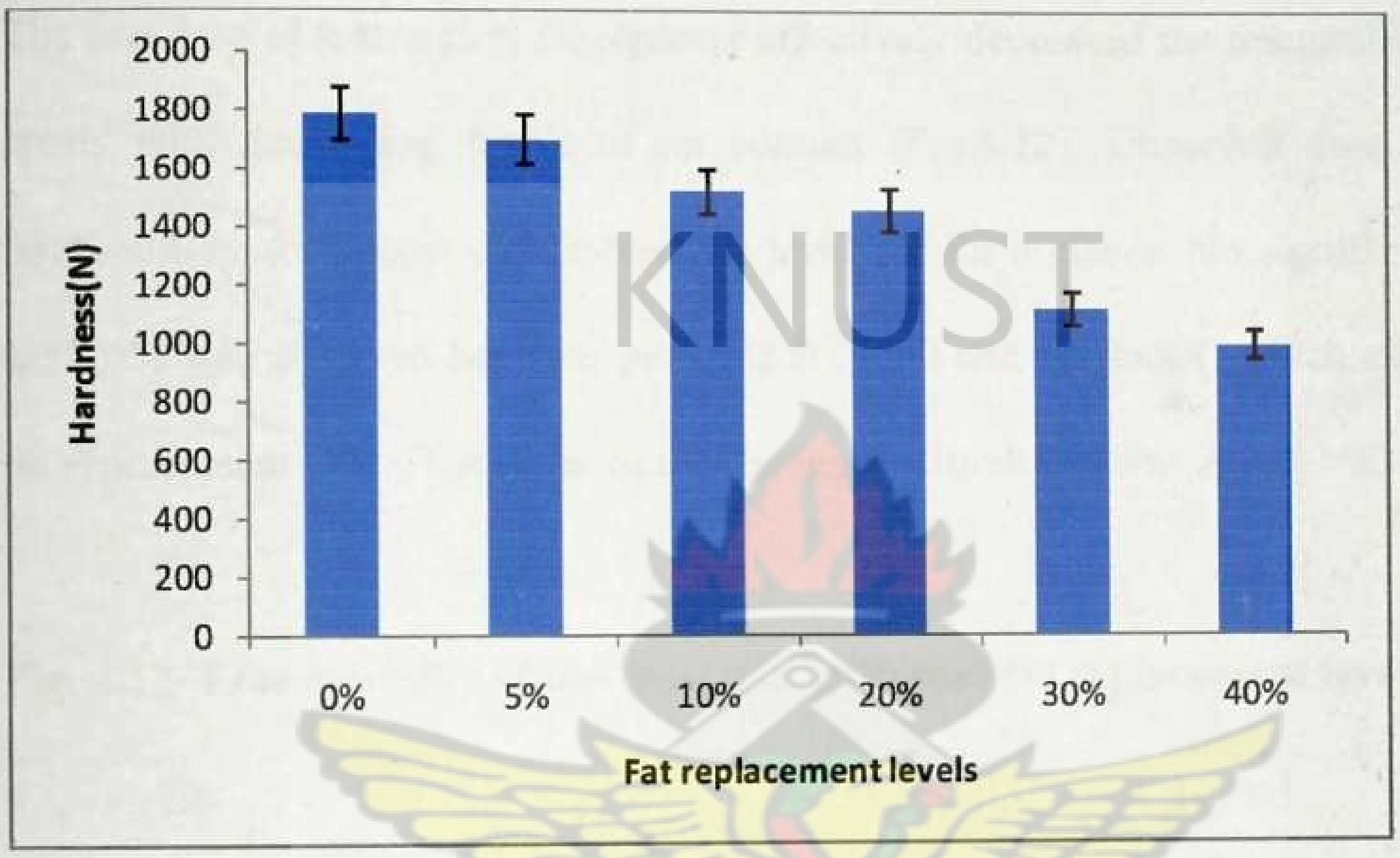
4.5 -Texture Profile Analysis

Texture is a mechanical behavior of foods that is measured by sensory (physiological or psychological) or by physical means. The measurement with the Texture Profile Analyzer (TPA) helps bakers to constantly and objectively monitor the quality of the baked products (Hathorn *et al*, 2008).

4.5.1 Hardness

The force necessary to attain a given deformation when the sample is placed between molars for biting is termed as hardness (Awad *et al.*, 2005). Several factors are known to affect the texture of pie crusts and include the amount of fat and liquid. One of the most important functions of fat is to tenderize baked products (Penfield and Campbell, 1990 b). The level of lemon peel fat replacement was a significant factor in the hardness values of the pie crusts (Fig 4.11) as significant differences ($p \leq 0.05$) were observed among most products for hardness. Data indicated that product A (0 %) significantly differed ($p \leq 0.05$) from the other products except product B (5 %).

Fig. 4.11- Hardness of pie crust with different fat replacement levels

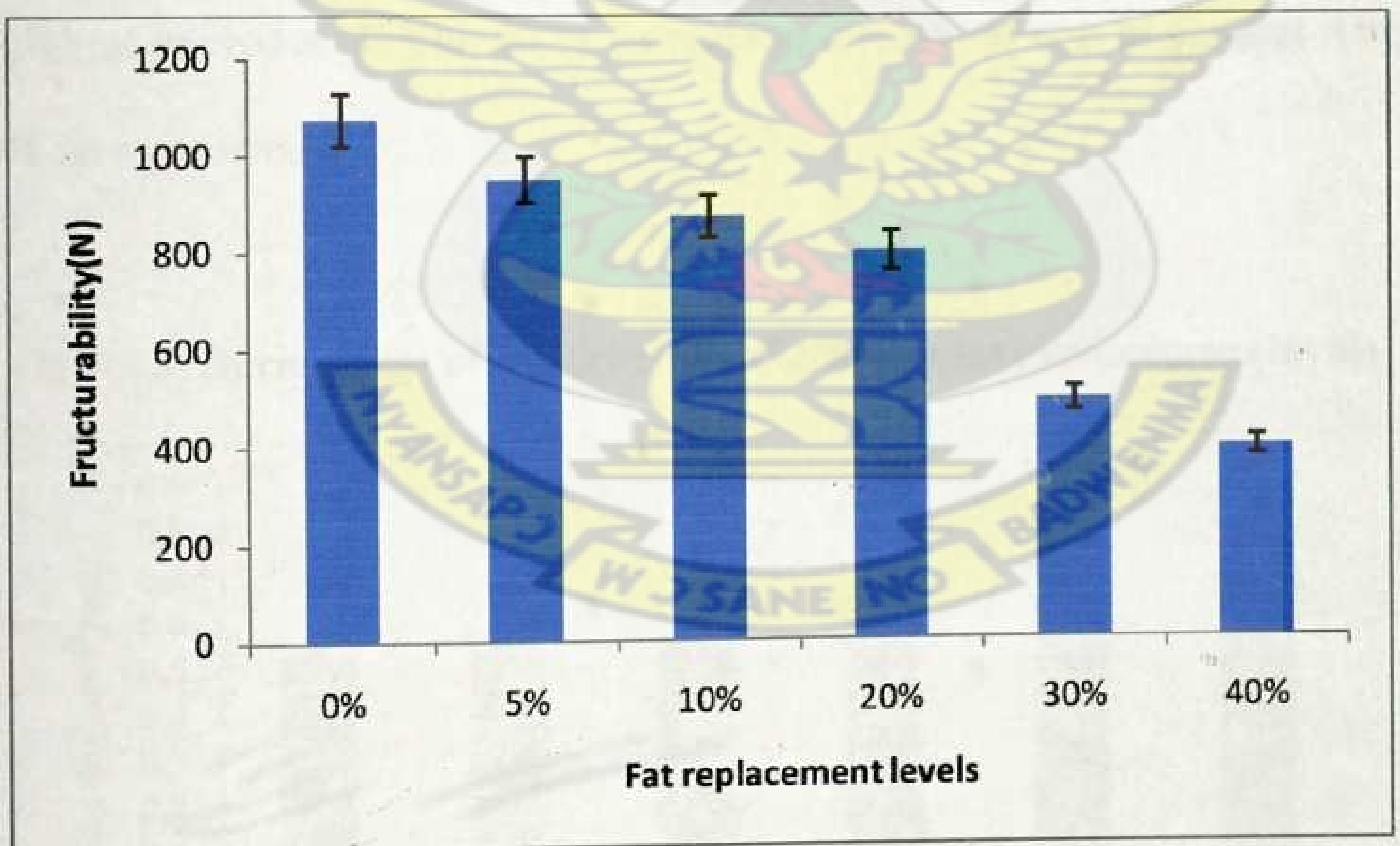


Furthermore, product B (5 %) was also not significantly harder ($p \geq 0.05$) than product C (10 %) but significantly harder when compared with products D (20 %), E (30 %) and F (40 %). Product F (40 %) had the least value for hardness and could be due to the high level of fat replacement. This trend of decreasing hardness conforms to work done by Paintsil (2009) on sensory and rheological properties of reduced-fat mango pie containing pawpaw-derived fat replacer. The report concluded that the reduced-fat fruit pie crust (FPT) was less hard compared with the full fat control (FPO). Moreover, this finding is in agreement with the results of Noronha *et al.* who reported that the increase in moisture content in imitation cheeses significantly ($p<0.001$) decreased the hardness. In this research, since the moisture content increased with increase in fat replacement, hardness was expected to decrease with increasing fat replacement levels.

4.5.2 Fracturability

The presence of lemon peel fat replacer effectively decreased the fracturability of the pie crusts with decreasing levels of fat content (Fig.4.12). Observed data revealed that fracturability decreased with increasing levels of fat replacer. No significant difference ($p \leq 0.05$) was observed between products B (5 %) and product C which contained 10 % fat replacement level. The order of decreasing fracturability was A > B > C > D > E > F.

Fig. 4.12- Fracturability of pie crust with different fat replacement levels

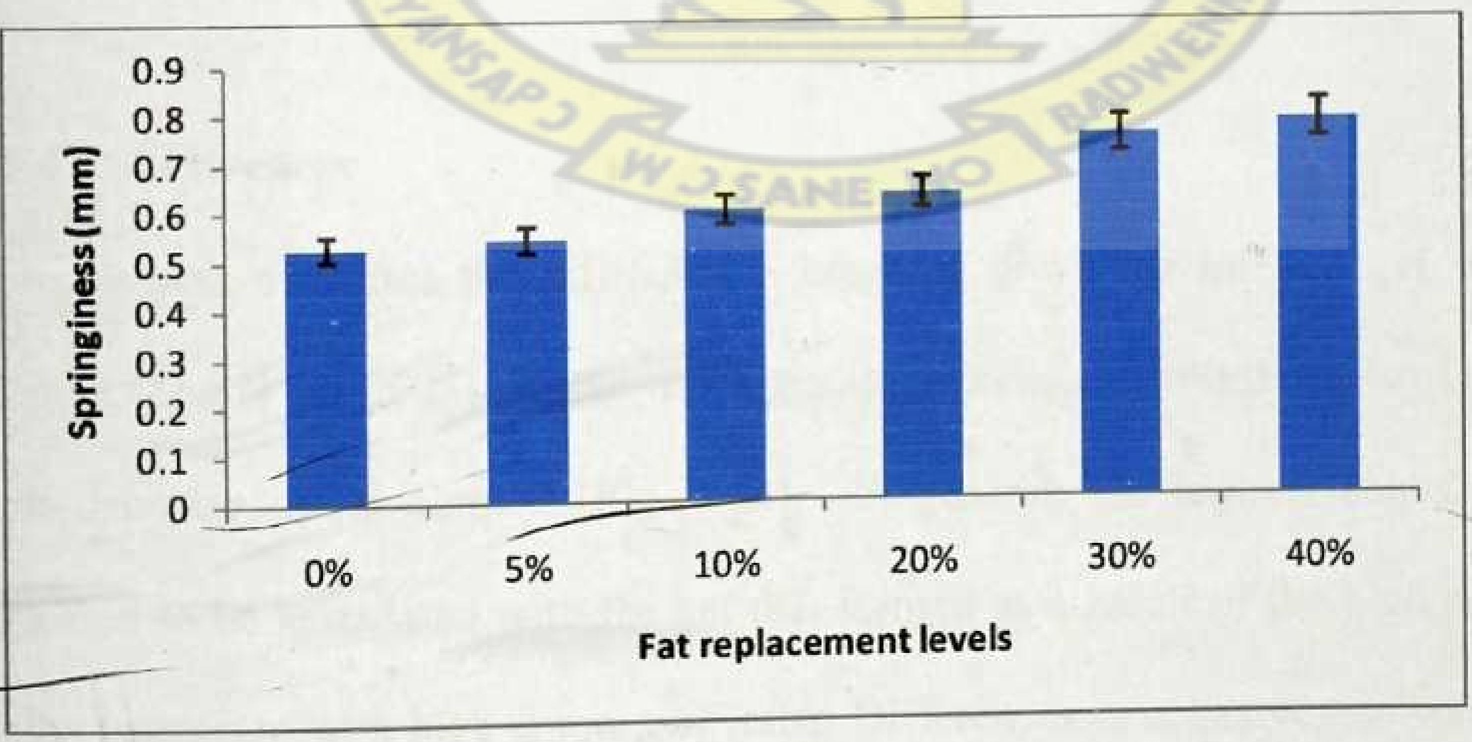


Furthermore, no significant difference ($p \geq 0.05$) was found to exist between products C (10%) and D (20%). Product A (control) had the highest value for fracturability (1072.6 N) and product F (40%) had the least value of 395 N. This is an indication that the ability of the product to fracture or disintegrate reduced as the content of fat was reduced. Ahmad *et al.* (2010) reported decrease in fracturability on the study of profile analysis of cake supplemented with soy flour.

4.5.3 Springiness

Springiness is sometimes referred to as elasticity and it is a measure of how much a product's structure is broken down by the initial compression (Lau *et al.*, 2000). High springiness is as a result of breaking the structure into few large pieces during the first Texture Profile Analysis compression whereas low springiness is when the structure is broken down into very small pieces (Lau *et al.*, 2000). Results showed an increase in springiness as the fat replacer was increased (Fig. 4.13). Springiness was found to be highest in product F with 40 % fat replacement and lowest in product A (control) with 0 % fat replacement.

Fig. 4.13- Springiness of pie crust with different fat replacement levels



This observation could be due to the formation of a gluten network which produces elasticity in the dough and the resultant baked product in the absence of sufficient shortening. Product A (0 %) had a value of 0.5259 mm and product F (40 %), a value of 0.7812 mm. No significant difference ($p \geq 0.05$) was observed between products A (0 %) and B (5 %) as well as between products C (10 %) and D (20 %). The degree of springiness increased in the order A< B < C < D < E < F which implied product F (40 %) was more elastic while product A (0 %) was more plastic, that is, cannot return to original structure after deformation. Dadkhah *et al.* (2012) reported an increase in springiness with increase in nutrim oat bran when studies were conducted on the effect of shortening replacement with nutrim oat bran on chemical and physical properties of shortened cakes. Lee *et al.* (2004) presented their own hypothesis as to the reasons for the increased springiness in a fat replaced product. It was proposed that as a result of an increase in Nutrim oat bran shortening replacement, cake's elastic behavior is increased at temperatures over 120 °C. In this research, the temperature used was 140 °C and therefore a similar result was expected.

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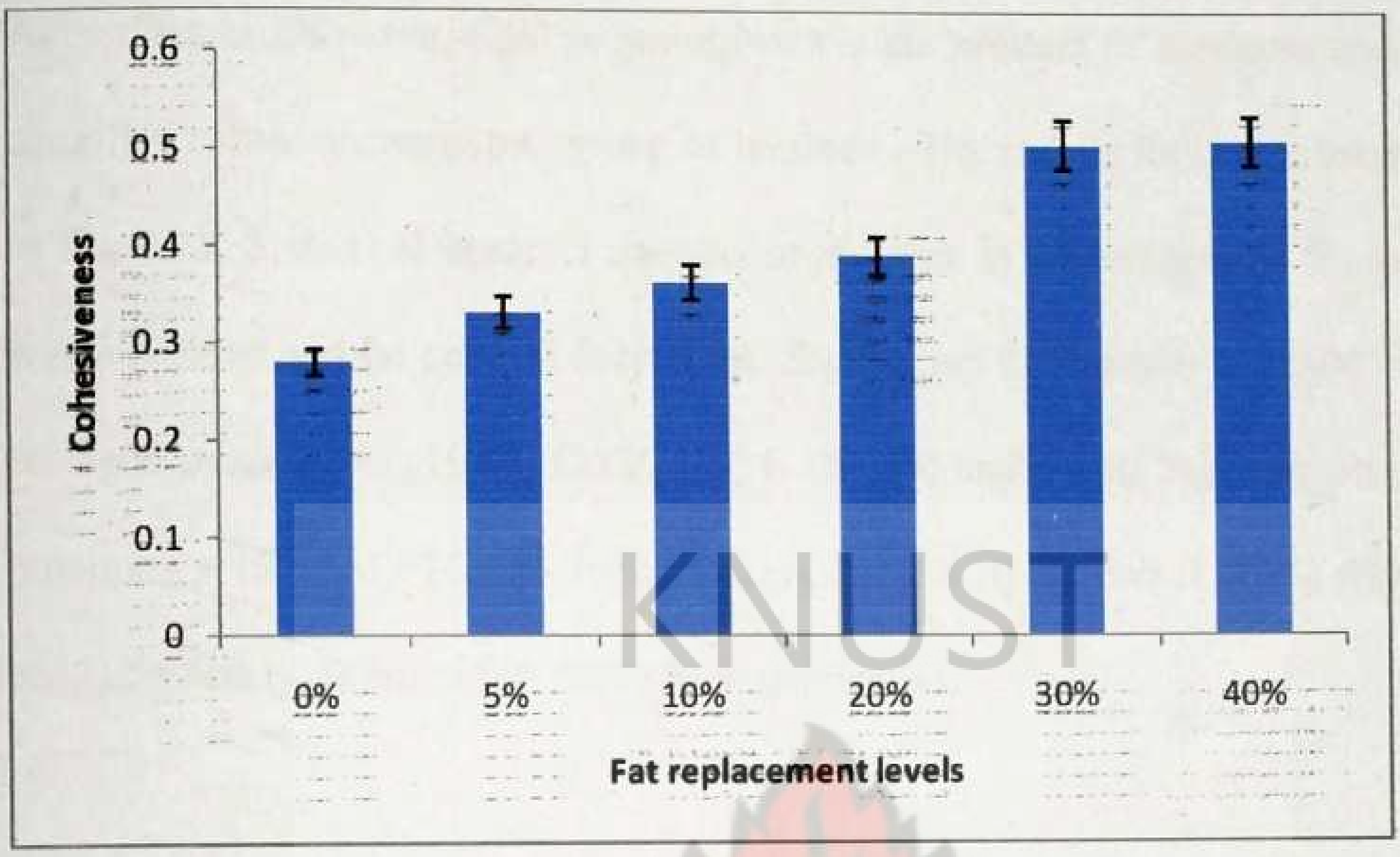
4.5.4 Cohesiveness

Cohesiveness measures the difficulty in breaking down the internal gel structure of a product (Zhu *et al.*, 2008). There was a gradual increase in cohesiveness of the pie crusts with decrease in fat content (Fig. 4.14). In general, the highest cohesiveness value appeared to be associated with the gel that formed as a result of the high pectin content which interacted with high amount of water. Differences in cohesiveness were significant among all the six products.

Fig. 4.14- Cohesiveness of pie crust with different fat replacement levels



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Product F (40 %) had the highest value of 0.5097 for cohesiveness and product A (0 %), the lowest value of 0.2793. The trend in cohesiveness was in the order F> E > D > C > B > A. Maache-Rezzoug *et al.* (1998) stated that when flour is mixed with fat before the addition of liquid for hydration, the fat prevents the formation of tough gluten network and produces less cohesive dough leading to a less cohesive product. So that reducing the fat results in a much cohesive product. There is also the formation of gel in the product since pectin in the fat replacer absorbs moisture to form gel. Therefore high energy was required to break the gel structure in products with high levels of replacement. Oreopoulou (2006) reported higher values for cohesiveness of cakes prepared with fat mimetic (Poly dextrose, Pectin, Inulin, C*delight, Dairytrim and Simplesse), than for full fat products.

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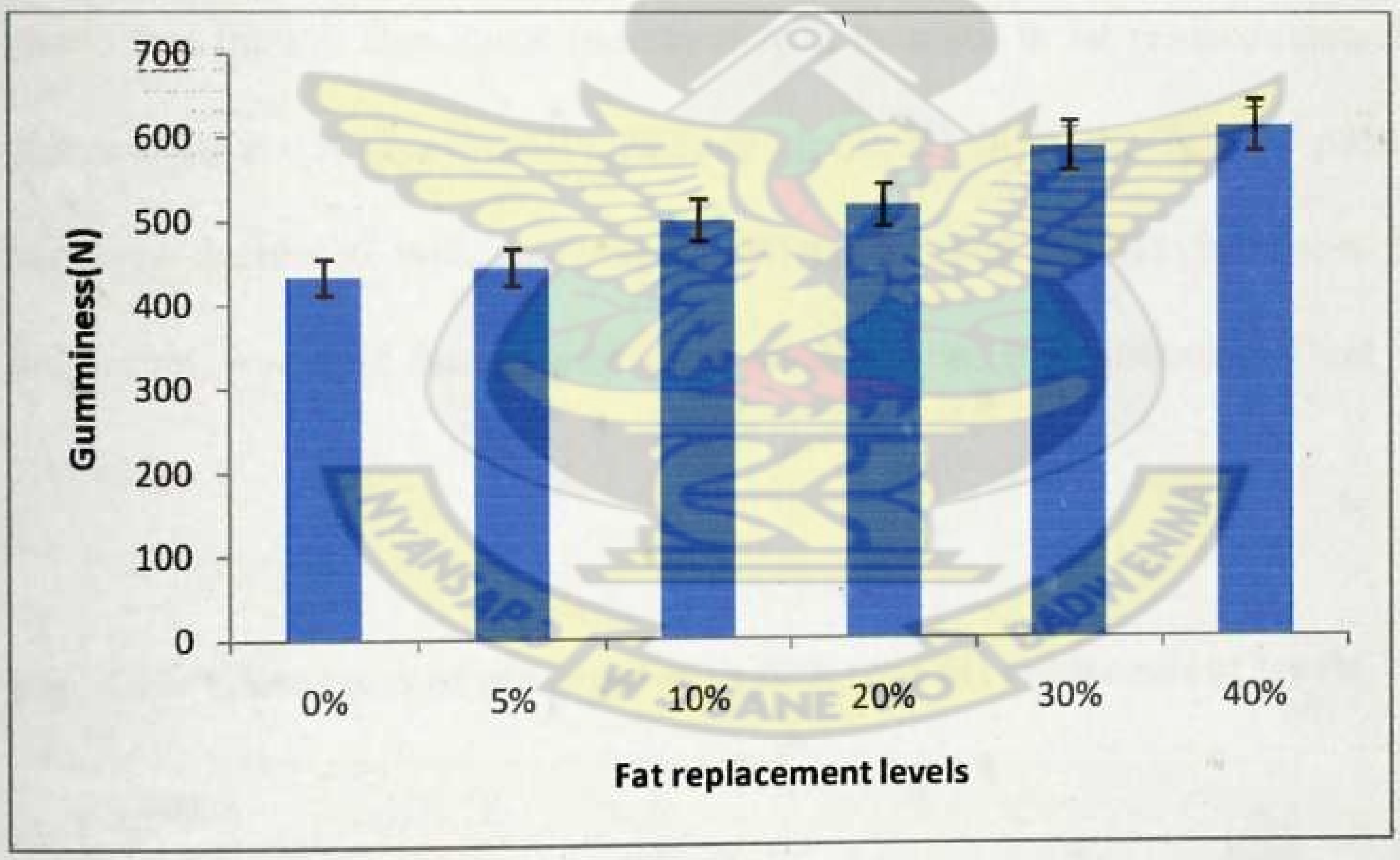
4.5.5 Gumminess

According to Zhu *et al.* (2008), gumminess is the product of hardness and cohesiveness, usually a complementary parameter of hardness. The results for gumminess are presented in Fig 4.15. Statistical analysis showed an increase in gumminess as the fat replacement was increased and fat content decreased. Significant differences ($p \leq 0.05$) were observed between products C (10%), D (20 %), E (30 %) and F (40 %) with product F (40 %) obtaining a value of 616.4 N. However, products A (0 %) and B (5 %) were found not to be significantly different ($p \geq 0.05$) from each other.

Fig. 4.15- Gumminess of pie crust with different fat replacement levels

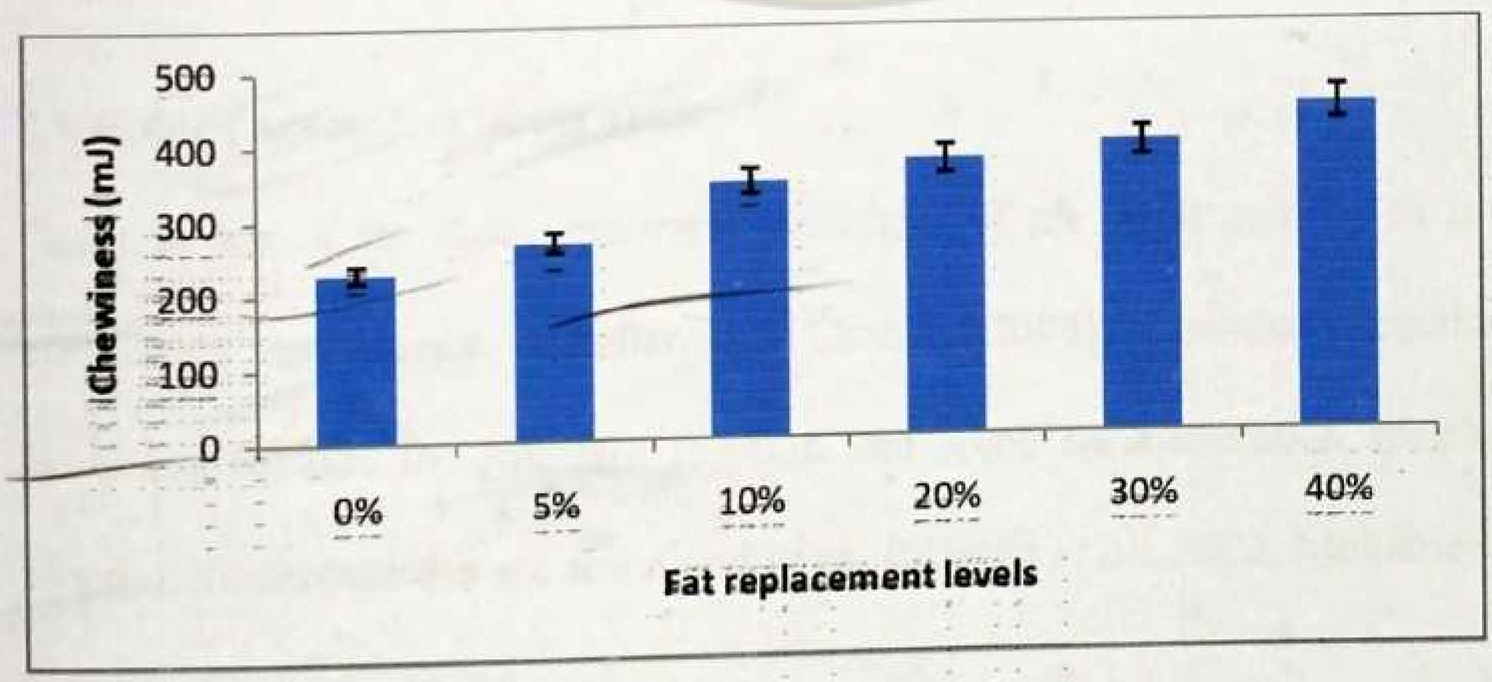


The increase in gumminess with increase in fat replacement could be due to the fact that the pectin absorbed water to form the gel-like structures in the product. Gum is desirable to some extent in baked products as it minimizes unnecessary fracturing of products especially during transportation.

4.5.6 Chewiness

Chewiness is the energy required to masticate a solid food to the point required for swallowing. With regards to chewiness, (Fig 4.16), significant differences ($p \leq 0.05$) were observed as the fat content was reduced and fat replacer increased. The results showed no significant difference ($p \geq 0.05$) between products C (10 %) and D (20 %). Furthermore, no significant differences ($p \geq 0.05$) were observed between D (20 %) and E (30 %). Product F (40 %) was the least chewy (difficult to chew) with a value of 446.1 mJ. Therefore, it seems that the greater the replacement percentage the greater the chewing force required. Chysirichote *et al.* (2011) reported an increase in chewiness in the crust of flaky Chinese pastry using inulin and maltodextrin (DE 10) as fat replacers. It was further stated that though chewiness increased with increase in fat replacement, the reduced fat pastries were not significantly different ($p \geq 0.05$) from the full fat product. Although hardness decreased with increase in fat replacement levels, chewiness increased with increasing levels of fat replacer as a result of the high amount of gel formed in the products.

Fig. 4.16- Chewiness of pie crust with different fat replacement levels



4.5.7 Resilience

Results for resilience showed no significant differences ($p \geq 0.05$) among products B (5 %), C (10 %) and D (20 %) however product A (0%) was significantly different from all the products (Fig.4.17). Furthermore, no significant difference ($p \geq 0.05$) was observed between products E (30 %) and F (40 %). Paintsil (2009) reported an increase in resilience of rock cakes with increasing levels of fat replacement and further stated that increase in resilience could be attributed to the decrease in fat content in the products.

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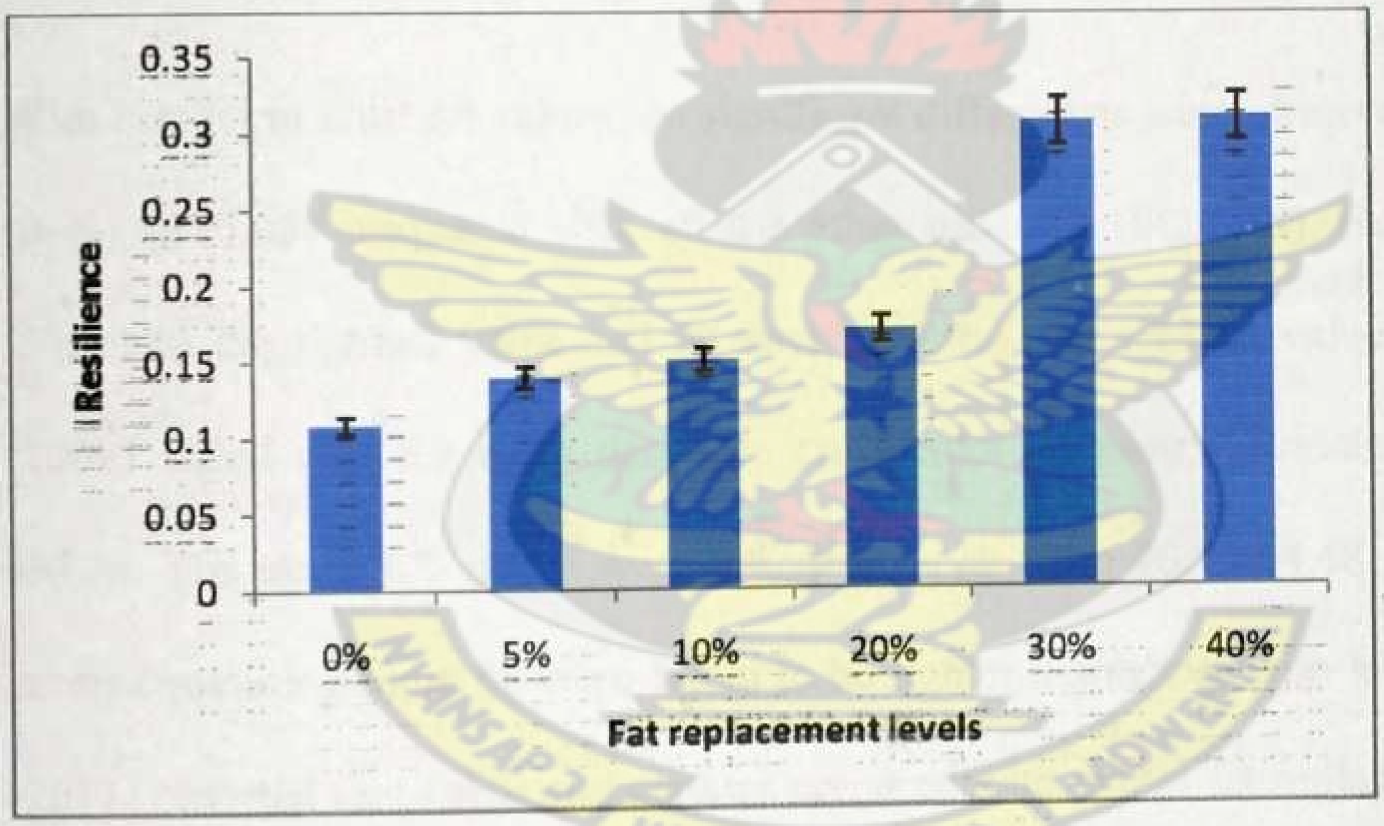
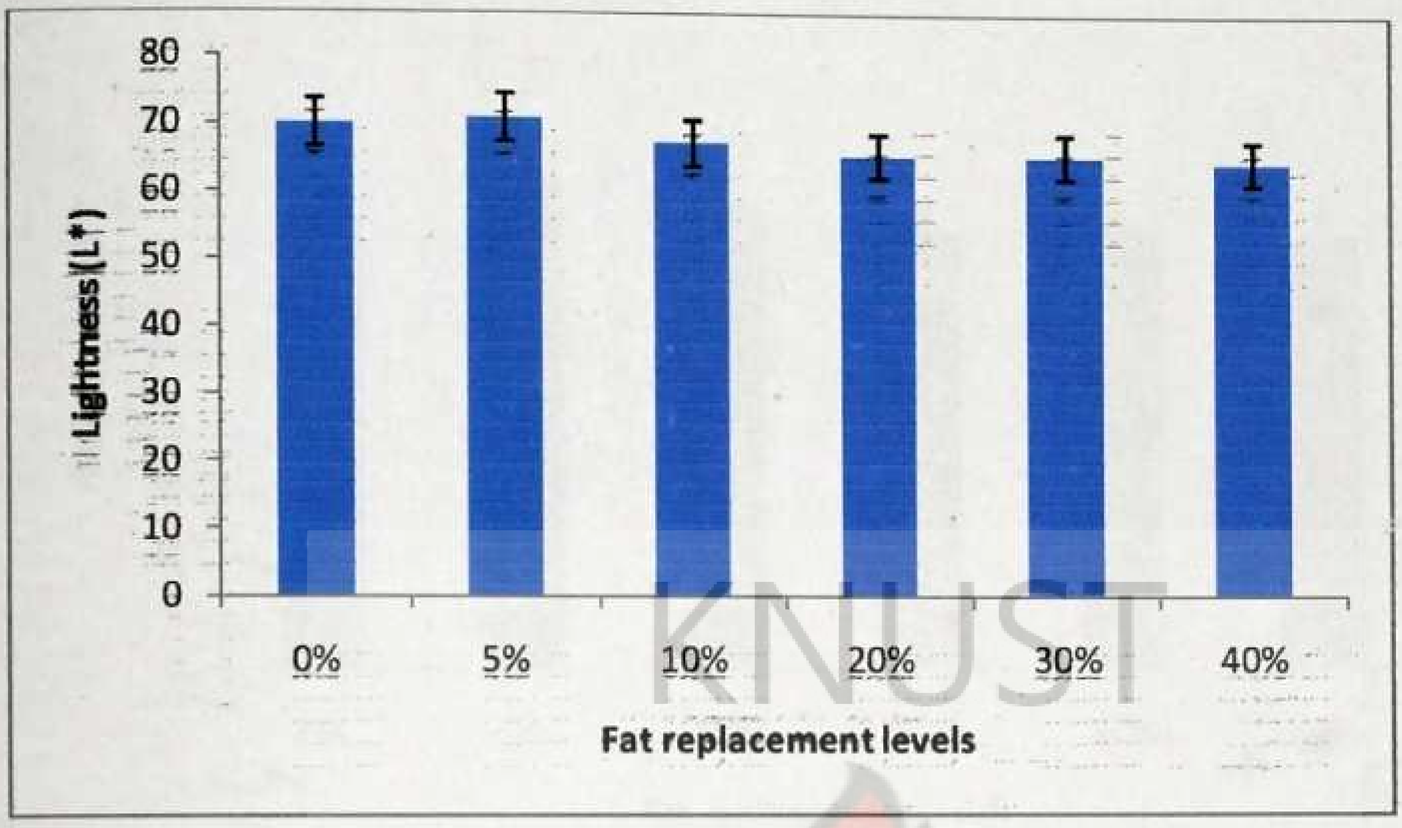
Fig. 4.17- Resilience of pie crust with different fat replacement levels



4.6 Color parameters of pie crust

Color is one of the most important indicators of pie crust quality, as it contributes to consumers' preference (Esteller and Lannes, 2008). Chemical reactions that cause browning include the Maillard reaction and some caramelization which occur mostly when monosaccharides are contained in pie (Gomez *et al.*, 2003; Mohamed *et al.*, 2008).

Fig. 4.18- L* values of pie crusts



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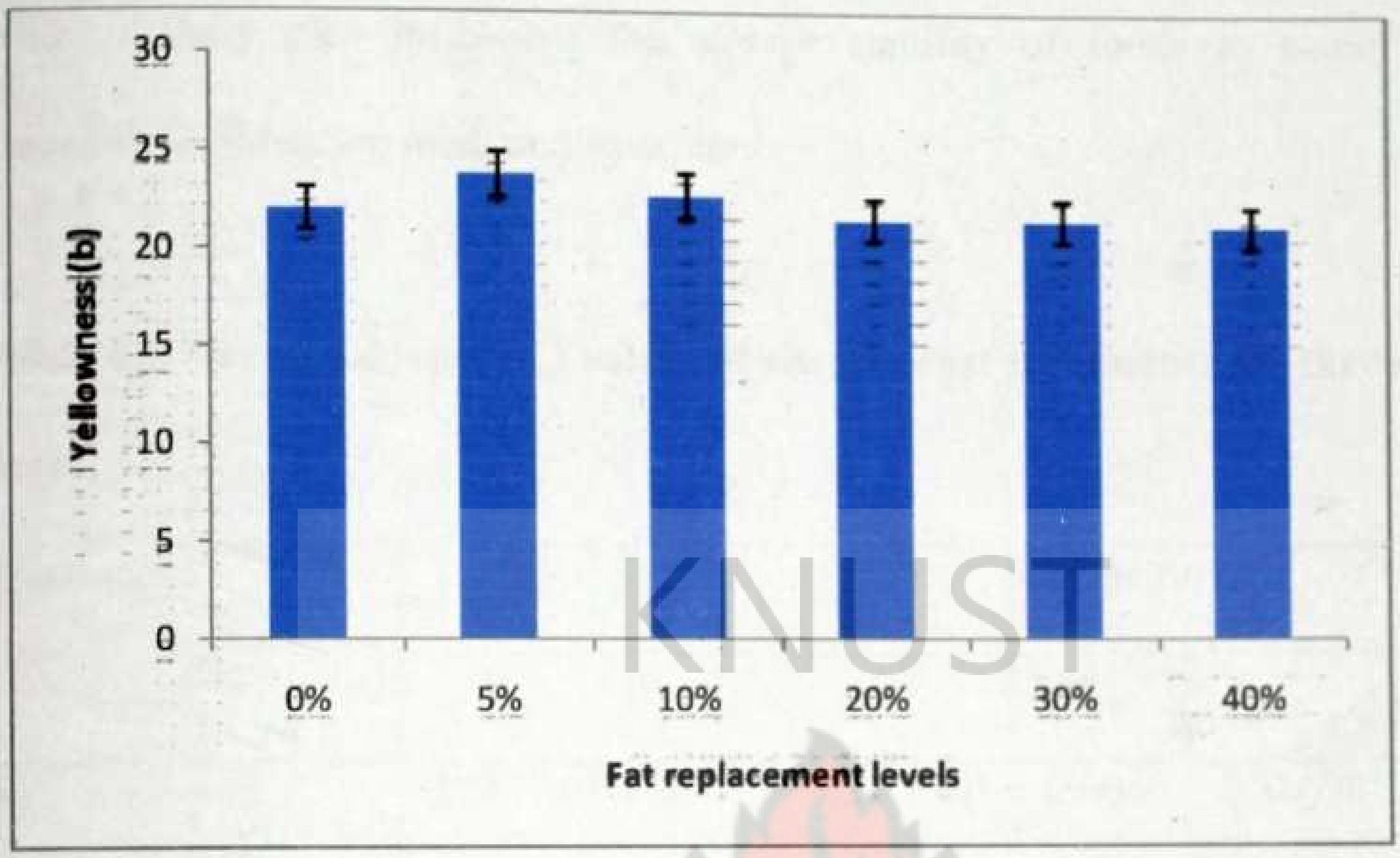
With respect to crust *L** values, no significant differences were observed when product A (0 %) ($P \geq 0.05$) compared with all the other products (Fig.4.18). However, product B (5%) had the lightest value and product F (40%), the darkest value (64.48). Yi *et al.* (2009) stated that the most desirable crust color of pastry (bread) should be golden brown. The mean L* values were found to range from 70.99-64.48. Generally, the pie crusts containing more fat were found to be lighter than those with less fat. Wafaa *et al.* (2011) reported that cakes and cookies prepared with pectin fat replacer decreased in L* value with increasing levels of fat replacement. It was however reported that, L* values for 25, 50 and 75% substitution were higher than that of the control.

Fig. 4.19- b* values of pie crusts



Yellowness, b*, values decreased with increasing levels of lemon peel fat replacer. Significant differences ($p \leq 0.05$) in yellowness were observed among the six products. Yellowness values of the crust were in the order: B > C> A > D > E > F (Fig.4.19). Yellowness in the crusts of product B (5 %) was significantly different ($p \leq 0.05$) from the rest of the products except A (0%) and C (10%). However, products A (0 %), C (10 %), D (20 %), E (30%) and F (40%) were not significantly different ($p \geq 0.05$) from each other. Wafaa *et al.* (2011) reported that cakes and cookies prepared with pectin fat replacer decreased in b* value with increasing levels of fat replacement. However, b* values for 25, 50 and 75% substitution were higher than that of the control.

4.7 Water activity

Water is a component of all foods that contributes to physical differences among food and the changes that food undergoes (Penfield and Campbell, 1990 c). Water activity, a_w, is a physical property that has a direct implication for microbiological safety of food. Water activity also influences the storage stability of foods as some deteriorative processes in foods are mediated by water.

Table 4.2- Water activity (a_w) values of six pie crust treatments for three storage times

Treatment	Storage time		
	1 hr	24 hr	72 hr
A	$0.741^{a} \pm 0.006$	$0.699^{a} \pm 0.006$	$0.698^{a} \pm 0.006$
B	$0.742^{a} \pm 0.008$	$0.685^{b} \pm 0.006$	$0.688^{b} \pm 0.007$
C	$0.771^{b} \pm 0.006$	$0.693^{a} \pm 0.006$	$0.689^{b} \pm 0.006$
D	$0.782^{c} \pm 0.006$	$0.703^{c} \pm 0.006$	$0.700^{c} \pm 0.006$
E	$0.788^{c} \pm 0.006$	$0.781^{d} \pm 0.006$	$0.768^{d} \pm 0.006$
F	$0.786^{c} \pm 0.006$	$0.782^{d} \pm 0.006$	$0.723^{e} \pm 0.006$

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Values with like letters indicate no significant difference ($p \geq 0.05$).

A = 0 % fat- replacement B = 5% fat -replacement

C = 10% fat- replacement D = 20% fat- replacement

E = 30% fat- replacement F =40% fat- replacement

Analysis indicated that the treatment and storage time interaction for a_w (Fig.4.20) was significant ($P \leq 0.05$). For 1 hour of storage, there was no significant difference ($P \geq 0.05$) between products A (0 %) and B (5 %) in their water activity values. In general, the water activity increased with increasing levels of fat replacement. Furthermore, the water activity of both the reduced fat pie crusts and the full fat pie crust were found to be lower than 0.9.

For 24 hrs of storage, no significant difference ($P \geq 0.05$) was observed among products A (0 %) and C (10 %) however significant difference ware observed when product A (0%) was compared with B (5%), D (20%), E (30%) and F (40%) (Fig.4.21). Although the water activity of most of the products reduced during storage, the reduction in water activity of products C (10 %) and D (20 %) was significant ($p \leq 0.05$).

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For 72 hrs of storage, no significant difference ($P \geq 0.05$) occurred between products B (5 %) and C (10%) however product A (0%) was found to be significantly different ($p \leq 0.05$) from the rest of the products. Product A (0 %) had water activity (a_w) value of 0.698 and F (40 %), a value of 0.723 (Fig.4.22). Water activity values for all the three storage times were below 0.8 which indicated that moulds and yeast that are normally found on products having a_w values from 0.88 to 0.98 cannot grow on the pie crust for these storage times. This could be explained that the pectin was able to bind water strongly and therefore there will be reduction in microbial growth. The reduced-fat pie crusts had a higher water activity ($p \leq 0.05$) for almost all the storage times than the control. This result was similar to studies conducted by Woods and Navder (2006) who used fiber (C–TRIM) as a fat replacer in chocolate chip cookies and Power *et al.* (2007) who also used pureed soy beans (tofu) as a fat replacer in short cake. In both studies, it was indicated that the addition of fat replacers increased the water activity of the reduced-fat products and could be due to the higher number of hydroxyl groups in the fat replacer which interact with water through hydrogen bonding.

CHAPTER FIVE

5.0 Conclusion

The lemon peel had higher amount of dietary fiber (14 %), while it had low contents of moisture (4.59 %), fat (0.08 %), ash (2.12 %) and protein (1.5 %). It also had high water holding capacity (86 %) and showed a high level of pectin content (21.26 %) which attests to its ability to be used as a fat replacer.

Sensory evaluation showed that, addition of lemon peel at different levels (0, 5 %, 10 %, 20 %, 30 % and 40 %) affected most of the attributes. Pie crusts prepared with 0 % and 5 % lemon peel fat replacer had the highest level of acceptance for all sensory attributes and no significant difference ($p \geq 0.05$) existed between the two products (A and B). However, 10 % replacement could also be recommended since it was rated as being fairly satisfactory.

For texture Profile Analysis (TPA), it was observed that hardness and fracturability decreased with increased in the level of fat replacement. However, springiness, cohesiveness, gumminess, chewiness and resilience increased with increased in lemon peel fat replacer. All the TPA characteristics of products A (control) were statistically higher than products containing fat replacer. The results indicated no significant difference ($p \geq 0.05$) between products A (0 %) and B (5 %) for all TPA values.

In particular, pie crust made with high levels of lemon peel fat replacer turned out dark in color while those with less fat replacer were lighter. The fat mimetic made from lemon peel could be used as an excellent replacement for fat if the bitterness is reduced or even removed. The nutrient composition of lemon peel gives it a high potential for use as a fat replacer.

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5.1 Recommendations

It is recommended for future research that:

1. The bitter principle which is limonin be masked or removed from the replacer to improve its use in food products.
2. Research is undertaken to determine the degree of esterification in the fibre of the lemon peel fat replacer to know the gelation properties.
3. Lemon peels fat replacer is used in other food products such as jam.

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APPENDIX

APPENDIX 1 – FORMULAE USED FOR CALCULATIONS

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a) $\% \text{ Moisture} = \frac{W_2 - W_3 \times 100}{W_2 - W_1}$

Where: W_1 = Weight of crucible, W_2 = Weight of crucible + Sample,

W_3 = Weight of crucible + Dry sample

b) $\% \text{ Ash} = \frac{W_3 - W_1 \times 100}{W_2 - W_1}$

Where: W_1 = Weight of porcelain crucible, W_2 = Weight of porcelain crucible + Food Sample,

W_3 = Weight of porcelain crucible + Ash

c) $\% \text{ Total nitrogen } (\% N) = \frac{X \text{ moles} \times (V_s - V_b)\text{ cm}^3 \times 14 \text{ g} \times 100}{1000 \text{ cm}^3 \quad \text{mg} \quad \text{moles}}$

$\% \text{ Protein} = \% N \times 6.25$

Where: mg = Mass of sample

X = Normality of acid, HCl

Vs = Titration value of sample

V_b = titration value of blank

6.25 = Protein conversion factor

d) $\% \text{ Fat} = \frac{W_2 - W_1 \times 100}{W_3}$

Where: W1 = Weight of empty flask

W2 = Weight of flask + fat

W3 = Weight of food sample taken

e) % Fibre = $\frac{\text{Weight of fibre obtained} \times 100}{\text{Dry weight of sample}}$

f) Total dietary fibre = weight of residue – weight (protein + ash)

Determination of blank:

B = blank, mg = weight of residue – P_B - A_B

Where: weight of residue = average residue weights (mg) for duplicate blank determinations

P_B and A_B = weights (mg) of protein and ash, respectively, determined in first and second blank residues.

Total Dietary Fibre (TDF) is calculated as follows:

TDF % = [(weight of residue – P- A – B)/weight of sample] × 100

Where: Weight of residue = average of weights (mg) for duplicate sample determinations

P and A = weights (mg) of protein and ash, respectively, in first and second sample residues; and weight of sample = average of two (2) sample weights taken (mg).

g) Water holding capacity = $\frac{\text{Mass of dry sample} \times 100\ \%}{\text{Mass of centrifuged sample}}$

h) % pectin = $\frac{\text{Final mass of sample}}{\text{Initial mass of sample}} \times 100\ \%$

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APPENDIX 2

ANOVA FOR PERCENT MOISTURE AND FAT CONTENTS OF PIE CRUST TREATMENTS

Parameter	Source of Variation	Df	Sum of Squares	Mean Square	F-ratio	p-value
Moisture						
	Treatments	5	359.906	71.981	168.59	0.000
	Within group	6	2.562	0.427		
	Total (corr)	11	362.467			
Fat						
	Treatments	5	241.711	48.342	285.75	0.000
	Within group	6	1.015	0.169		
	Total	11	242.726			

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APPENDIX 3

QUESTIONNAIRE FOR SENSORY EVALUATION OF PIE CRUST TREATMENTS

Acceptability Test of pie

Name...................................... Date.....................

Product....................................

Sample code................................

Please before you are samples of pie. Using the scale below, please examine it in terms of Appearance, Colour, Aroma, Taste, Texture, Mouthfeel and Overall acceptability.

Scale	Interpretation	Appearance	Colour	Aroma	Taste	Chewiness	Gumminess	Mouthfeel	Overall Acceptability
9	Like Extremely								
8	Like Very Much								

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7	Like Moderately								
6	Like Slightly								
5	Neither like or dislike								
4	Dislike Slightly								
3	Dislike Moderately								
2	Dislike Very Much								
1	Dislike Extremely								

Comments:...

....

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APPENDIX 4:

ANOVA TABLE FOR TREATMENT EFFECTS ON CIE L*, a*, b* COLOUR PARAMETERS OF PIE CRUST

Lightness						
	Treatments	5	169.892	33.978	55.23	0
	Within group	24	14.765	0.615		
	Total (corr)	29	184.657			
Yellowness						
	Treatments	5	22.916	4.583	13.88	0
	Within group	24	7.926	0.33		
	Total (corr)	29	30.842			

Lightness						
	Treatments	5	169.892	33.978	55.23	0
	Within group	24	14.765	0.615		
	Total (corr)	29	184.657			
Yellowness						
	Treatments	5	22.916	4.583	13.88	0
	Within group	24	7.926	0.33		
	Total (corr)	29	30.842			

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APPENDIX 5:

ANOVA TABLE FOR SENSORY PARAMETERS OF PIE CRUST TREATMENTS

Parameter	Source of Variation	Df	Sum of Squares	Mean Square	F-ratio	p-value
Appearance						
	Treatments	5	348.617	69.723	91.39	0
	Within group	294	224.3	0.763		
	Total (corr)	299	572.917			
Color						
	Treatments	5	396.707	79.341	80.73	0
	Within group	294	288.96	0.983		
	Total (corr)	299	685.667			
Aroma						
	Treatments	5	191.977	38.395	48.78	0
	Within group	294	231.42	0.787		
	Total (corr)	299	423.397			
Taste						
	Treatments	5	1521.31	304.262	625.81	0
	Within group	294	142.94	0.486		
	Total (corr)	299	1664.25			

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Chewiness						
	Treatments	5	808.4	161.68	193.45	0
	Within group	294	245.72	0.836		
	Total (corr)	299	1054.12			
Gumminess						
	Treatments	5	799.267	159.853	199.65	0
	Within group	294	235.4			
	Total (corr)	299	1034.667			
Mouth feel						
	Treatments	5	1179.387	235.877	302.04	0
	Within group	294	229.6	0.781		
	Total (corr)	299	1408.987			
Overall acceptability						
	Treatments	5	1674.827	334.965	572.82	0
	Within group	294	171.92	0.585		
	Total (corr)	299	1846.747			

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APPENDIX 6:

ANOVA TABLE FOR TEXTURE PROFILE ANALYSIS OF PIE CRUST TREATMENTS

Parameter	Source of Variation	Df	Sum of Squares	Mean Square	F-ratio	p-value
Hardness						
	Treatments	5	4914314	982863	17.87	0
	Within group	54	2969629	54993		
	Total (corr)	59	7883944			
Fracturability						
	Treatments	5	3513076	702615	21.61	0
	Within group	54	1755712	32513		
	Total (corr)	59	5268788			
Springiness						
	Treatments	5	0.56969	0.11394	108.06	0
	Within group	54	0.05694	0.00105		
	Total (corr)	59	0.62663			
Cohesiveness						
	Treatments	5	0.43951	0.0879	75.84	0

	Within group	54	0.06259	0.00116		
	Total (corr)	59	0.5021			
Gumminess						
	Treatments	5	276596	55319	11.83	0
	Within group	54	252476	4675		
	Total (corr)	59	529073			
Chewiness						
	Treatments	5	270090	54018	25.01	0
	Within group	54	116620	2160		
	Total (corr)	59	386710			
Resilience						
	Treatments	5	0.391521	0.078304	162.85	0
	Within group	54	0.025965	0.000481		
	Total (corr)	59	0.417486			

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