EFFECT OF PROCESSING VARIABLES ON SOME QUALITY ATTRIBUTES OF AIR-FRIED CHICKEN NUGGETS FROM FUNAAB INDIGENOUS BROILERS

BY

AYOOLA, GRACE TEMITOPE (PG 15/0327)

B.Sc (Hons) (Bowen)

A DISSERTATION SUBMITTED TO FOOD PROCESSING AND VALUE ADDITION PROGRAMME, CENTRE FOR EXCELLENCE IN AGRICULTURAL DEVELOPMENT AND SUSTAINABLE ENVIROMENT FEDERAL UNIVERSITY OF AGRICULTURE, ABEOKUTA.

OCTOBER 2018

DECLARATION

I hereby declare that this Dissertation was written by me and it is a correct record of my own research work. It has not been presented in any previous application for any degree of this or any other University. All citations and sources of information are clearly acknowledged by means of references.

....

AYOOLA, GRACE TEMITOPE

Date: ....

CERTIFICATION

We certify that this Dissertation entitled “Effect of processing variables on some quality attributes of air fried chicken nuggets from FUNAAB Indigenous Broilers” is the outcome of the research carried out by G.T. AYOOLA, in the programme of Food Processing and Value Addition, centre for excellence in agricultural development and sustainable environment, Federal University of Agriculture, Abeokuta.

.... ………………………

Dr. O.P. Sobukola Date

(Major supervisor)

....

Prof. T.A Shittu Date

(Co-supervisor)

....

Dr. (Mrs) K. Sanwo Date

(Co-supervisor)

....

Prof. T.A Shittu Date

(Programme Leader)

....

Prof. O.D Akinyemi Date

(Director, CEADESE)

ABSTRACT

Traditional deep fat frying technology usually results in high fat based products which are not compatible with recent consumers demand. Hence, this study aimed at optimizing the processing conditions of air fried chicken nuggets from FUNAAB Indigenous broilers (FIB). Central composite design was used to investigate the effects of frying temperature (FT; 155-175 ^{0}C), and frying time (Ft; 10-30 mins) on some quality attributes of chicken nuggets from FIB. Thirteen experimental runs were applied. The quality attributes of fried chicken nuggets which include oil, and moisture content, redness, yellowness and lightness were determined using standard laboratory procedures. Textural attributes such as hardness (N), cohesiveness, springiness, stringiness (mm), chewiness (N), adhesiveness (N.s) and gumminess (N) were also determined. Numerical optimization technique was used to obtain the optimum processing conditions of air-fried chicken nuggets from FIB. The sensory acceptability of the optimized air-fried chicken nuggets was compared with optimized deep fat fried chicken nuggets using thirty untrained panellists. Data were analysed using response surface methodology. The mean values of oil and moisture contents, lightness, redness, and yellowness were in the range 8.05-15.31%, 56.03-69.44%, 34.77-68.60, 14.03-27.87, and 26.87-55.98, respectively. Also, adhesiveness, chewiness, cohesiveness, and gumminess had values of 2.31-9.06 N.s, 14.43-45.31 N, 0.58-0.74 mm, and 23.28-58.39 N, while hardness, springiness and stringiness ranged between 42.49-89.47 N, 0.44-0.84 mm, and 3.67-9.26 mm, respectively. The regression coefficient of determination (R^2) of the quadratic models ranged between 0.32 and 0.87. Frying time (main effect) and frying temperature (quadratic effect) had a negative significant ($p<0.05$) effect on moisture content of air-fried chicken nuggets. Oil content decreased with increase in frying time and frying temperature. The quadratic effect of frying time was significant

($p<0.05$) on the lightness parameter of air-fried chicken nuggets. The effect of frying time was significant ($p<0.05$) on redness. Frying time significantly ($p<0.05$) affected yellowness negatively. No significant ($p<0.05$) effect of process variables on Hardness, adhesiveness, cohesiveness, gumminess and chewiness, were observed. However, springiness and stringiness were significantly ($p<0.05$) affected by frying time. The FT of 155 ^{0}C, and Ft of 10 min was obtained as the optimum processing conditions. Sensory assessment of optimized air-fried and deep fat fried chicken nuggets revealed that for all the sensory attributes investigated, there was no significant ($p>0.05$) difference in taste, texture and aroma. However, significant ($p<0.05$) differences were observed in appearance, texture and overall acceptance of optimized air-fried and deep fat fried chicken nuggets. This research concluded that, air frying of chicken nuggets could be an alternative method in producing healthier and acceptable fried chicken nuggets.

DEDICATION

This book is dedicated to the Almighty God who has been faithful to me throughout the period of this project and my parents Rev and Rev (mrs) S.A. AYOOLA, and siblings Mrs Adegbite, Miss Mercy Temiloluwa, and Miss Deborah Toluwanimi AYOOLA.

ACKNOWLEDGEMENTS

I am immensely thankful to the Almighty God, the creator and preserver of all, my source, strength, provider and support. Special thanks to my supervisor, Dr. O.P. Sobukola for his support, patience and guidance towards the completion of this research work. I pray God will bless him abundantly. I am also grateful to my co-supervisors: Prof T.A. Shittu and Dr. (Mrs). K. Sanwo for their contributions and time. My profound appreciation and gratitude goes to my parents, Rev S.A and (Mrs) Ayoola, without whose support this research work would have been impossible. I pray the Almighty will bless and keep them in His mercies. My appreciation also goes to Dr. (Mrs) Kajihausa, and Mrs Omidiran, Dr A.A Adebowale, Dr A.O Obadina of the Department of Food Science and Technology, Federal University of Agriculture, Abeokuta. My special thanks to my siblings Mrs Rhoda Adegbite and her husband, Temiloluwa and Toluwani for their love and support. To my friends and colleagues, Faloye opeyemi, Ayandipe Dorcas, Adesina Boluwatife, and all Dr Sobukola's undergraduate students; may God bless you all abundantly.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER ONE

1.0 INTRODUCTION

Chicken comprises the major constituent of poultry species in Africa. Despite the wide spread of exotic strains, local chickens are known to be predominant in developing countries (Bett *et al.*, 2012). They play an important role in the economic development of rural communities and they are known to be relatively resistant to some infectious diseases, good converters of poor quality feeds and have products that are preferred by consumers (Mengesha, 2012). FUNAAB -Indigenous broilers are a crossbreed chicken between improved indigenous chicken and exotic species with improved reproductive performance, increased average bird size, egg fertility; hatchability and survivability (Peters, 2000). Chicken can be processed into different forms such as fried chicken, chicken sticks, chicken sausages, chicken burgers, chicken meat balls, butters chicken, and chicken nuggets.

Fried food is very common and generally acceptable worldwide. Battered and breaded foods represent a fast-growing category in most high-convenience consumer societies such as the United States (Shukla, 1993). The trend of using batter and breading on chicken has increased remarkably since the 1980s, and such products constitute the largest segment of the further-processed poultry market (Parinyasiri and Chen, 1992). Chicken nuggets are one of the most popular types of breaded food products. They are a restructured meat product coated with a batter-breading layer that acts as a barrier to moisture loss, as well as oil uptake in addition to carrying spices and other ingredients for flavour enhancement. Chicken meat is usually the main composition of nuggets, fish or combination with vegetable protein and gum could also be used.

Frying is essentially a dehydration process involving rapid heat and mass transfer in food immersed in hot oil, which leads to a succession of physical and chemical changes in the product (Tarmizi and Ismail, 2008; Andrés-Bello *et al.*, 2011; Dueik *et al.*, 2010). It is extensively employed in domestic as well as industrial practice, due to its ability to create unique sensory properties, including texture, flavour and appearance, which make the food more tasty and desirable (Dana and Saguy, 2006). Furthermore, its operational simplicity in the context of commercial practice, convenience, and economic viability, has resulted in extensive sales of a large variety of fried products (Mehta and Swinburn 2001). Despite many studies correlating fried product consumption with increased health risks (Krokida *et al.*, 2001; Mariscal and Bouchon, 2008), and increasing consumer awareness of this relationship (Mariscal and Bouchon, 2008), there is no sign to suggest that consumers will give up eating fried products (Dana and Saguy, 2006; Tarmizi and Ismail, 2008; Sayon-Orea *et al.*, 2014). These issues have prompted the fried product industry to search for ways and means to produce healthier products without compromising on the desirable appearance, texture, flavour and taste attributes (Garayo and Moreira, 2002; Fan *et al.*, 2005; Da Silva and Moreira 2008; Mariscal and Bouchon, 2008; Andrés-Bello *et al.*, 2011; Andrés *et al.*, 2013). One such process is hot air frying, which aims to produce a "fried product" by sparging, essentially, hot air around the material instead of immersing it in hot oil. Hot-air frying is a novel method consisting of frying food with a small amount of oil dispersed in a stream of hot air as external fluid. The product is constantly moved in the air-frying chamber to favour the mass and heat transfer between the product and the external fluid. Air is also distributed more uniformly through the product, which minimizes variations in product quality. The product gets dehydrated in the process and a crust, typically associated with frying, gradually appears on the product. Oil application could be done before or during the process to lightly coat the food product, in order to provide the taste, texture and appearance typical of fried products. The amount of oil used is significantly lower than in deep oil frying giving, as a result, very low fat products (Andrés *et al.,* 2013).

Food process optimization helps to obtain the suitable processing conditions in products with acceptable quality attributes (Sobukola *et al.,* 2008). Response surface methodology (RSM) is a collection of statistical and mathematical techniques use in new product development, improve new products, and optimizing processes whereby the response is influenced by some variables and the objective is to optimize this response. RSM has important application designed, which defines the effect of the independent variables, alone or in combination, on the processes. In addition, it is used in analysing the effects of the independent variables, this experimental methodology generates a mathematical model which describes the chemical or biochemical processes of the product (Anjum *et al.,* 1997; Myers and Montgomery, 1995). It is the most common method applied in food processing.

Some examples of the RSM applications in food processes include optimization of fura production, processing parameter optimization for obtaining dry beans with reduced cooking time, optimization of edible oil extraction from ofada-rice bran and optimization of microwave-assisted hot-air drying conditions of okra (Jideani *et al.,* 2010; Akinoso and Adeyanju, 2012; Schoeninger *et al.,* 2014; Kumar *et al.,* 2014). Sobukola *et al.* (2010) optimized the pre- fry drying treatment and also used hot water blanching prior deep fat frying of yam slices using response surface methodology. Similarly, Akinpelu *et al.* (2014) and Esan *et al.* (2015) also reported on the optimization of vacuum frying conditions during deep fat frying on high quality fried plantain and sweet potato chips, respectively. For each of this report, the best processing conditions were obtained in order to produce fried samples of acceptable quality attributes.

1.1 Justification

Good nutrients, wholesomeness and convenience of the food itself are important factors in producing good fried food products. Unfortunately, fried foods are high in fat contents and reaching in some cases 1/3 of the total food product by weight. Even though this kind of food ensures a high level of satiety, however this can pose a great risk to consumer (Mellema, 2003). It is also known that a high fat diet is one of the major factors that cause an increase in the incidence of cardiovascular disease (Moreira and Barrufet, 1998). Chicken nuggets is one of the most popular breaded fried products enjoyed by many people and the market trend for consumption of healthier fried foods has forced the snacks industry to develop an alternative technology which will maintain a low-fat chicken nuggets with a juicy interior and also a crispy/crunchy external surface. Also, because of this, much research is being aimed in developing fried food products with a reduced fat content. A detailed study on the optimization process of air frying conditions during production of chicken nuggets is very crucial. Information on air-fried chicken nuggets from FUNAAB- Indigenous broilers using the optimization approach is scarce in literature.

General objective

The overall aim of this research work is to study the effect of the processing variables on some quality attributes of air- fried chicken nuggets from FUNAAB- Indigenous Broilers.

1.2 Specific objectives

The specific objectives are to:

i. Determine the effect of frying temperature and frying time on some quality attributes of chicken nuggets
ii. Determine the sensory attributes of the optimized air-fried chicken nuggets; and
iii. Compare the quality of optimized air-fried nuggets with established optimized atmospheric fried samples

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Chicken

Nigeria is a country with heavy human population and this population is continuously on the rise. This increase had led to the high demand for the available animal and poultry products in all parts of the country. Among the cheapest and highly affordable protein source for this teeming population is mainly the poultry products. Poultry, particularly chickens are very important and has been recognized as an important genetic resource among the avian species (Olowofeso, 2005). Chickens are the most widely distributed of all livestock species in Nigeria with a population of 166 million birds (FAOSTAT, 2007). Chickens play very significant socio-cultural and economic roles in most African societies. Local poultry stocks serve as major source of animal protein to the poor since they are accessible to rural households. Chickens make up of 98% of the total poultry species numbers (Chickens, ducks and turkeys) in Africa. (Gueye, 2003). Poultry contributes to a large extent in the form of meat and eggs for a majority of the population in developing countries.

2.2 Indigenous Broilers

Indigenous chickens are widely distributed in the rural areas of tropical and sub-tropical countries where they are kept by majorly the rural farmers. Africa indigenous chickens are hardy, adaptive to rural environments, high survivability on little or no inputs to feed availability.

Indigenous chicken constitutes 80% of the major population of poultry in the rural areas in Nigeria according to (RIM, 1992). They are independent and hardy birds which has the capacity to withstand harsh weather conditions and adapt to adverse environment. They have the ability to hatch their own eggs, brood and scavenge for their foods and also possess high immunity to withstand diseases. Due to these attributes and also their pigmentation, taste, leanness and suitability for special dishes, they are highly preferred by major Nigerians. (Ajayi, 2010).

2.3 FUNAAB- Indigenous Broilers

FUNAAB-Indigenous broilers are a crossbreed chicken between improved indigenous chicken and exotic species with improved reproductive performance, increased average bird size, egg fertility, hatchability and survivability (Peters, 2000). They exhibit high genetic variance performance in their performance, therefore have great prospective for genetic improvement through cross breeding (Omeje and Nwosu, 1983; Adebambo *et al.,* 1999, 2009; Adedeji *et al.,* 2004). The FUNAAB- Indigenous poultry breeding project started in 1994 with collection of 500 birds all over South Western Nigeria comprising Normal feathered, Frizzle feathered and Naked Neck indigenous birds. Crossbreeding within the last era to generate the indigenous broiler lines has added value to the body weight from 1.2kg at 10 weeks to (1.6- 1.9) kg for dihybrid crossing. Current trihybrid comprises 2 exotics and one indigenous line to generate (25-37.5) % indigenous blood. The current weight at 8 weeks ranged from 1.5-1.9kg although with a corresponding increase in age at first egg to 24-26 weeks in the trihybrids. These have been developed as the parent stock line for the production of commercial FUNAAB indigenous broilers (COFI-Broilers).

2.4 Chicken Nuggets

Chicken nugget is part of the popular meat product worldwide. Nuggets are a restructured meat product with batter and coater to retain the quality (Lukman *et al.,* 2009). It requires less time to prepare and nutritionally more acceptable than any other fried products. It is prepared by using chicken meat, vegetable protein, gum and some proportion of chicken skin. After preparation, it is submerged in a frying medium to pre-fry before being packed. Chicken nuggets are fried foods with characteristics of crunchy crust, soft core, well developed colour and substantial oil absorption during their processing. The chicken nugget was invented in the 1950s by Robert C. Baker, a food science professor at Cornell University (Barbut, 2001).

2.5 Fried Foods

Fried foods are delicious, appetizing, pleasant and popular around the world. One of the main reasons for this attractiveness is the “textural properties of the food: dry and crispy crust, tender inside” (Mellema, 2003). Unfortunately, fried foods are also high in fat, in some cases reaching 1/3 of the total food product by weight (Mellema, 2003). The development of low-caloric food products with reduced fat and cholesterol levels has become very essential in research and food industry (Ang, 1990).

2.6 Frying Process

Frying improves the sensory appeal of food, especially by giving food a crunchy texture and rich taste. During frying, a double transfer takes place: water is released from the food and oil or fat enters into the food. In addition, during deep frying, the food is subjected to chemical and physical transformation at high temperature, which can result in diverse effects. Over repeated frying cycles, the frying medium deteriorates due to processes such as oxidation and polymerisation, which lead to changes in the performance of the oil or fat

During the frying process, water evaporates from the fried product, creating voids that are penetrated by the oil (Blumenthal, 1996). As the water evaporates, the crust of fried foods is formed on the exterior of the product. During frying there are three simultaneous processes that occurs; heat transfer from the hot oil to the product, mass transfer of the water from the interior of the product to the exterior and then into the oil, and mass transfer of the oil into the product. The frying oil undergoes chemical changes because of the high temperatures and the presence of water vapour (steam) therefore, as long as there is moisture to evaporate, the product can stay at a temperature of about 100ºC (Blumenthal, 1996, Tarmizi and Ismail, 2008).

2.6.1 Heat transfer

During frying there is a rapid rise in the surface temperature of the food placed in hot oil, the internal moisture is vaporized into steam, the surface begins to dry. A crunchy crust forms on the outside as the plane of evaporation moves inside the food (Fellows, 2000) and hot fat begins to penetrate the food. There are two modes of heat transfer during frying: conduction and convection. Conduction occurs within the food. The degree of heat transfer greatly depends upon thermal conductivity, thermal diffusivity, specific heat and density (Buhri and Singh, 1994). The convective heat transfer occurs between the food and the surrounding frying oil. The water vapour foams escaping out of the food create turbulence inside the frying medium and cause a major obstruction for the heat transfer (Levine, 1990). The amount of water vapour escaping from the food decreases with increasing frying time due to exhaustion.

2.6.2 Mass transfer

The primary modes of mass transfer during frying (especially deep fat frying) are moisture loss and fat uptake. The moisture loss during the frying can be summarized into three different periods:

- An initial heating to boiling point of free water and evaporation of superficial moisture content.
- Evaporation of free or capillary water.
- Decrease in the drying rates and increase of the product's temperature to the frying oil temperature. At this stage no driving force for further evaporation exists, and reactions, which are activated by high temperatures, continue to occur (Vitac, 2000).

The moisture loss, oil uptake and crust formation in fried products is primarily in the surface region (Keller *et al.,* 1986; Farkas *et al.,* 1991). The water vapour evaporation is quiet rapid initially during frying. This process is obstructed by the formation of the thick crust; as a result pressure starts building inside the product due to the accumulation of excess vapour and results in the formation of cracks in the crust. These cracks serve as conduits for the oil entry into the product. (Mallikarjunan *et al.,* 1997) and Alberto *et al.* (1999) observed a reduction in the moisture content with increase in frying time due to evaporation. The initial moisture transfer from the chicken during frying when the frying oil temperature was low was only in the liquid form. But as the frying progressed, a moving moisture front separates the wet and the dry regions advances into the chicken drum body, which results moisture transfer predominantly in vapour mode. The liquid mode of moisture transfer is slower than the vapour mode (Mallikarjunan *et al.,* 2009).

2.7 Deep Fat Frying

Deep fat frying is one of the oldest and most common unit operations used in the food preparations. It results in products with a unique flavour-texture combination. The primary reason for the popularity of deep fat foods may be desirable characteristics like soft, juicy interior and thick and crispy outer crust (Garcia *et al.*, 2002). The soft and moist interior along with the crispy crust improves the palatability of the deep fat foods. Deep fat frying is among the major staple foods in UK, Asia and North America. Among the fried foods, fried chicken is one of the most popular in the United States (Ngadi *et al.,* 1997).

Deep fat frying can be defined as the process of cooking foods by immersing food into the frying oil with a temperature of 150 to 200°C, which is well above the boiling temperature of water (Farkas *et al.,* 1996). It is a complex unit operation involving simultaneous mass transfer of various phases, microstructural changes and heat transfer

(Bouchon *et al.,* 2003). Frying involves a counterflow of water vapour (bubbles) and frying oil at the surface of the product (Keller *et al.,* 1986).

2.8 Hot- Air Frying

Hot-air frying is a new technique to get fried products through the direct contact between an external emulsion of oil droplets in hot air and the product into a frying chamber. The product is constantly in motion to promote homogeneous contact between both phases. In this way, the product is dehydrated and gradually appears the typical crust of fried products. The amount of oil used is significantly lower than in deep-oil frying giving as a result of very low fat products. There are no references or scientific publications that describe the mechanisms and kinetics of mass transfer phenomena and volume change taken place during the hot air-frying (Andrés *et al.,* 2013). Therefore, a better scientific understanding of this technique is necessary in order to extend its application either to fast food restaurants or industries for instance, due to not only to healthy benefits to consumers but also to the economic and environmental advantages such as the cost saving, the oil volume used and the absence of effluents after frying. Although, air frying produced products with a substantially lower fat content but with similar moisture contents and colour characteristics, it required much longer processing times, typically 21 minutes in relation to 9 minutes in the case of deep fat frying. The slower evolution of temperature also resulted in lower rates of moisture loss and colour development reactions.

Plate 1: A typical homemade Air-fryer. Source: Philips Air-frying cook book.

2.9 Breading of Fried Food Products

Coating with breading is commonly done after batter application (an exception can be after the pre-dust application, if the surface is quite wet), and is used to create a unique appearance, texture, as well as increase the volume and weight of the product. The type of breading can range from simple flour, to structured baked crumbs. Usually, the breading is a cereal based product which has been baked and later ground into fine, medium or large size crumbs (Barbut, 2013). Among various types of fried food products, breaded foods are increasingly favoured by consumers due to their unique textural properties such as a porous crispy crust and more desirable colour and flavour. There is a wide variety of breaded food products available in the market. These include breaded chicken nuggets, fish and sea food, meat, vegetables and fruits. Breaded chicken nuggets are one of the most popular fried products. Breading is defined as a dry mixture of flour, starch and seasonings with a coarse nature that is applied to moistened foods prior to cooking. Breading comprises up to 30% of the weight of the food. The starch content of the breading provides a base for crust formation especially in foods with low starch content such as meats and vegetables. The breading layer functions as a barrier to reduce moisture loss from the food and consequently to reduce the oil absorption (Rao and Delaney, 1995). Breading also improves desirability of the food by enhancing the appearance of the fried product and resulting in a deep golden colour upon frying. It also functions as a carrier of spices and seasonings that enhance the taste.

Food coatings seem to be a promising answer to solve the everlasting higher oil uptake problem in the deep fat frying foods. The effectiveness of a food coating depends on its mechanical and barrier properties, its microstructure and the composition of the substrate (Garcia, 2002). According to Barbut (2013), breading is of different types:

- Flour: flour is an economical way of coating. This gives fried products low surface browning and the coating pick up is relatively low.
- Bread crumbs: this comes in different sizes and provides a distinct crust during frying process; therefore medium to high browning can be obtained. It has a more defined structure compare to flour which gives the fried products a crispy texture.
- Mixture of seeds and grains: natural seeds and whole grains such as sesame seeds, pumpkin seeds, corn flakes etc can also be used for coating. It also helps to increase the surface browning, difference in appearances, roughness in surface, taste disparity, and adds to variety of fried products. (Barbut, 2013).

Breading granulation is divided into three sizes and it helps to achieve different functional and textural attributes and coating pickups. Mallikarjunan, (2001), divided it into: fine, medium and coarse particle sizes.

2.9.1 Pre-dusting

Pre-dust is a protein-based coating used to increase the adhesion ability of the batter and breading. Pre-dust is only applied when the surface of meat has low adhesion ability. For example, whole meat muscle, such as tenders, has low adhesion ability because of the hydrophobic surface of meat membrane. The pre-dust will adhere to the meat surface by absorbing the free water from meat, creating an intermediate layer between the meat and batter (Barbut, 2001). The major components of a pre-dust are flours, cracker meal, and some seasonings and spices to increase functional flavours. Non-meat proteins, such as soy, egg albumen, and whey, will be added to the pre-dust to increase the adhesion ability.

2.9.2 Quality properties of breaded fried foods

The main quality parameters in fried foods are sensory (appearance, flavour and texture) and nutrition parameters. These quality characteristics are determined by measuring related properties of the product such as moisture and fat contents, colour, flavour and texture (Moreira *et al.,* 1999). Moisture and fat contents are considered to be important parameters in fried food quality determination (Altunakar *et al.,* 2004). Moisture content has a distinctive influence on the texture desirability of the fried food. Therefore, minimizing the moisture loss from the food during frying is important to maintain the fried food quality. Moisture content also has an influence on the amount of fat absorbed by the food because the oil is absorbed as a replacement to the moisture loss from the food. Fat content is very important in fried food quality considering both textural and health concerns. A product with high oil content is oily and tasteless while a product with very low fat content has a hard and unpleasant texture (Moreira *et al.,* 1999). Reduced-fat foods are now being increasingly demanded by consumers due to health concerns.

2.9.2 Moisture and oil content

Oil and moisture content

Oil absorption is essentially a quantitative water replacement process. Oil absorption is a complex phenomenon that happens mostly when the product is removed from the fryer during the cooling stage (Sun and Moreira, 1994). Baumann and Escher (1995) found that varying frying oil temperature under atmospheric conditions caused a slight increase in the final oil content of chips. Oil absorbance increased with increase frying temperature and time (Krokida *et al.,* 2000, 2000; Gamble and Rice, 1987). Higher oil temperatures result in a faster development of a solid crust and consequently surface properties that are favourable for oil absorption. In vacuum frying, the final oil content of potato chips is not a function of oil temperature, but depending on frying time (thus remaining moisture), which increases with decreasing oil temperature (Krokida *et al.*, 2001c). Based on the capillary theory of frying, water in the sample vaporizes, and subsequently creates capillary pathways, thus enabling oil uptake to occur (Guillaumin, 1988). This was evidenced by the high correlation between moisture loss and fat uptake. Despite efforts to study the mechanisms and control oil uptake (Moreira *et al.*, 1997; Saguy and Pinthus, 1995; Ufheil and Escher, 1996), most fried foods contain significant amounts of oil.

2.9.3 Colour

Colour is essential for consumer acceptability and preference of food products. The colour of an object which the human eyes observe is due to the reflected light from that object. Human eyes can detect the hue differences by specific descriptive terms such as red, blue, yellow and green while simultaneously being able to describe the Chroma difference by intensity and the value differentiated by brightness. Due to the limitation of visual description, reflectance colorimetry is the most common way to detect poultry meat colour. Minolta and Hunter LAB colorimeters are the most common used in the meat industry. CIE (Commission International de l'Eclarirage) is developed CIE X, Y, Z system to define the colour using three primary colours, X (red), Y (green) and Z (blue) in the 1930s (Barbut, 2001). Then it was replaced by CIE L*a*b* (CIELAB) colour space system in the 1970s because the value differences are not easily detected by human eyes. L*, a* and b* values are used to determine the colour characteristic in the CIELAB system. L* value represents the lightness of surface ranging from 0 (black) to 100 (white); a* value measures the amount of red or green, with positive value indicating red and negative value indicating green; b* value represents yellow or blue, with positive value indicating yellow and negative value indicating blue (Minolta, 1998). The lightness of a meat product is influenced by the denaturation of meat proteins and extracellular water.

2.9.4 Texture

Texture of beef remains the most important aspect of eating quality of beef in North America (Brooks *et al.,* 2000) and has been extensively researched to understand, control, and predict this characteristic. Meat juiciness is also an attribute valued by most consumers. Although consumers routinely pay more for cuts of meat that are typically more tender (Thompson, 2002), there is some expectation that the meat will also be juicy. Moreover, meat juiciness plays a key role in meat texture (Dransfield *et al.*, 1994), probably contributing to its variability.

Properties of beef texture include both initial (first bite with incisors) and overall tenderness (after multiple chews) as well as more complex sensory attributes of chewing and mouthfeel with multiple descriptors such as fiber cohesiveness, adhesion, friability, chew count, mealiness, mushiness, softness, amount of residual connective tissue, rubberiness, and hardness.

Hardness of fried foods refers to the force applied to compress the food in the mouth which must not be too hard (Verela *et al.*, 2009). Chewiness is derived from the combination of hardness, cohesiveness, and springiness and it is the time required to masticate a food product at a constant rate so as to reduce its consistency before swallowing. Adhesiveness is the amount of work needed to overcome the attractive forces between the surface of the food product and the surface of the material with which it comes in contact. Cohesiveness refers to the strength of internal bonds making up the body of foods and the degree to which a food can be deformed before it ruptures. Gumminess is the energy required to break down a semi solid food products to a state of swallowing. Springiness is also related to elasticity of samples.

2.9.5 Health issues

Coronary heart disease is the single leading cause of death in the United States. It caused 479, 305 deaths in 2003 alone. Cardiovascular disease was the cause of 37.3% of all deaths in the United States in 2003 (American Heart Association, 2006). The excessive consumption of fat, especially saturated fat, has been linked to the development of cardiovascular disease. Dietary trans-fatty acids enhance the risk of developing coronary heart disease (Ruiz-Roso and Varela, 2001). While deaths from cardiovascular disease and coronary heart diseases have been decreasing over the last several years, there is still much to be concerned about. Excess fat consumption from fried foods can be a key contributor to coronary heart disease (Browner *et al.,* 1991), as they can contain 10-40% oil (deMan, 1999). Browner *et al.* (1991) estimated that if all Americans reduced consumption of saturated fat, the corresponding reductions in cholesterol levels could reduce deaths from coronary heart disease by 5-20%, depending on age. There is also an association between dietary fat and obesity. The prevalence of overweight, obese, and morbidly obese Americans increased significantly from the time the Third National Health and Nutrition Examination Survey (NHANES III) was performed between 1988-1994 (Kuczmarski *et al.,* 1994) until a survey (NHANES 1999- 2000) was performed by Flegal *et al.* (2002) from 1999-2000. Obesity is considered a pandemic and is associated with cardiovascular disease, type 2 diabetes, hypertension, sleep apnea, and certain cancers (Poirier *et al.,* 2006). In 1997, Swedish researchers discovered that cooking food at high temperatures can lead to the formation of acrylamide, a known neurotoxin and potential carcinogen (Erickson, 2004). Rats fed fried feed had N-(2-carbamoylethyl) valine (CEV) adduct levels ten times higher in their haemoglobin than rats fed unfried feed. This adduct is formed when acrylamide reacts with globin. In an analysis of the feed, fried feed had approximately fifteen times more acrylamide present than unfried feed (Tareke *et al.,* 2000). Granda and Moreira (2005) investigated the possibility of vacuum frying potato chips to reduce the formation of acrylamide. The acrylamide content of vacuum fried potato chips was 94% less than traditionally fried potato chips. The lower temperatures used in vacuum frying (118-140 ^{0}C) compared to those in traditional frying (150-180 ^{0}C) were cited as the cause of the reduced acrylamide content. The biggest concern for the presence of acrylamide is in starch-rich foods (i.e. potato chips, French fries); however, protein-rich foods, especially ones coated in batter and breading before being fried, still contain a not insignificant amount of acrylamide (Tareke *et al.,* 2002).

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

Broiler chicken was obtained from the FUNAAB farm, Federal University of Agriculture, Abeokuta. Other materials used for sample preparation such as clean bowls, mincer, and stainless steel knives were obtained from the Food Processing Laboratory of the Federal University of Agriculture, Abeokuta.

3.2 Methods

3.2.1 Preparation of chicken nuggets

The broiler chicken was slaughtered, dressed and manually deboned and skinned. The nuggets formulation consisted of chicken breast meat, which was pre -dusted with wheat flour and breaded. The average weight of the chicken nuggets were determined and each sample was weighed before dipping into batter in order to have a uniform range (Sorgi *et al.,* 2012), as shown in figure 1.

3.2.2 Frying Process

A commercial hot Air fryer (low fat Air fryer, Model T14001, Philip, China) was used to fry the chicken nuggets. Three samples of chicken nuggets sprayed with 0.5 ml of frying oil were put into the basket. Three different temperatures were chosen i.e. 155, 165 and 175^{0}C and the frying time selected were 10-30 minutes respectively. These conditions were arrived at after a series of experimental trials. After this, the fried chicken nuggets were allowed to cool down at ambient temperature and were stored in a zip lock bags for further analysis.

Chicken breast

↓

Cutting and Forming

↓

Weighing

↓

Pre- dusting (wheat flour)

↓

Immersing into egg albumen

↓

Breading

↓

Weighing

↓

Air frying (155ºC, 165ºC and 175ºC at 10-30 minutes)

↓

Packaging

Figure 1: Processing of fried chicken nuggets (Modified method of Soorgi *et al*., 2012)

3.3 Analytical Methods

3.3.1 Determination of moisture content

The moisture content of the fried chicken nugget was determined using the method described by AOAC (2000). Five grams of each sample was weighed into a cleaned, dried and pre-weighed moisture pan. The pan with its content was dried in an oven at 105^{o}C for 3 hours. Thereafter the samples were cooled in a desiccator and weighed. The moisture pan was taken back into the oven and allowed to stay for another one hour. This process was repeated until all the fried samples in the pan gave constant weight. The percentage moisture content was estimated as weight loss using the formula below:

$$\text{Moisture content (\%)} = \frac{w_1 - w_2}{w} \text{x}100 \qquad \text{………………... (1)}$$

Where:

W_1 = weight of pan + fresh sample

W_2=weight of pan + dry sample

W= weight of sample

3.3.2 Determination of oil content

The fat content was determined by Soxhlet method (AOAC, 2000). Approximately two gram of fried sample was placed in a free fat thimble, plugged lightly with cotton wool. The thimble was placed in the extractor and petroleum ether was added until it siphons over. More petroleum was added until the barrel of extractor is half filled. The condenser was replaced and all joint was securely tightened and the extractor placed on the boiling water bath. The solvent was allowed to boil gently for the system to siphon over at least ten times.

CALCULATION

$$\% \text{ Fat} = \frac{w_3 - w_2}{w_1} \text{ x } 100 \quad \text{……………….} (2)$$

w_1 = Weight of sample (g)

w_2 = Empty extraction cup weight (g)

w_3 = Extraction cup + residue weight (g)

3.3.3 Determination of colour parameters

The colour intensity of the chicken nuggets were measured using a Konica Minolta Colour Measuring System (Chroma meter CR-410, Minolta LTD, Japan) as described by Zahra *et al*. (2014). The lightness (L^*), redness (a^*) and yellowness (b^*) values were obtained after calibrating the instrument using a white tile. Four replicate readings were taking for each fried chicken nuggets and the average value were reported. The results were expressed in accordance with the CIELAB system where:

L* is known as the lightness [L =0 (black), L = 100 (white)],

a* (-a = greenness, + a = redness)

b* (-b values = blueness, + b* value = yellowness)

3. 3.4. Determination of texture parameters

Compression Test was performed on the fried chicken nugget samples using a Universal Testing Machine (Model: M500-100ATCapacity:100kN, Stable Micro Systems Ltd., Godalming, Surrey UK). The fried chicken nuggets of uniform size were selected. The textural features of fried chicken nuggets were measured by compressing it with a 75 mm diameter probe. The probe was allowed to compress up to 50 mm depth at a crosshead speed of 50 mm/min. The samples were compressed twice and the following parameters were determined: hardness, adhesiveness, springiness, cohesiveness, chewiness, gumminess and Stringiness.

3.3.5 Experimental design

Response surface methodology (RSM) based on central composite design was used in this study. The procedure was based on the fact that quality attributes (moisture and oil contents, textural properties, colour parameters) of air fried chicken nuggets is functionally related to air frying conditions (temperature and time). Two un-coded independent variables in the process were frying temperature (155,165, and 175 °C), and frying time (10, 20, and 30 minutes). A total of thirteen combinations (Table 2) were generated for the two independent variables with five centre points (the level of combination in which the value of the un-coded variable was zero). Response surfaces was developed using the fitted quadratic polynomial equations obtained from the response surface regression analysis. The level of significance for all tests was set at 95 % using analysis of variance (ANOVA) for each response.

3.4 Optimization procedure

The processing parameters were optimized with respect to the responses of oil content, texture (breaking force), moisture content, and colour parameters. The constraints were frying time, frying temperature, oil content, texture profile analysis, moisture loss, and colour. A numerical optimization technique was used for simultaneous optimization of the multiple responses. The desired goal for each processing parameter and response was chosen. All the processing parameters were kept within the specified parameter ranges, and in order to search for a solution, goals was combine into an overall composite function, D(x), called the desirability function (Myers and Montgomery 2002) and it is define as:

$D(x) = (d1 \times d2 \times \ldots\ldots d_n)^{1/n}$ (6)

Where, d1, d2 … d_n are the responses, and 'n' is the total number of responses in the measure. Numerical optimization finds a point that maximizes the desirability function.

Response surface plots will help in understanding the effects of varying the processing parameters on the response. A similar method was reported by Chakraborty *et al.*, (2007).

Table 1: The un-coded values for the independent variables

Variables	-1	0	+1
Frying Temperature (^{o}C)	155	165	175
Frying Time(min)	10	20	30

Table 2: Experimental runs showing different combination of independent variables

Experimental Runs	Frying Temperature (°C)	Frying Time (min)
1	165	20
2	165	5.86
3	165	34.14
4	155	30
5	155	10
6	150.86	20
7	165	20
8	165	20
9	165	20
10	179.14	20
11	175	30
12	175	10
13	165	20

3.5 Sensory Analysis of Chicken Nuggets (Acceptance test)

The acceptance test was determined using the method described by Lukman *et al.* (2009). Thirty consumer panelists made up of students of Federal University of Agriculture, Abeokuta, Ogun State, Nigeria were used to investigate the acceptability of the fried chicken nuggets. The sensory attributes evaluated includes colour, appearance, odour, taste, gumminess, hardness, juiciness and overall acceptability of fried chicken nuggets prepared using the optimized frying conditions (air fried and deep fat fried) on a nine-point hedonic scale ranking nine for like extremely and one for dislike extremely. The average and mean values of scores for each of attributes were computed and analyzed statistically.

3.6 Data Analysis

A second- order polynomial model for the dependent variables as shown in equation (4) was established to fit the experimental data. An Analysis of variance (ANOVA) test was carried out using Design – Expert Version 6 (Stat-Ease Inc., Minneapolis, MN.USA) to determine level of significance at 5% level. The generalized regression model fitted was

$$\gamma = \beta_{\circ} + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} X^2 + \sum \sum_{i<j-1}^{2} \beta_{ij} X_i X_j + \epsilon \text{ ………………} (4)$$

Where Y is the response; β_0 is a constant; while βi, βii , and βij are linear, quadratic and interaction coefficients, respectively; and ε is error.

CHAPTER FOUR

4.0 RESULTS

The mean value of moisture content (Table 3) of air-fried chicken nuggets from FUNAAB- indigenous broilers ranged from 56.03 - 69.44%. Figure 2 shows the response surface plot of moisture content of air-fried chicken nuggets. From the plot, a decrease in moisture content was observed as frying temperature and frying time increased. Frying time (main effect) and frying temperature (quadratic effect) had a negative significant ($p<0.05$) effect on moisture content of air-fried chicken nuggets from FUNAAB- indigenous broilers. However, the interaction effect of frying temperature and time decreases moisture content as they increases. The model developed (R^2) for moisture content was able to predict more than 75% of the experimental data.

The mean value of oil content of air-fried chicken nuggets from FUNAAB- Indigenous broilers ranged from 8.05 -15.03%. Figure 3 shows an overview of the surface plot for oil content. From the plot, it was apparent that oil content decreased with increase in frying time and frying temperature. The process variables showed no significant ($p>0.05$) effect on the oil content of air-fried chicken nuggets as evident from Table 4. The regression model developed (R^2) was low and predict more than 43% indicating a predictive accuracy.

The mean value of lightness ranged from 34.77% - 68.83%. As shown in Figure 4, an increased in lightness parameter was observed as frying temperature and frying time increased. Table 4 showed the regression coefficient of the responses as function of independent variables. The quadratic effect of frying time was significant ($p<0.05$) on the lightness parameter of air – fried chicken nuggets from FUNAAB indigenous broilers.

Table 3: Mean values of the responses at different experimental runs

Runs	Moisture content (%)	Oil content (%)	Lightness	Redness	Yellowness
1	69.44	15.31	44.90	24.47	48.79
2	68.93	10.35	68.60	22.69	55.98
3	56.03	12.48	64.83	14.03	46.84
4	56.19	13.65	41.82	18.10	26.87
5	62.01	8.05	34.77	25.25	47.53
6	58.91	15.03	42.46	19.98	44.09
7	61.73	10.57	43.16	26.26	45.59
8	61.55	9.53	46.09	27.87	50.00
9	67.17	14.12	47.40	27.54	46.90
10	60.73	10.73	48.02	24.93	45.98
11	58.88	10.10	53.72	23.76	40.35
12	64.75	12.57	53.94	19.97	48.28
13	63.32	10.12	51.41	27.37	52.30

Values are means of duplicate

Table 4: Regression coefficients of the responses as a function of the independent variables

Parameters	Moisture	Oil content	Lightness	Redness	Yellowness
B_0	64.64	11.93	46.59	26.70	48.72
A	1.00	-0.64	4.87	0.92	2.11
B	-3.74*	0.77	0.19	-1.95*	-5.19*
A^2	-2.58*	0.21	-3.15	-1.78*	-3.71
B^2	-1.25	-0.52	7.58*	-3.83*	-0.52
AB	-0.012	-2.02	-1.82	2.74*	3.18
R^2	0.75	0.43	0.69	0.87	0.68
F-Value	4.27	1.05	3.16	9.47	2.91

A is frying temperature
B is frying time

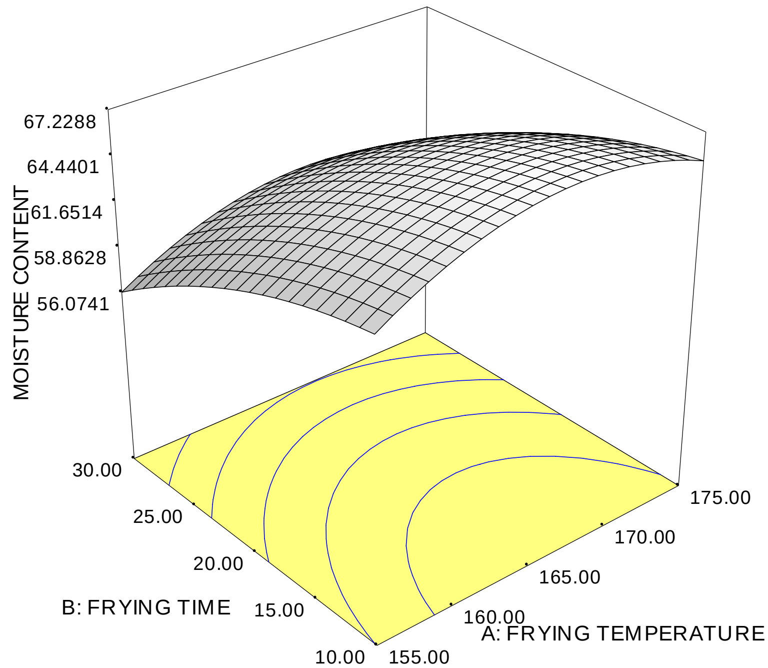

Figure 2: Response surface plot for Moisture Content (%) of Air fried chicken nuggets at different experimental conditions

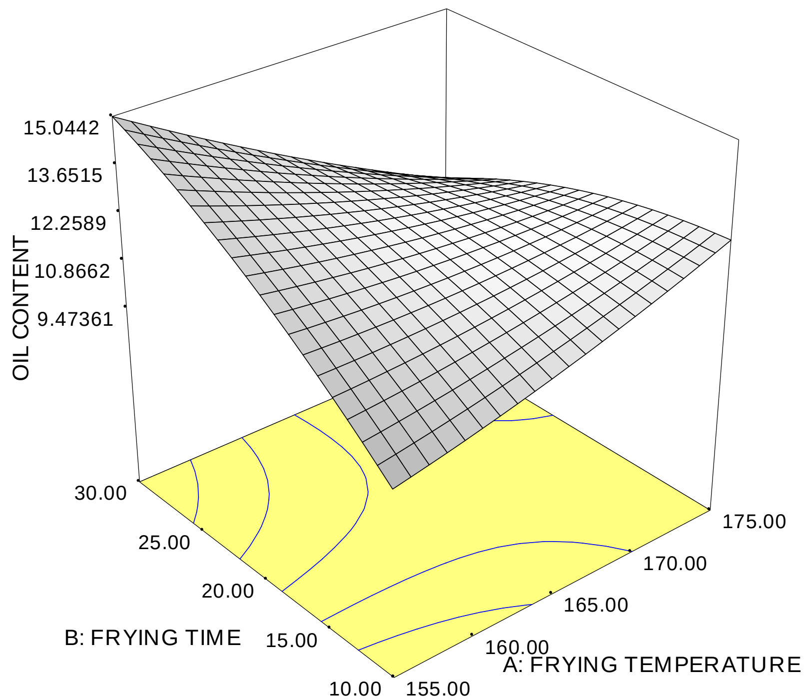

Figure 3: Response surface plot for Oil Content (%) of Air fried chicken nuggets at different experimental conditions

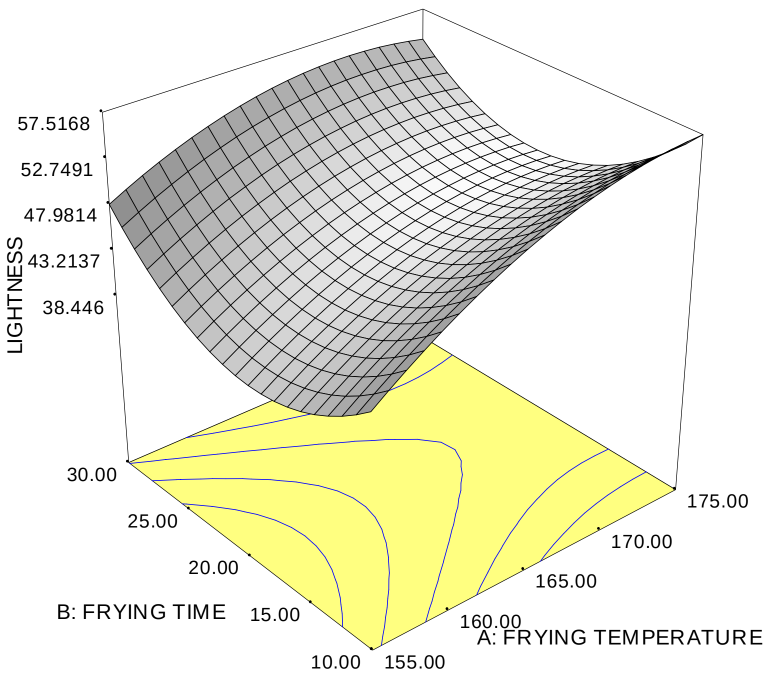

Figure 4: Response surface plot for Lightness of Air fried chicken nuggets at different experimental conditions

However, interaction effects of frying time and frying temperature had no significant ($p>0.05$) effect. The regression coefficient (R^2) of lightness was able to predict 69% of the model.

The quadratic model developed for Redness parameter was able to predict more than 87% of the experimental data indicating a predictive accuracy. The mean value of redness ranged from 14.03 – 27.87% (Table 3). From the response surface plot (Figure 5), a decrease in redness was observed as frying time increased, however as frying temperature increased, redness of the air-fried chicken nugget increased. From Table 4, the main effect of frying time significantly ($p<0.05$) affect redness. The quadratic effects of frying temperature and frying time as well as interaction between frying time and frying temperature were also significant ($p<0.05$) of redness The mean value of yellowness parameter of air-fried chicken nuggets from FUNAAB indigenous broiler ranged from 26.87 – 55.98%. From the response surface plots (Figure 6), it is clear that as frying time increased yellowness increased but a reduction in yellowness was observed as frying temperature increased. From Table 4, the main effect of frying time significantly ($p<0.05$) affected yellowness negatively, and the regression coefficient of the model developed for yellowness was able to predict 68% of the experimental data. The model developed for adhesiveness was able to predict more than 36% of the experimental data indicating a predictive accuracy. The mean value of adhesiveness ranged from 2.31 – 9.06% (Table 5). The surface plot (Figure 7) showed an increase in adhesiveness as frying time increased. Also, as frying temperature increased adhesiveness decreased. The process variables showed no significant ($p>0.05$) effect on the adhesiveness of air-fried chicken nuggets as evident from Table 6.

The mean value of chewiness ranged from 14.43 – 45.37% (Table 6). The regression model developed (R^2) was able to predict more than 54% of the experimental data indicating a predictive accuracy. Figure 8 showed the response surface plot of chewiness of air- fried chicken nuggets from FUNAAB indigenous broilers. As observed from the figure, increase in frying time resulted in an increase in chewiness, however as frying temperature increased chewiness decreased. The process variables showed no significant ($p>0.05$) effect on the chewiness of air-fried chicken nuggets. The quadratic model developed for Cohesiveness was able to predict more than 40% of the experimental data. The mean value of cohesiveness ranged from 0.58 – 0.74% (Table 5). From the surface plot (Figure 9), frying time increased cohesiveness increased and as frying temperature increased cohesiveness decreased. The process variables showed no significant ($p>0.05$) effect on the cohesiveness of air-fried chicken nuggets. Figure 10 showed the response surface of Gumminess of the air fried chicken nuggets, from the figure, an increase in gumminess was observed as frying time and frying temperature increased. No significant ($p> 0.05$) effect were found on the gumminess based on the interaction of frying time and frying temperature. The model developed (R^2) was low, predict more than 32% of the experimental data. The mean value of gumminess ranged from 23.28% – 58.39% (Table 5).

Figure 11 showed the response surface plot of hardness of the air fried chicken nuggets. From the figure, an increase in hardness was observed as frying time and frying temperature increased. The process variables showed no significant ($p>0.05$) effect (main, quadratic, interaction) on the hardness of air-fried chicken nuggets from FUNAAB indigenous broilers. The mean value of hardness ranged from 42.89N – 89.47N (Table 5). The regression coefficient (R^2) of hardness was able to predict 43% of the quadratic model.

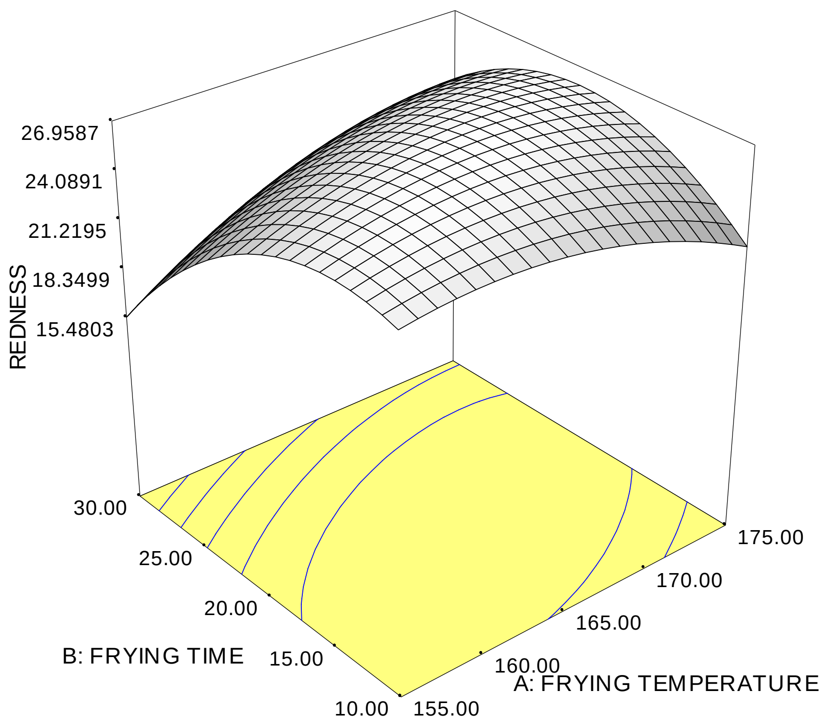

Figure 5: Response surface plot for redness of air fried chicken nuggets at different experimental conditions

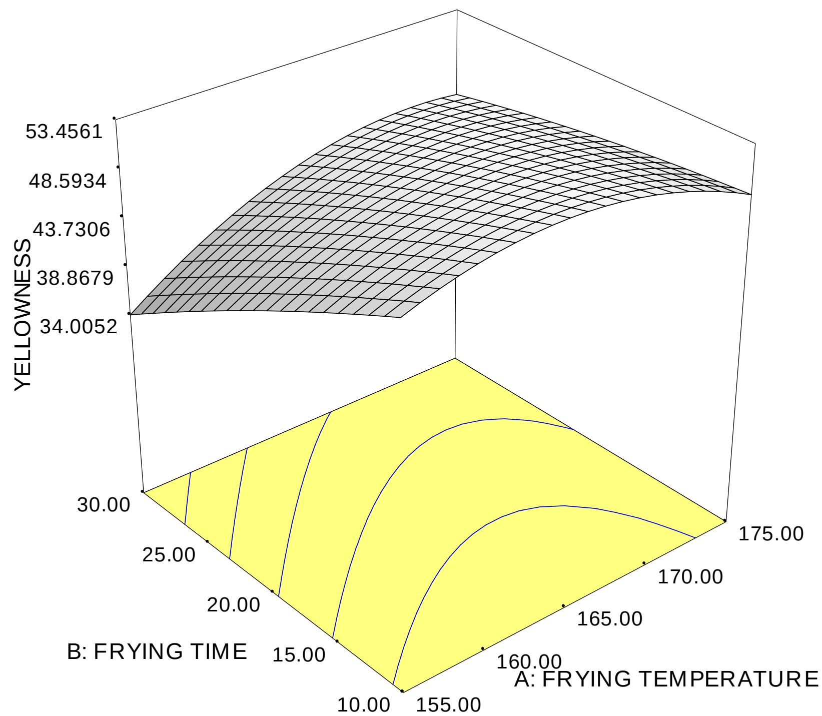

Figure 6: Response surface plot for yellowness of air fried chicken nuggets at different experimental condition

The mean value of stringiness of air-fried chicken nuggets from FUNAAB indigenous broilers ranged from 0.44mm-0.84mm. From Figure 12, stringiness increased as frying time increased and stringiness decreased as frying temperature increased. Quadratic effect of frying time showed a significant effect ($p<0.05$) on stringiness. Table 4 showed the regression coefficient of the responses as a function of independent variables. The model developed as coefficient of determination (R^2) was able to predict more than 70% indicating a predictive accuracy. In Figure 13, springiness decreased as frying time increased and springiness increased as frying temperature increased. Quadratic effect of frying time showed a significant effect ($p<0.05$). The mean value of stringiness of air-fried chicken nuggets from FUNAAB indigenous broilers ranged from 3.67-9.26 MM. The model developed as coefficient of determination (R^2) was able to predict more than 66% indicating a predictive accuracy.

Response surface methodology (RSM) was used to optimize the frying temperature and frying time and to select the significant ranges for variables in the most important step in order to retain high quality of air fried chicken nuggets. All responses were the main quality parameters of the air fried chicken nuggets studied in this research which were also the criteria based on desirability concept with frying temperature and frying time as well as the main quality parameters serving as the constraints to process optimization. The solution to the optimized air fried chicken nuggets is presented in Table 7 with a frying temperature of 155 ^{0}C and frying time of 10 minutes. In order to compare the air frying process with deep fat frying process, the optimized processing conditions obtained was used (frying temperature of 155 ^{0}C and frying time of 10 minutes). Data are presented in Table 8.

Table 5: Mean values of texture profile analysis at different experimental runs

Runs	Adhesiveness	chewiness	Cohesiveness	Gumminess	hardness	springiness	stringiness
1	9.06	28.01	0.59	46.22	74.45	0.47	9.26
2	5.08	14.43	0.58	32.69	51.69	0.44	8.42
3	4.78	35.95	0.69	44.48	65.43	0.81	4.31
4	8.8	26.89	0.66	31.58	47.56	0.84	3.67
5	2.31	27.75	0.64	23.28	42.49	0.67	6.12
6	3.64	45.37	0.69	52.56	89.47	0.75	5.4
7	4.45	27.6	0.74	43.35	64.54	0.75	5.5
8	3.58	25.89	0.62	41.98	66.6	0.7	6.55
9	3.89	29.54	0.68	39.08	89.04	0.57	6.82
10	3.77	23.84	0.65	33.86	51.64	0.65	6.57
11	5.23	28.01	0.74	35.37	44.99	0.81	4.41
12	4.58	27.94	0.65	49.74	75.5	0.59	6.61
13	4.8	28.72	0.64	58.39	84.4	0.62	6.47

Values are means of duplicate

Table 6: Regression coefficients of texture profile as a function of the independent variables

parameter	adhesiveness	chewiness	Cohesiveness	gumminess	hardness	springiness	stringiness
B^0	5.16	27.95	0.65	45.80	75.81	0.62	6.92
A	-0.14	-3.64	4.179E-003	0.48	-2.88	-0.031	0.36
B	0.84	3.71	0.033	1.33	-0.75	0.11*	-1.31*
A^2	-0.50	2.76	0.013	-2.77	-5.61	0.055	-0.71
B^2	0.12	-1.94	-4.500E-003	-5.09	-11.60	0.018	-0.52
AB	-1.46	0.23	0.018	-5.67	-8.89	0.013	0.063
R^2	0.34	0.54	0.40	0.32	0.43	0.70	0.66
F-VALUE	0.78	1.62	0.94	0.65	1.07	3.19	2.76

Where A is frying temperature
B is frying time

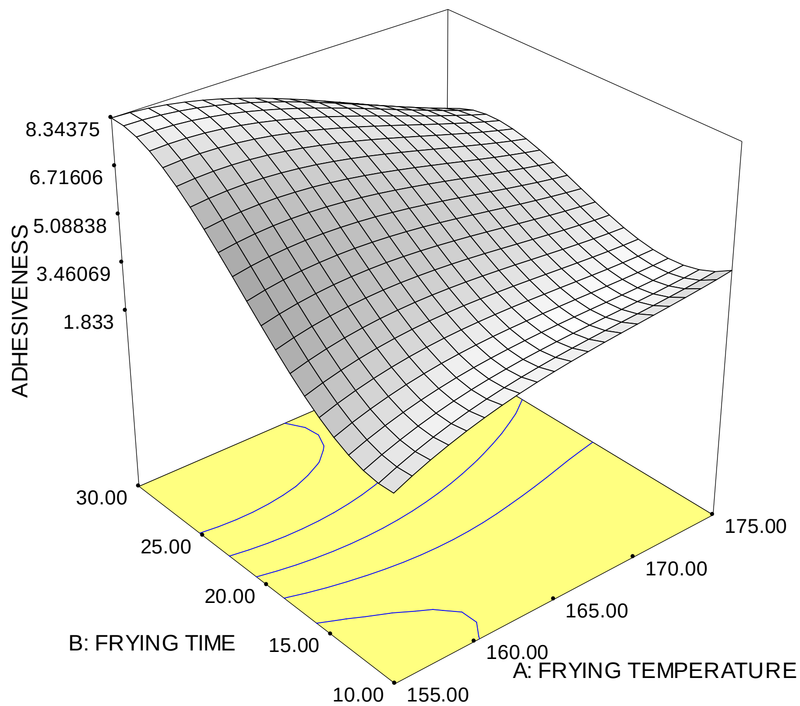

Figure 7: Response surface plot for Adhesiveness of Air fried chicken nuggets at different experimental condition

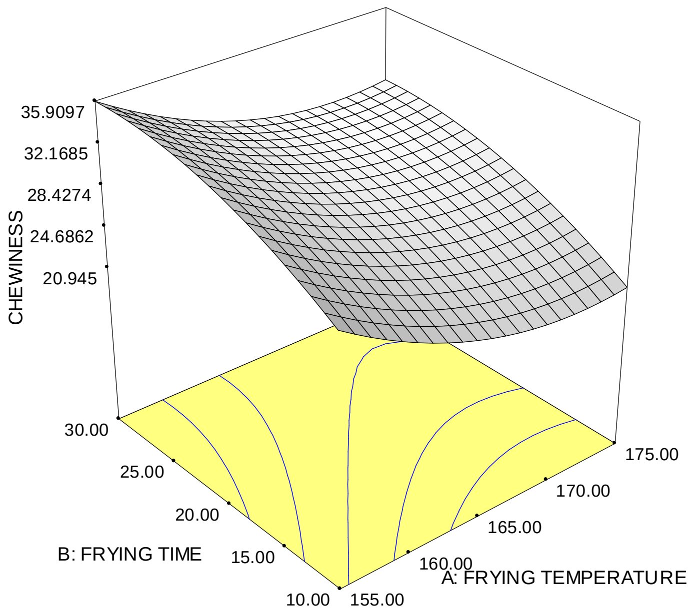

Figure 8: Response surface plot for Chewiness of Air fried chicken nuggets at different experimental condition

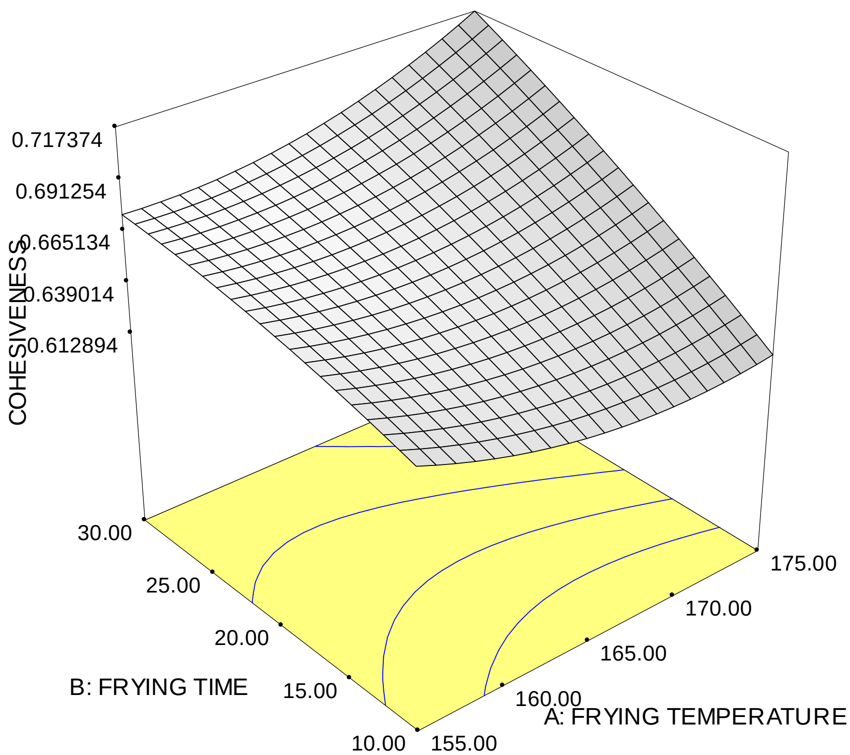

Figure 9: Response surface plot for Cohesiveness of Air fried chicken nuggets at different experimental condition

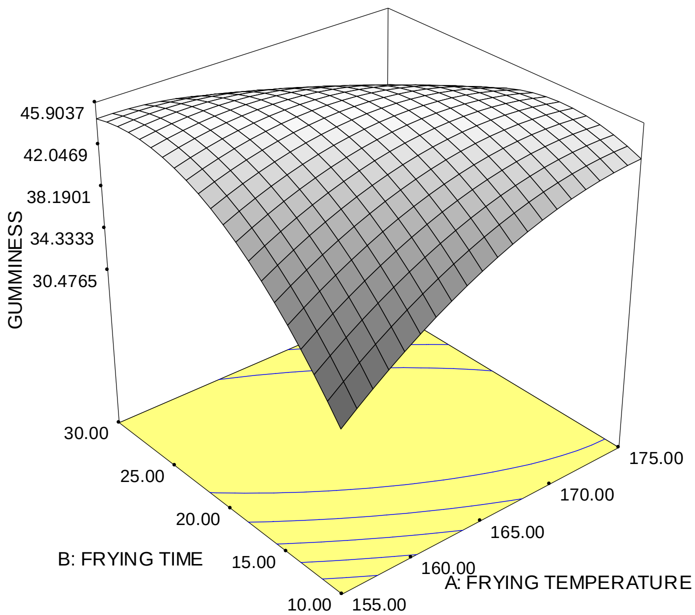

Figure 10: Response surface plot for Gumminess of Air fried chicken nuggets at different experimental condition

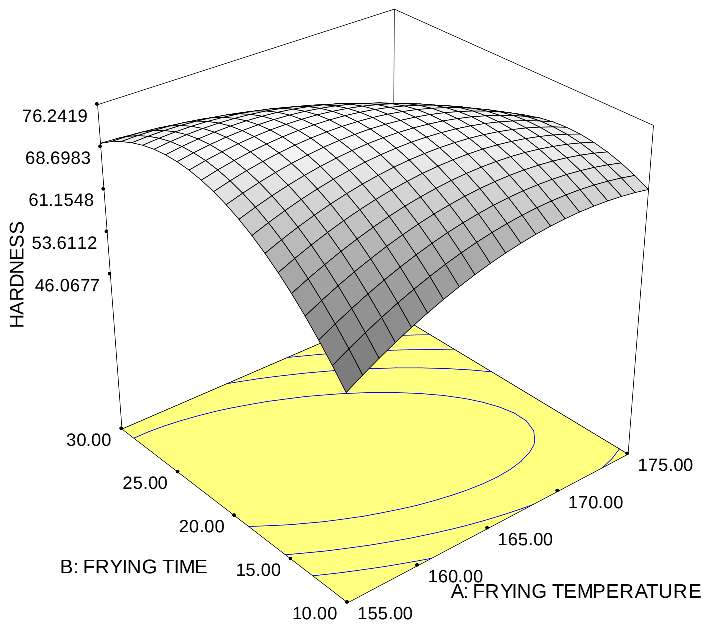

Figure 11: Response surface plots for Hardness of Air fried chicken nuggets at different experimental condition

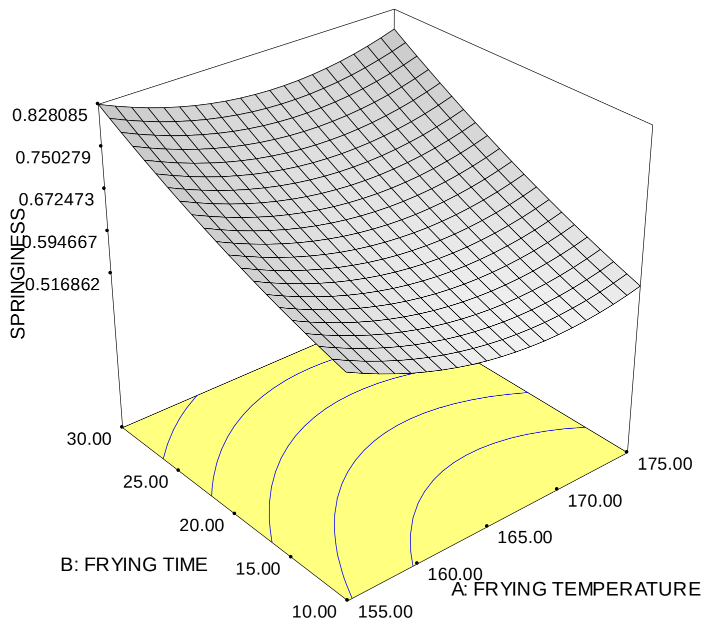

Figure 12: Response surface plot for Springiness of Air fried chicken nuggets at different experimental condition

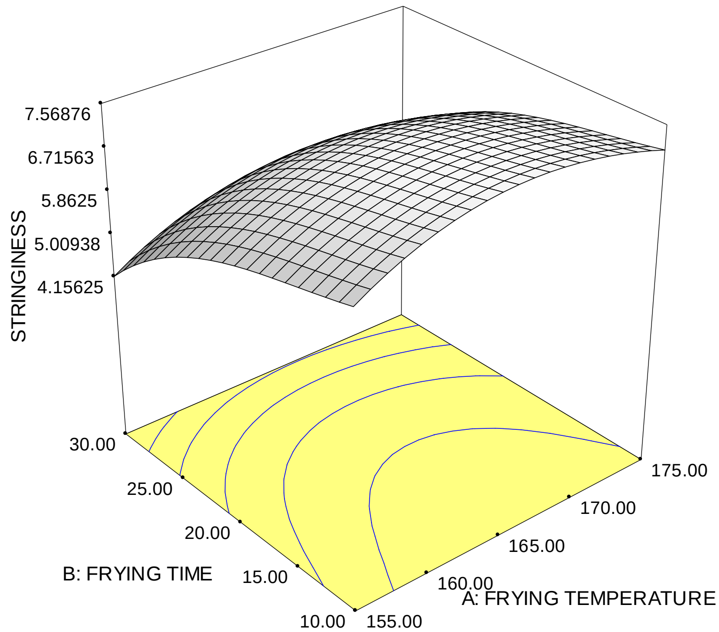

Figure 13: Response surface plot for Stringiness of Air fried chicken nuggets at different experimental condition

Table 7: Solutions to the optimization of air frying of chicken nuggets

No	FT	Ft	L*	A*	B*	MC	O.C	ADH	CHEW	COHE	GUMM	HRD	SPRN	STRIN	DESIRABILITY	
1	155	10	44.15	24.85	50.75	63.53	9.47	1.85	28.94	0.64	30.48	53.34	0.62	6.61	0.60	Selected
2	173.18	30	54.75	22.72	44.86	58.73	10.15	5.16	28.77	0.71	35.94	50.07	0.78	5.04	0.49	
3	173.1	30	54.76	22.71	44.87	58.75	10.16	5.18	28.77	0.71	36.02	50.24	0.78	5.04	0.49	
4	175	11.93	54.56	22.72	48.40	65.27	12.17	3.61	22.63	0.63	43.70	67.55	0.56	6.98	0.46	

Where, FT= frying temperature, Ft=frying time, a*=redness, b*=yellowness, L*=lightness, HRD=hardness, ADH= adhesiveness, CHEW=chewiness, COHE=cohesiveness, GUM = gumminess, STR=stringiness, SPR=springiness.

Table 8: Mean values of instrumental analyses of optimized deep fat and air fried process of chicken nuggets samples

Quality Attributes	DF	AF	t –Stat	P(T<=t)2-tail
Oil uptake (%)	11.12	6.42	40.91	0.016
Moisture loss (%)	57.55	47.92	214.11	0.003
Hardness	88.15	60.77	2738	0.00023
Adhesiveness	-0.005	0.019	-23	0.028
Cohesiveness	0.68	0.78	-8	0.08*
Chewiness	39.94	38.93	101	0.006
Gumminess	58.67	46.27	1240	0.0005
Springiness	0.69	0.84	-15	0.04
Stringiness	5.29	2.59	270	0.002

*Significance at ($p<0.05$)
Where DF is Deep-fat frying
AF is Air frying

The oil and moisture content, redness, yellowness and lightness values for the deep fat frying process and air frying process were 11.12 and 6.42%; 55.55 and 47.92%; 23.64 and 22.28; 57.35 and 47.69; and 68.63 and 57.62, respectively. With respect to the texture profile parameters, the hardness, adhesiveness, cohesiveness and chewiness mean values for the deep fat fried and air fried chicken nuggets from FUNAAB - Indigenous broilers were 88.15 and 60.77 N; 0.005 and 0.019 N.s ; 0.68 and 0.75; and 39.94 and 38.93 N, respectively. Also, the mean values for gumminess, springiness and stringiness were 58.67 and 46.27 N; 0.69 and 0.84 mm; and 5.29 and 2.59 mm, respectively for FUNAAB-Indigenous and exotic breed deep fat fried chicken nuggets respectively. Based on nine-point hedonic scale (1=dislike extremely, 9=like extremely), sensory scores (Table 9), showed the acceptability of fried chicken nuggets for the deep fat fried and air fried chicken nuggets from FUNAB-Indigenous Broiler. It was observed that the products were moderately accepted with deep fat fried chicken nuggets having the sensory rating of (6.63 -7.57) while the air fried nuggets rating ranged between (5.80 - 7.17). No significant ($p>0.05$) differences was observed between the deep fried and air fried chicken nuggets for taste, flavour and aroma. However, significant ($p<0.05$) differences were observed in terms of appearance, texture and overall acceptability.

Table 9: Comparison of Sensory acceptability of fried Chicken Nuggets using optimized frying conditions

Quality Attributes	DF	AF	t –Stat	P(T<=t)2-tail
Taste	7.33	7.17	-0.535	0.60
Appearance	7.43	5.80	-6.498	4.1E-07*
Texture	7.27	6.20	-4.75	5.08E-05*
Flavour	6.63	6.70	0.166	0.867
Aroma	6.83	6.47	-1	0.325
Overall acceptance	7.57	6.57	-4.663	6.45E-05*

*Significance at ($p<0.05$)

Where DF is deep fat frying

AF is air frying

CHAPTER FIVE

5.0 DISCUSSION

Frying process implies a series of complex mass transfer processes between the food and the fluid phase giving. As a result two counter current-fluxes: a stream or water flow from the food to the hot oil and an oil inlet into the food (Krokida *et al.* 2000; Ziaiifar *et al.* 2008). Mechanism of moisture content during frying has been reported as a dehydration process (Mir-Bel *et al.,* 2012: Bingol *et al.,* 2014). In this study moisture content significantly decreases with increase in frying time and frying temperature. Decrease in moisture content observed is attributed to the hot air frying process where food materials heated in a closed system with forced convection of heat transfer is being applied. Rapid hot air is being blown over the food product which causes the transfer of water molecules away from the structure. This leads to the initial rapid decrease in moisture content, because of the loss of surface and unbound inner water. Therefore the rate of moisture loss increases with frying temperature and frying time (Nur'aliaa *et al.,* 2016). These results are consistent with higher heat flux observed in the case of deep-fat frying and are also in agreement with Andrés *et al.* (2013) who compared moisture loss kinetics between air frying and deep fat frying.

Air frying is a technology that permits the reduction of fat content in fried products by 90% (Andres *et al.,* 2012). One of the most important qualities attributes of air fried product is the low oil content and moisture content. High oil content is costly to the processor and can result to an oily and tasteless product. In addition, with the increasing health consciousness of the consumer, the demand for lower oil content of fried foods has increased. Hence the consumer trend is toward less greasy and healthier products (Moreira *et al.,*1999). Since air frying is frying using air and few droplet of oil, therefore little amount of oil is used and absorbed. Decrease in fat content was because of fat drainage from the chicken nuggets samples even when no oil was used during frying process. There is no oil entering the food since there is no other liquid that would replace the water that was removed from the pores because of capillary pressure. (Nur'aliaa *et al.*, 2016), which is also in accordance of air frying technique which get fried product through direct contact between an external emulsion of oil droplet in hot air, from this the amount of oil used during this process is minute (less than 2%) attributing to low oil content of the air fried chicken nugget from FUNAAB- indigenous broilers.

Colour of fried product is an important parameter and to be controlled during processing together with texture, moisture and oil contents. Colour of the fried product is a result of moisture loss, oil migration and maillard reaction that depends on the amount of reducing sugar and amino acids of proteins at the surface, temperature and time of frying (Krokida *et al.,* 2001). The evolution of colour is considered one of the most important quality characteristics of fried products. Heat and mass transfers during frying cause physico-chemical changes that affect the colour development of fried products (Heredia *et al.,* 2014). The steady dehydration of fried product suggests the increase of crusty surface but also the appearance of a brown colour as a result of maillard's reaction (Moyano *et al.,* 2002). Lightness is a critical parameter in the frying industry as it is usually the first quality attributes evaluated by consumers when determining product acceptance. Low lightness values indicate a dark colour and are mainly associated with non-enzymatic browning reactions (Sobukola *et al.,* 2013). The increase in lightness could be explained as a result of luminosity which depends on the amount of free water present on the surface favouring the reflection of light (Hunt, 1980).

Redness was affected by the process variables, in fried chicken nuggets. Elevated a* values can be linked to dark brown colour which are not desirable because this is linked to a burnt unacceptable fried chicken nuggets and this could also be as a result of decreases in acrylamide generation, a carcinogenic compound directly related to increase of redness in air frying conditions (Gokmen *et al.*, 2006). The measurement of the redness in fried products is used to determine the optimal frying point.

In general, high values of redness are not desirable which means that positive values are not advisable because they indicate an orange colour as a result of non-enzymatic browning (the product will be too fried) (krokida *et al.,* 2001). However, increase in redness as a result of increase in temperature could be associated with differences in terms of individual heat transfer coefficient which are lower in hot air frying. b* parameter (indicates yellowness) shows a notable increase as frying time and temperature increased. The higher the value of b* the greater the yellowness and this colour is desirable in fried products. This was also reported by Becalski *et al.*, 2003, Haase *et al.,* 2003 and Pedreschi *et al.,* 2005).

Texture plays an important role in determine the consumer acceptability and perception of any processed food products. Texture of fried products are mainly characterized by the formation of a surface crusts which is also the parameter which is most appreciated by consumers. This crusty texture is a consequence of changes in the external layers of the product at a cellular level. Meat system is influenced by muscle proteins and their interaction with other meat ingredients. Differences in textural properties of fried chicken nuggets could be attributed to changes in physical and chemical properties that take place during frying process. These physico-chemical changes incudes the physical damage caused by cutting the product, the formation of a rough layer with a release of intracellular materials, starch gelatinization, protein denaturalization, water evaporation, expansion, tissue browning and oil ingress (Bouchon *et al.,* 2001). Non meat ingredients are also responsible for changes in textural properties of meat products during frying (Serdaroglu *et al.*, 2005). Among all textural properties, hardness is the most important parameters because it decides the commercial value and consumer's acceptability of the fried meat product (Chambers and Bowers, 1993), and also the firmness and cutting stress of the nuggets (Singh, 1995). Increase in hardness as frying time increased could be associated to lower fat content of the chicken nuggets which is in line with the studies conducted by Ulu (2004) which observed low hardness values in meat balls with higher fat content. According to Lin *et al.* (2000) the higher the temperature, the harder the fried product obtained. The harder texture could possibly be attributed to greater moisture loss during frying. However, the higher frying temperature and time also increased the cutting stress value of the samples and these conditions are related to the hardness value. The longer the frying time the more crust were formed on the surface of the product. The formed crust made the texture harder and cutting stress became high (Evanuarini and Purnomo, 2011). Springiness and cohesiveness behaviours are the indicators reflecting the visco-elastic properties of fried food products. Increase in springiness and cohesiveness could be correlated with the influence of moisture in the product (Hsu and Yu, 1999). Air frying has induced more moisture loss in the product affecting the visco-elastic behaviour and the effects were evident in the springiness and cohesiveness values in the fried products. The changed in Cohesiveness might be attributed to the incorporation of breading and battering of the chicken nuggets. This was in consonance with the findings of Lin and Lin (2004) which reported a decrease in cohesiveness with the increasing level of bacterial cellulose (Nata) in Chinese style meat balls. Gumminess is the product of hardness and cohesiveness and it simulates the energy required to disintegrate a semi-solid food before swallowing. Increased in gumminess could be due to the viscosity of the batter on the fried meat (Youseef and Barbut, 2011). These results were also in agreements with the findings by Ulu (2004). Adhesiveness is the amount of work needed to overcome the attribute force between the surface of the food product and the surface of the meat which it comes in contact with. This is more of surface characteristics and depends on a combined effect of adhesive and cohesive forces, and others including viscosity and visco-elastic (Adhikari *et al.,* 2001). Low adhesiveness could be associated with low water content of food products. Water interactions with solids are the prime cause of adhesiveness in low moisture foods (Adhikari *et al.,* 2001). Chewiness is derived from hardness, cohesiveness and springiness. Chewiness indicates the length of time required to chew a food at a constant rate in order to reduce its consistency so that it may be swallowed. Decreased in chewiness could be attributed to coatings of chicken nuggets, Lin and Lin (2004) also reported decrease in chewiness and Das *et al.* (2006).

When optimized air fried samples and optimized deep fat fried samples were compared, deep fat fried samples had higher values of oil uptake, moisture content, hardness, chewiness, gumminess, stringiness. However, the optimized air fried samples were high in adhesiveness and springiness. Significant ($p<0.05$) difference was observed in cohesiveness. This proves that food cooked via air frying technique has a significantly lower oil content compared to the traditional deep fat fried food. Increase in temperature resulted to increase of moisture loss in food. It was observed that air-fried samples had similar moisture content with the deep fat fried ones. However, when temperature increased with time, the moisture content inside the air-fried products was slightly higher compared to deep fat products. The absence of oil during air frying contributed to the higher value of moisture content. The oil used in deep fat frying entered the voids of the samples and hence lower its moisture content (Moreira *et al.,* 1999). In deep fat frying, the hardness increased significantly, the product changed from rubbery, soggy material to harder products with crispier crust after a long period of frying (Nur'aliaa et al., 2016). Higher value in hardness represents the crispiness of the crust where lower value of hardness indicated lower breaking force required to fracture the sample. Hence, deep fat fried samples had a crispier crust than air-fried samples.

Chicken nuggets fried with air frying were moderately liked compared to deep fat frying. In terms of appearance, and texture (the extent of brownness and evenness of fried samples), there was significant ($p>0.05$) difference between air fried and deep fat samples. Air fried samples appeared dry and puffed when compared with deep fat fried samples which can be attributed to the amount of oil used to fry the samples. In terms of texture, deep fat samples had smoother texture compared to air fried samples which felt tough, and is also in consistent with the lower values of oil and moisture content in air fried samples than deep fat fried samples. With regards to aroma, deep fat fried product gave a fried smell and flavour compared to air fried samples. However, no significant ($p<0.05$) difference was recorded in terms of taste, flavour and aroma.

5.1 CONCLUSION

This study has shown that air frying conditions such as frying temperature and frying time significantly ($p<0.05$) affected some quality attributes of air fried chicken nuggets, which includes: moisture content, oil content, redness in term of colour, hardness, and cohesiveness, compared to deep fat frying.

The optimized air frying conditions for FUNAAB indigenous broilers was frying temperature of 155ºC and frying time of 10 minutes.

No significant ($p>0.05$) difference were observed between the optimized air fried and deep fat frying in terms of taste, flavour and aroma but appearance, texture and overall acceptance were significantly ($p<0.05$) affected.

References

Adhikari B, Howes T, Bhandari BR, Truong V (2001) Stickiness in foods: mechanisms and test methods – a review. Int J Food Prop 4:1–33

Altunakar, B., Sahin, S., &Sumnu, G. (2004). Functionality of batters containing different starch types for deep-fat frying of chicken nuggets. European Food Research and Technology, 218, 318–322. doi:10.1007/s00217-003-0854-5

Andres, A., Arguelles, A., Castello, M.L. and Heredia, A. (2012): mass transfer and volume changes in French fries during air frying. Food Bioprocess Technol., 6: 1917-1924.

Andres, A., Arguelles, A., Castello, M. L. and Heredia, A. 2013. Mass transfer and volume changes in French fries during air frying. Food Bioprocess Technology 6: 1917-1924.

Anjum, M. F., Tasadduq, I., & Al-Sultan, K. (1997). Response surface methodology: A neural network approach. European Journal of Operational Research, 101,65–73.

Adebambo, A.O., Mobegi, V.A., Mwacharo, J.M., Oladejo, B.M., Adewale ,R.A., Ilori, L.O., Makanjuola, B.O., Afolayan, O., Bjonstand, G., Jianlin, H. and Hannotte O.(2010). Lack of phylogeographic structure in Nigerian village chickens as revealed by mitochondrial DNA D-loop sequence analysis. International Journal of Poultry Science 9(5S): 503-507.

Adebambo, A.O., J.M. Mwacharo and O. Hannote, 2009. Characterization of Nigeria indigenous chicken ecotypes using microsatellite markers. Proceedings of the 3rd Nigeria International Poultry Summit. Feb. 22-26. SI. Ola., pp: 84-91.

Adedeji, T.A., O.A. Adebambo and M.O. Ozoje, 2004. Early growth performance of crossbred from different sire strains. Proceedings of the 29th Annual conference of the Genetic Society of Nigeria, Oct. 11-14, University of Agriculture, Abeokuta, Nigeria., pp: 126-129.

Adeyanju, J.A., Olajide, J.O. and Adedeji, A.A. (2016) Development of Optimum Operating Conditions for Quality Attributes in Deep-Fat Frying of Dodo Produced from Plantain Using Response Surface Methodology. Food and Nutrition Sciences, 7, 1423-1433

Ajayi F.O. 2010. Nigerian indigenous chicken: Avaluable genetic resource for meat and egg production. Asian journal of poultry science 4(4):164-172, 2010

Akinpelu, O. R., Idowu, M. A., Sobukola, O. P., Henshaw, F., Sanni, A. S., Bodunde, G., Munoz, L. (2014). Optimization of processing conditions for vacuum frying of high quality fried plantain chips using response surface methodology (RSM). Food Science and Biotechnology. 23, 1121–1128.

Akinoso R., Adeyanju A. (2012) optimization of edible oil extraction from ofada Rice Bran using Response Surface Methodology. Food Bioprocess Technol 5: 1372-1378.

Alberto, d., Gillies, T., Olivier, V., Dominique, D., Anne-Lucie, R. W. (1999). "Kinetics of moisture loss and fat absorption during frying for different varieties of Planatains." Journal of the Science of Food and Agriculture 79: 291-299.

American Heart Association. 11 June 2006. American Heart Association. 11 June 2006.

Andrés-Bello, A., García-Segovia, P., & Martínez-Monzó, J. (2011). Vacuum frying: An alternative to obtain high-quality dried products. Food Engineering Reviews, 3, 63–78.

Ang, J. F. (1990). Reduction of fat in fried foods containing powedered cellulose. . Conference on: Fat and Fiber: Practical Implications for the Calorie Reduce Products. Washington. D.C.

AOAC. 2000. Official Methods of Analysis of AOAC International, 17th ed. Washington,

Barbut, S. 2001. Poultry products processing: an industry guide. CRC Press, Boca Raton, FL.

Barbut, S. 2013. Frying – effects of coating on crust microstructure, texture and colour of meat. Meat Sci. 93:269.

Barbut, S. and I. Pronk. Lelieveld, H. and Y. Motarjemi 2013. HACCP. Poultry and Egg Processing Using HAACP Programs. In: Food Safety Management. (Eds). Elsevier Pub, New York, NY

Baumann, B., Escher, E. (1995). "Mass and heat transfer during deep fat frying of potato slices. Rate of drying and oil uptake. " Lebensmittel- Wissenschaft und-Technologie 28: 395–403.

Becalski, A., Lau, B.P.Y., Lewis, D., and Seaman, S. W. (2003). Acrylamide in foods occurrence, sources, and modelling. Journal of Agricultural and food chemistry, 51 (3), 801-923.

Bett, H.K, R.C. Bett, K.J. Peters, A.K. Kahi and W. Bokelman 2012. Linking utilization and conservation of indigenous chickens resources to value chains Journal of Animal Production Advances. 2: 23-52.

Bingol G, Wang B, Zhang A, Pan Z, McHugh TH. 2014. Comparison of water and infrared blanching methods for processing performance and final product quality of French fries. Journal Food Engineering 11: 135-42.

Bligh, E.G. and W. Dyer. 1959. A rapid method of total lipid extraction and purification. Canadian J. Biochem. Physio. 37: 911-917.

Blumenthal, M.M. (1991). A new look at the chemistry and physics of deep-fat frying. Food Technol. 45(2): 68-71, 94.

Blumenthal, M.M. 1991. A new look at the chemistry and physics of deep-fat frying.

Blumenthal, M.M. 1996. Frying Technology. In Bailey's Industrial Oil and Fat Products. Volume 3: Edible Oil and Fat Products: Products and Application Technology (5th ed.). Y.H. Hui, ed. John Wiley & Sons, Inc. 605 Third Avenue, New York, NY.

Bouchon, P., Aguilera, J. M., & Pyle, D. L. (2003). Structure oil absorption relationship during deep-fat frying. Journal of Food Science, 68, 2711–2716.

Bouchon, P., Hollins, P., Pearson, M., Pyle, D, L., and Tobin, M.J. (2001). Oil distribution in fried potatoes monitored by infrared microspectroscopy. Journal of food science, 66, 918-923.

Browner, W. S., Westenhouse, J., Tice, J. A. (1991). "What if Americans ate less fat? A quantitative estimate of the effect on mortality." Journal of American Medical Association 265: 3285-3291.

Buhri, A. B., Singh, R. P. (1994). Thermal property measurement of fried foods using differential scanning calorimeter. Developments in Food Engineering. T. Yano, Masuno, R. London, Blackie Academic and Professional: 283-285.

Chambers, E. IV; Bowers, J. R. 1993. Consumer perception of the sensory qualities in muscle foods. FoodTechnol. 47(11):116, 118- 120

Da Silva, P., & Moreira, R. (2008). Vacuum frying of high-quality fruit and vegetable based snacks. Lebensmittel–Wissenschaft and Technologie, 41(10), 1758–1767.

Dana D, Saguy IS (2006) Review: Mechanis of oil uptake during deep-fat frying and the surfactant effect-theory and myth. Adv Colloid Interface Sci 128–130:267–272

Das A K., Anjaneyulu A S R., and Kondaiah N. (2006). Development of reduced beany flavour full fat soy paste for comminuted meat products. Journal of Food Science. 71 (5): 395-400.DC

Dueik, V., Robert, P., & Bouchon, P. (2010). Vacuum frying reduces oil uptake and improves the quality parameters of carrot crisps. Food Chemistry, 119, 1143–1149.

Dransfield, E. (1994). Tenderness of meat, poultry and fish. In: Quality Attributes and their Measurement in Meat, Poultry and Fish Products. Pearson, A.M. and Dutson, T.R., (eds.). Black Academic&Professional.UK, p. 289-315.

Fan, L., Zhang, M., & Mujumdar, A. (2005). Vacuum frying of carrot chips. Drying Technolgy, 23, 645–656.

deMan, J.M. 1999. Principles of Food Chemistry, Third Edition. Aspen Publishers, Inc. p. 65-70.

Donhowe, I. G., Fennema, O. R. (1993). "The Effects of plasticizers on crystallinity, permeability, and mechanical properties of methylcellulose films." Journal of Food Processing and Preservation 17: 247-257.

Erickson, B.E. 2004. Finding acrylamide. Anal. Chem. 76(13): 247A-248A.

Esan, T.A., Sobukola, O.P., Sanni, L.O., Bakare, H. A., and Munoz, L. (2015). Process optimization by response surface methodology and quality attributes of vacuum fried yellow fleshed sweet potato (Ipomea batatas L.) chips. Food and Bioproducts Processing, 95, 27-37.

FAOSTAT, 2007. Food and Agricultural Organization statistical databases. CDROM.

Farkas, B. E., & Singh, R. P. (1991). "Physical properties of air-dried and freeze-dried chicken white meat." Journal of Food Science 56(3): 611–615.

Farkas, B.E., R.P. Singh and T.R. Rumsey. 1996. Modeling heat and mass transfer in immersion frying. I. Model development. J. Food Engr. 29: 211-226.

Fellows, P. 2000. Food Processing Technology: Principles and Practice, 2nd edition. CRC Press, LLC, Boca Raton, FL.

Fiszman, S. M., Salvador, A., & Sanz, T. (2005). Effect of the addition of different ingredients on the characteristics of a batter coating for fried seafood prepared without a pre-frying step. Food hydrocolloids, 19, 703–708.

Flegal, K.M., M.D. Carroll, C.L. Ogden, and C.L. Johnson. 2002. Prevalence and trends in obesity among US adults, 1999-2000. 288: 1723-1727.

Gamble, M.H., P. Rice and J.D. Selman, 1987. 28. USDA, 2011. National nutrient database for standard Relationship between oil uptake and moisture loss reference. Web site: (http://ndb.nal.usda.gov/). during frying potato slices from c.v. Record UK. 29. Kenawi, M.A., 2003 Chemical composition, Tubers. Intern. J. Food Sci. and Technol., 22: 233-241.

Kumar D, Singh BP, Kumar P. 2004. An overview of the factors affecting sugar contents of potatoes. Ann Appl Biol 145: 247-56

Gamble, M.H., Rice, P., 1987. Effect of pre-fry drying on oil uptake and distribution in potato chip manufacture. International Journal of Food Science and Technology 22 (5), 535–548.

Garayo, J. and R. Moreira. 2002. Vacuum frying of potato chips. J. Food Engr. 55: 181-191.

Garcia, M. A., Ferrero, C., Bertola, N., Martino, M., Zaritzky, N. (2002). "Edible coatings from cellulose derivatives to reduce oil uptake in fried products." Innovative Food Science and Emerging Technologies 3: 391-397.

Gokmen, V., Palazoglu, T.K., and Senyuva, H.Z. (2006). Relation between the acrylamide formation and time-temperature history of surface and core regions of French fries. Journal of food Engineering 77(4), 972-976.

Granda, C. and R.G. Moreira. 2005. Kinetics of acrylamide formation during traditional and vacuum frying of potato chips. J. Food Proc. Engr. 28: 478-493.

Gueye. E>F., 2003. Production and consumption trend in Africa. World poultry. 19:12-14.

Guillaumin, R. 1988. Kinetics of Fat Penetration in Food. Pp82- 92.

Haase, N. U., Mattaus, B., and Vosmann, K. (2003). Acrylamide formation in foodstuffs-minimising strategies for potato crisps. Deutsche Lebensmittel-Rundschau 99, 87-90.

Heredia A., Castello M.L., Arguelles, A., and Andres A. (2014). Evolution of mechanical and optical properties of French fries obtained by hot air-frying. LWT – Food Science and Technologh 57, 755-760.

Herly Evanuarin and Hari Purnomo (2011). physical and organoleptic quality of chicken nuggets fried at different temperature and time. Journal Agric food Tech, 1 (8) 133- 136

Hsu, S.Y. and S.H. Yu, 1999. Effects of phosphate and Serdaroglu, M. and O. Degrmencioglu, 2004. Effects of water on qualities of low-fat emulsified meatball. J. Food Eng., 39: 123-130.

Hunt, J.W.G, (1980). Measuring colour. Ellis Horwood Ltd, ISBN 0-7458-0125-0.

Jideani, V. A., Oloruntoba, R. H., & Jideani, I. A. (2010). Optimization of Fura production using response Surface Methodology. International Journal of Food Properties, 13(2), 272-281.

Keller, C., Escher, F., Solms, J. (1986). "A method for localizing fat distribution in deep fat fried potato products." Lebensmittel-Wissenschaft und Technologie 19: 346-348.

Krokida, M.K., Orepoulou, V., and Maroulis, Z. B. (2000). Water loss and oil uptake as a function of frying time

Krokida, M.K., Orepoulou, V., and Maroulis, Z. B. and Marinos-Kouris, D. (2001): Deep fat frying of potato strips- quality issues. J. Drying Tech. 19: 879-935.

Krokida, M. K., Oreopolou, V., Maroulis, Z. B., & Marinos-Kouris, D. (2001c). Colour changes during deep far frying. Journal of Food Engineering, 48, 219–225.

Kumar, D., Prasad, S., and Murthy, G. S. (2014). The optimization of microwave-assisted hot air drying conditions of okra using response surface methodology. Journal of Food Science and Technology, 51(2), 221-232.

Kuczmarski, R.J., K.M. Flegal, S.M. Campbell and C.L. Johnson. 1994. Increasing prevalence of overweight among US adults: the National Health and Nutrition Examination Surveys, 1960 to 1991. J. Am. Med. Assn. 272: 205-211.

Levine, L. 1990. Understanding frying operations, Part I. Cereal Foods World. 35: 272-273.

Levine, L. 1990b. Understanding frying operations, Part II. Cereal Foods World. 35: 514- 517.

Lin, S., Huff, H. E. and Hsieh, H. 2000. Texture and chemical characteristics of soy protein meat analog extruded at high moisture. Journal of Food Science 65 (2): 264-269.

Lin K W., and Lin H Y., (2004). Quality characteristics of Chinese-style meatballs containing bacterial cellulose (Nata). Journal of Food Science. 69: 107-111.

Lukman, I., Huda, N. and Ismail, N. 2009. Physicochemical and sensory quality of duck nuggets containing different type of flour. Paper Presented at 11th ASEAN Food Conference, 21-23 October 2009, Brunei Darussalam

Magdelaine, P., Spiess, M. P., And Valceschini, E. 2008. Poultry Meat Consumption Trends in European. World's Poultry Science Journal, 64(01): 53–64.

Mallikarjunan, P., Chinnan, M. S., Balasubramaniam, V. M., Phillips, R. D. (1997). "Edible coatings for deep fat frying of starchy products." Lebensmittel-Wissenschaft und Technologie 30: 709-714.

Mallikarjunan, P., M.O. Ngadi, M.S. Chinnan. 2009. Breaded Fried Foods, Taylor and Francis: Boca Raton, FL. 180p.

Mallikarjunan, P. 2001. The use of edible coatings and vacuum packaging to improve the shelf- life of Cavendish bananas. Engineering Food, Proceedings of the Eighth International Congress on Engineering and Food (ICEF8)

Mariscal, M. And Bouchon, P. 2008. Comparison Between Atmospheric and Vacuum Frying of Apple Slices. Food Chemistry, 107(4), 1561–1569.

Mellema, M. 2003. Mechanism and Reduction of Fat Uptake in Deep-Fat Fried Foods. Trends in Food Science and Technology, 14, 364-373.

Mengesha, 2012. Indigenous chicken production and the innate characteristics. Asian Journal of poultry science 6, 56-64.

Mehta U, Swinburn B. 2001. A review of factors affecting fat absorption in hot chips. Crit Rev Food Sci Nutr 41(2): 133-54.

Meyers, M. A. (1990). Functionality of hydrocolloids in batter coating systems. Batters and breadings in food processing. R. L. K. Kulp. St. Paul, The American Association of Cereal Chemists.: 117–141.

Mir-Bel, J., Oria, R., & Salvador,M. L. (2012). Influence of temperature on heat transfer coefficient duringmoderate vacuumdeep-fat frying. Journal of Food Engineering, 113(2), 167–176.

Mittelman, N., Mizrahi, S., Berk, S. (1984). Heat and mass transfer in frying, in engineering and food. Engineering Sciences in the Food Industry. B. M. Mckenna. London, Elsevier Applied Science. 1:21-25.

Minolta, K. 1998. Precise color communication. Color control from perception to instrumentation, Osaka, Japan.

Moreira, R. G., Sun, X., and Chen, Y. (1997): factors affecting oil uptake in tortilla chips in deep-fat frying. J Food Eng 31:485-98.

Moreira, R.G. and M.A. Barrufet. 1998. A new approach to describe oil absorption in fried foods: a simulation study. J. Food. Engr. 35: 1-22.

Moreira, R.G., M.E. Castell-Perez and M.A. Barrufet, 1999. Deep-Fat Frying fundamentals and applications. Aspen Publishers, Inc., Gaithersburg, Maryland, pp: 75-104.

Moyano, P. C., Rı´oseco, V. K., & Gonzale´z, P. A. (2002). Kinetics of crust color changes during deep-fat frying of impregnated French fries. Journal of Food Engineering, 54, 249–255.

Moyano, P. C. and Pedrechi, F. (2006): Kinetics of oil uptake during frying of potato slices: effect of pre-treatments. LWT-Food Science and Technology, 39, 91-98.

Munoz, A. M. 1986. Development and application of texture reference scales. Journal of Sensory Studies 1: 55-83.

Myers, R. H., & Montgomery, D. C. (1995). Response surface meth-odology: Process and product optimization using designed experiments. New York: Wiley

Myers, R.H. and Montgomery D.C. (2002). Respose surface methodology. Product and process optimisation using designed experiments. 2nd Edition, John Wiley and sons, New yorks.

Ngadi, M. O., Watts, K.C., and Correia, L.R. (1997). "Finite element method modeling of moisture transfer in chicken drum during deep fat frying." Journal of Food Engineering 32(1): 11-20.

Olowofeso, O. 2005. Estimation of genetic diversity and genetic distances of chicken populations in Haimen-China with two-fold techniques. Ph.D. Thesis, Yangzhou University, Yangzhou, P. R. China.

Oluwatosin O, Olawoyin E, Agiang A, De Neji C. And Iso E: 2007. Nutritional Evaluation of the Thigh and Breast Muscles of Four Cockerel Strains. African Journal of Animal aBiomedicalSciences 2(2): 26-31.

Oluyemi, J. A. And Roberts, 2000. Poultry Production in Warm, Wet Climate. Second Edition Spectrum Books, Ltd, Ibadan. Pp 190

Omeje, S.S.I. And Nwosu, C.C. 1988. Utilization of The Nigeria Chicken in Poultry Breeding Assessment of Crossbreed Heterosis in Growth and Egg Production. Journal of Animal Breedingand Genetics 106:417-425.

Parinyasiri, T, and T.C. chen 1992. Yields and breading dispersion of chicken nuggets during deep fat frying as affected by protein content of breading flour. Journal food process. Journal food process preserv. 15: 369-376.

Pedreschi, F, Moyano, P. Kaack, K and Granby k (2005). Colour changes and acrylamide formation in fried potato slices. Food Research Intternational 38 (2005) 19

Pedreschi, F, Kaack, K. (2006). Acrylamide content and colour development in fried potato strips. Food Research International, 39(1), 40-46.

Pedreschi, F. And Moyano, P. 2005. Effect of Pre-Drying On Texture and Oil Uptake of Potato Chips. LWT - Food Science and Technology, 38:99-604.

Pedreschi, F., Moyano, P., Santis, N., And Pedreschi, R .2007 Physical Properties of Pre-Treated Potato Chips. Journal of Food Engineering 79:1474–1482

Peters, S. O. 2000 “Genetic Variation in The Reproductive Performance of Indigenous Chicken and The Growth Rates of Its Pure and Half Bred Progeny”, M.Sc. Thesis Dept. Of Animal Breeding and Genetics, Univ. Of Agric. Abeokuta: 120.

Poirier, P., T.D. Giles, G.A. Bray, Y. Hong, J.S. Stern, F.X. Pi-Sunyer and R.H. Eckel. 2006. Obesity and cardiovascular disease: Pathophysiology, evaluation, and effect of weight loss. Circulation. 113(6): 898-918.

Qiao, J., N. Wang, M.O. Ngadi, And S. Kazemi. 2007. Predicting Mechanical Properties of Fried Chicken Nuggets Using Image Processing and Neural Network Techniques. Journal of Food Engineering 79(3): 1065–70.

Rao, V.N.M. & Delaney, R.A.M. (1995). An engineering perspective on deep-fat frying of breaded chicken pieces. Food Technol. 49(4): 138-141.

RIM (Resources inventory and management Ltd), 1992, Nigeria national livestock survey. Federal department of livestock and pest control services Abuja, Nigeria, pp 287.

Ruiz-Roso, B. and G. Varela. Health issues. In Frying: Improving Quality. J.B. Rossell, ed. Cambridge, UK: Woodhead Publishing Limited. 59-84.

Sayon-Orea, C.; Bes-Rastrollo, M.; Gea, A.; Zazpe, I.; Basterra-Gortari, F.J.; Martinez-Gonzalez, M.A. Reported fried food consumption and the incidence of hypertension in a mediterranean cohort: The sun (seguimiento universidad de navarra) project. Br. J. Nutr. 2014, 112, 984–991.

Saguy, I.S. And Pinthus, E.J. 1995. Oil Uptake During Deep-Fat Frying: Factors and Mechanism. Food Technol. 49(4): 142-145, 152.

Sahin, S., Sastry, S. K., And Bayindirli, L. 1999. Heat Transfer During Frying of Potato Slices. 3:19–24.

Sahin, S.,AndSumnu, S.G., 2009.Advance In Deep-Fat Frying Of Foods Pp1–4

Serdaroglu, M., G. Yildiz Turp and K. Abrodimove, 2005. Quality of low-fat meatballs containing legume flours as extenders. Meat Sci., 70: 99-105.

Schoeninger, V., Coelho, S. R. M., Christ, D., & Sampaio, S. C. (2014). Processing parameter optimization for obtaining dry beans with reduced cooking time. LWT - Food Science and Technology, 56(1), 49-57

Shukla, T. P. (1993). "Batter and Breading for Traditional and Microwavable Foods. Cereal Foods World 38(9): 701-702.

Singh, R.P. 1995. Heat and Mass Transfer in Foods During Deep-Fat Frying. Food Technol. 49(4): 134-137.

Singh, R.P.1995. Heat and mass transfer in foods during deep-fat frying. Food Technology 4:134-137

Sobukola, O.P, Awonorin, S.O, Sanni, L.O, Bamiro, F.O. 2010 Optimization of Pre-Fry Drying of Yam Slices Using Response Surface Methodology. International Journal of Food ProcessEngineering 33: 626-648.

Sobukola, O.P, Awonorin, S.O, Sanni, L.O, Bamiro, F.O. 2008 Optimization of Blanching Conditions Prior to Deep Fat Frying of Yam Slices. International. Journal of Food Process Engineering11 (2): 379-391

Soorgi, M., Mohebbi, M., Mousavi, S. M. and Shahidi, F. 2012. The effect of methylcellulose, temperature, and microwave pretreatment on kinetic of mass transfer during deep fat frying of chicken nuggets. Food and Bioprocess Technology 5 (5): 1521-1530.

Sravan, L., Jaspreet, S. S., Pawan, S. T., Leslie, D., And Christine, A. 2013 Experimental Study On Transport Mechanisms During Deep Fat Frying of Chicken Nuggets. LWT – Food Science andTechnology, 50(1):110–119.

Suderman, D. R. (1983). Use of batters and breadings on food products: A review. In Batter and breading technology, . Westport, CT, AVI Publishing Company.

Sun, X., And Moreira, R.G. 1994. Oil Distribution in Tortilla Chips During Deep-Fat Frying. ASAE Meeting. St. Joseph, Mich. Paper #94-6506.

Szczesniak AS (1975) Texture characterization of temperature sensitive foods. J Texture Stud 6:139–156

Szczesniak, A. S., Brandt, M. A. and Friedman, H. H. 1963. Development of standard rating scales for mechanical parameters and correlation between the objective and sensory methods of texture evaluation. Journal of Food Science 28: 397-403.

Tareke, E., P. Rydberg, P. Karlsson, S. Eriksson and M. Tornqvist. 2000. Acrylamide: A cooking carcinogen? Chem. Res. Toxicol. 13: 517-522.

Tareke, E., P. Rydberg, P. Karlsson, S. Eriksson and M. Tornqvist. 2002. Analysis of acrylamide, a carcinogen formed in heated foodstuffs. J. Agric. Food Chem. 50: 4998-5006.

Tarmizi AHA, Ismail R. 2008. Comparison of the frying stability of standard palm olein and special quality palm olein. J Am Oil Chem Soc 85(3):245-251.

Thompson, J., 2002. Managing meat tenderness. Meat Sci. 62, 295-308.

Ufheil, G., & Escher, F. 1996. Dynamics of Oil Uptake During Deep-Fat Frying of Potato Slices. 29(7), 640-644.

Ulu, H., 2004. Effect of wheat flour, whey protein concentrate and soya protein isolate on oxidative process and textural properties of cooked meatballs. Food Chem., 87: 523-529.

Varela, G., Bender, A. E., Morton, I. D. (1988). Frying of food: Principles, changes, new approaches. Chichester, U.K, Ellis Horwood Ltd.

Vitac, O. (2000). Caracterisation experimentale et modelisation de l'' operation de friture. Massy, France, Ecole Nationale Superieure des Industries Agricoles et Alimnetaires, Ph. D. Thesis: 262 pp.

Youssef, M. K. and Barbut, S. (2011). Fat reduction in comminuted meat products-effects of beef fat, regular and pre-emulsified canola oil. Meat Sci. 87: 356-360.

Ziaiifar AM, Achir N, Coartois F, Trezzani I, Trystram G. 2008. Review of mechanisms, conditions, and factors involved in the oil uptake phenomenon during the deep fat frying process. Intl J Food Sci Technol 43(8): 1410-23.