HEAT TRANSFER AND QUALITY CHARACTERISTICS OF BREADED AND NON-BREADED CHICKEN NUGGETS BAKED IN A RADIANT WALL OVEN

by

EMINE OZEN

(Under the Direction of Rakesh K. Singh)

ABSTRACT

A Radiant Wall Oven (RWO) was used to bake breaded and non-breaded chicken nuggets with lower fat content than that of fried nuggets with similar quality. The nuggets were baked at temperatures ranging from 347 to 407° C with different processing times, fried at 190° C for 2 min, and baked at 225° C for 10 min in a conventional oven (CO). The heat transfer and quality of the RWO baked nuggets were compared to those of fried and CO baked nuggets. Non-breaded nuggets experienced the highest heat flux and heat transfer coefficients followed by corn and chickpea flour breaded nuggets, respectively. The linear distance and lightness of the RWO baked nuggets were not different from those of the control treatments. The moisture content of the RWO baked nuggets was significantly higher and the fat content of the RWO baked breaded nuggets was lower than that in the fried nuggets.

INDEX WORDS: Color, Chicken Nugget, Infrared Heating, Radiant Heat Transfer Coefficient, Radiant Wall Oven, Texture

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EMINE OZEN

B.S. Pamukkale University, Turkey, 2013

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA
2018

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by

Emine Ozen

Major Professor: Rakesh K. Singh
Committee: William L. Kerr
Fanbin Kong

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
May 2018

DEDICATION

This thesis work is dedicated to my family, who has been a constant source of support and encouragement during the challenges of graduate school and life. I am truly thankful for having you in my life.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. Rakesh Singh, for the patient guidance, encouragement and advice he has provided throughout my time as his student. I have been extremely lucky to have a supervisor who cared so much about my work, and who responded to my questions and queries so promptly. I would like to thank Dr. Kerr and Dr. Kong for their assistance with my research. I would also like to thank Turkish Ministry of Education for giving me this opportunity to study abroad. I thank to all of my friends for their friendship and help in research. Additionally, a warm acknowledgement to Carl Ruiz for his help in the pilot plants and his friendship.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The chicken nugget was introduced by the fast-food industry in the late 1970s. It has enhanced importance and a high consumption rate compared to other poultry products. Therefore, it represents the biggest success story in the poultry industry. To manufacture this product, heat treatments such as immersion frying, and baking are essential because the main goal is to improve the sensory characteristics (texture and color) of the nuggets (Barbut 2012). The most popular food preparation method is immersion frying because it is an easy way to prepare meals for consumers, it has low cost, and produces good taste. Immersion frying is associated with attractive sensorial properties like golden color, a crunchy crust, a tender and moist core, and flavor. The fried products also benefit producers since they are value added products. Although the fried food products have benefits to producers and consumers, there are numerous disadvantages of this type of product. After the frying process, the fried products have excessive oil content. Millions of pounds of this type of food product are consumed each year in the United States. Because of the high oil content, the fried foods may significantly impact consumer health by causing obesity and obesity-related health problems. Additionally, the gigantic fried food industry affects the environment due to oil waste disposal. To get rid of oil waste, caustic cleaning agents must be used properly. Therefore, an alternative to the immersion frying process that provides the same attractive sensorial properties and preparation convenience is needed to protect consumer heath, to increase the processors' profit by decreasing oil use, and to protect the environment by reducing oil waste.

The goal of this research was to produce baked products in short time with low fat content mimicking the quality of fried products. It was also envisioned that the determination of overall heat transfer coefficient facilitates the understanding of its relationship with the product quality. This relationship also provides guidance that helps us compare similar types of equipment and processing conditions.

The objectives of this study are

I. To experimentally determine the overall heat transfer coefficient of RWO processing during the baking of chicken nuggets with different breading ingredients and non-breaded chicken nuggets

II. To analyze the color and texture of chicken nuggets baked in RWO

III. To compare the color and texture of chicken nuggets baked in RWO with chicken nuggets baked in a convection oven and with fried chicken nuggets.

References

Barbut, S. (2012). Convenience breaded poultry meat products - New developments. *Trends in Food Science & Technology*, 26, 14–10. doi:10.1016/j.tifs.2011.12.007

CHAPTER 2

LITERATURE REVIEW

Breading

Breading refers to cereal-based flour mixes or dry bread crumbs. Breading contains leavening agents and seasonings to improve the texture, color, and flavor of baked or fried foods. The breading of chicken nuggets typically includes unprocessed flour and seasonings, and it is called "batter" when the same preparation is mixed with water (Chen et al. 2016).

Suderman and Cunningham (1983) divided breading into two categories. The first type of breading includes crackers or bread crumbs applied to food products in a dry form, and the second type of breading includes seasoning, flour, and starch applied over battered or moistened foods. The coating contributes a crisp texture and a desirable color; additionally, it prevents moisture loss but also controls oil uptake (Dogan et al. 2005).

Coating food with flour is the most economical and the simplest way to have surface browning especially for fried products (Barbut 2015). Corn products have a broad range of functional effects on the coating of food products, affecting color, flavor, texture, oil absorption, and moisture retention. Corn coating has important effects on the color of the coated food products. Yellow corn contains carotene, which provides a good natural color. Therefore, corn-coated food products need no added color in their ingredients. Yellow corn provides a highly desirable golden-brown color on the surface and enhances the appearance of the food. Increasing the ratio of corn flour in the coating blend increases crispness and reduces puffiness in coating systems. The surface appearance of corn-flour-coated foods is the result of the combination of protein structure and content, moisture content, the flow characteristic of batter systems, leavening retention, and other factors. Because many factors affect surface appearance, no specific factor has been shown to explain the effect of corn flour on the appearance of foods coated with it (Burge 1990). Chickpeas (Cicer arietinum L.) are the most consumed legume crop grown around the world. Chickpeas are rich in essential amino acids and a good source of carbohydrates. They are beneficial for human health and prevent cardiovascular disease, type 2 diabetes, digestive diseases, and some types of cancers (Jukanti et al. 2012). The coating of fried foods controls the texture, color, and fat content of the food. The higher protein level in the coating increases crispness, roughness, and brittleness, and it also makes the darker color (Olewnik and Kulp 2016). Proteins improve crispness by preventing the escape of gas in their structure (Davis 1983). Barutcu et al. (2009) used different kinds of flour (wheat, corn, chickpea, rice, and soy) to bread chickens. They found that microwave baked chicken had a darker color and that its moisture content decreased when the flour with a high level of protein was used

Color

The appearance of a food product, especially its color, is the first quality parameter assessed by consumers (Lawless and Heyman 2010). Colorimeters are used to instrumentally determine the color of a product. The color is defined by three-dimensional color space CIE (International Commission on Illumination). L is the coefficient of lightness ranging from 0 to 100. From black to white (McGuire 1992), chroma or saturation is intensity of the color in the same lightness (Barrett and et al. 2010), and the hue angle represents red-purple color (0°), yellow (90°), bluish-green (180°) and blue (270°) (McGuire 1992).

The Maillard reaction improves the color of chicken nuggets because of the reducing sugars in the breading compositions. The reaction rate depends on the water activity, pH, the environment temperature, and the food composition (Carbasa and Ibarz, 2000). Researchers have measured the effect of different coating types and different processing conditions on the color of nuggets. Ngadi and others

(2007) studied the effect of hydrogenated and non-hydrogenated canola oil with different frying times on color. They stated that when the hydrogenation degree decreased, and a shorter processing time was used, the chicken nuggets had a lighter color. Dogan et al. (2004) found that the degree of the Maillard reaction of the fried battered chicken nuggets increased by protein content. They also compared different protein types and found that egg albumen (3%) and soy protein isolate (3%) coated nuggets had a significantly lighter color compared to chicken nuggets coated batter without protein addition. Whey protein isolate (3%) had the darkest and reddest color. Albert et al. (2014) reported that the coating type (egg or commercial batter and the batter coating number—one or two) did not affect the saturation and hue angle of the chicken nuggets. Rahimi et al. (2018) used different types of infrared radiation cooking for chicken nuggets. They reported that pre-frying-IR cooking had a darker color and that IR cooking-post frying had a more yellowish color. They noted that the nuggets had darker oleo when a higher intensity of infrared processing was used. Adedeji and Ngadi (2011) coated chicken nuggets with batters formulated with different ratios of wheat flour, rice flour, and carboxymethyl cellulose. They concluded that carboxymethyl cellulose coated nuggets had significantly higher lightness, whereas the saturation of batter formulated with rice flour and hydrocolloid had higher saturation. The hue value remained the same for all samples. Gokce et al. (2015) used different batter formulations including wheat, corn, soy, and rye flours to coat chicken nuggets for deep fat frying. Although all the different coated chicken nuggets had similar redness values, and the batter formulated with corn flour had the highest degree of yellowness.

Texture

Crispness is one of the most important textural characteristics of food products all around the world. It indicates the level of freshness and the quality of a food product. It is a good characteristic to have pleasing textural contrasts with textural characteristics of food products. Crispiness is important in texture combinations, and it signifies ideal cooking (Antonova, 2011).

Although it is the most important textural attribute, there is no universally accepted definition for crispness. There is no exact perception for crispness, too. It is the correlation of the loudness of sound and oral tactility when a crisp food is bitten (Vickers and Christensen, 1980).

There are many instrumental analysis methods to determine the crispness of food products, but the best method has not been found because of the different perceptions of crisp foods. Although there is no best instrumental method, the most objective determination of crispness is perhaps the measurement of mechanical properties. Mechanical measurements indicate the structure of the food products in terms of resistance to a compression of a texture analyzer probe (Antonova, 2011).

Vickers and Christen (1980) analyzed the crispness of the food products (celery, turnips, white radish, gingersnap, Triscuit, waverly wafers, rye crisp, lorns doone, and saitine with different levels of water activation). They compared sensory crispness with instrumental crispness. Young modulus in instrumental snap test indicated the closest relation to sensory crispness. It was found that the perception of crispness is a mostly vibrotactile acoustical sensation. Snapping tests are good for determining the crispness of crisp products, but they are not appropriate for breaded chicken products (chicken nuggets or chicken breasts). Due to the relationship between crispness and vibrotactile acoustical sensation, acoustical texture measurement was used to determine breaded chicken products' crispness (Maskat and Kerr 2002; Albert et al. 2014). The crispiness of chicken nuggets can be evaluated by mechanical and acoustic measurements such as frequency and intensity of the force and sound (Maskat and Kerr 2002; Albert et al. 2014). Maskat and Kerr coated chicken nuggets with different particle sizes. The compressive force for firmness was measured, and the acoustical test for crispness was conducted. Although the firmness significantly increased by the particle size of breading ($P<0.05$), there was no significant difference in the acoustical test (P<0.05). Albert et al. (2013) evaluated the effect of the number of coatings (one or two) on the texture and sensory characteristics of microwave breaded chicken nuggets. The nuggets were breaded with a one-layer coating including a beaten pasteurized egg or batter and breading or a two-layer coating including a one-layer pasteurized egg or batter and breading and an additional one-layer pasteurized egg or batter and breading. They used sensory assessment, an 8-member quantitative descriptive analysis (QDA ®), a texture analyzer to cut nuggets with a light knife blade, and an acoustical detector to determine the crispness of the chicken nuggets. They concluded that there was no difference between the max Sound Pressure Level (SPL), but two-layer chicken nuggets had the subtle difference in terms of the number of sound peaks and the number of force peaks. There was no significant correlation between sensory and texture analyses to determine crispness (P<0.05).

Radiant Heat Transfer

Heat is transferred via three methods; conduction, convection and radiation. Conduction is molecular heat transfer between neighboring molecules of solid materials. Convection is molecular heat transfer between molecules in different locations. Radiation heat transfer is transmitted by electromagnetic waves through space. The electromagnetic waves (between 0.1 μm and 1000 μm) emitted by a hot source are absorbed by a lower temperature surface, which increase the energy level of that surface and produce heat (Toledo 2007; Lienhard and Lienhard 2016).

There are many electromagnetic wave spectra shown in Table 2.1. Thermal radiation is between 0.1 μm and 1000 μm wavelengths. Infrared radiation is from 0.7 μm to 1000 μm. Near infrared radiation is from 0.7 μm to 30 μm and far infrared radiation is from 30 μm to 1000 μm (Sakai and Hanzawa 1994). When food materials are exposed to Infrared radiation (IR), they absorb heat energy generated from IR like radiofrequency (RF). Efficiency, wavelength, and reflectivity characteristics of IR make this method of heat transfer more useful than other applications of heat transfer. Its higher thermal efficiency and fast heating rate/response time attracts food processors to this thermal processing. (Sakai and Hanzawa 1994).

In radiative heating, energy balance is calculated by the terms of reflection, absorption, and transmission of radiation. Reflectivity (ρ) is the ratio of the reflected part of incoming radiation to the total incoming radiation, absorptivity (α) is the ratio of absorbed radiation to incoming radiation, transmissivity (τ) is the ratio of transmitted radiation to the total incoming radiation. The energy balance can be calculated by an equation;

$$\rho+\alpha+\tau = 1 \qquad (1)$$

This fundamental principle is important for understanding infrared radiation heat transfer because heat flux can be calculated to figure out the relation of IR heat transfer to penetration depth in food materials (Jun and others 2011).

Different surfaces have their own abilities to absorb radiation. These surfaces can be classified as black or gray bodies. A black body absorbs all incident radiation on it. Emissivity (ε) is a property that is a ratio of emitted radiation at a given temperature. Emissivity is 1 for a black body. If emissivity is lower than 1, the surface is considered a gray body (Toledo 2007). The spectral black body emissive power distribution was reported by Max Planck in 1901. This distribution is known Planck's law and it is applied to calculate the radiative heat flux value in a certain temperature for a product (Jun et al. 2011).

$$E_{b\lambda}(T,\lambda) = \frac{2\pi h c_0^2}{n^2\lambda^5[e^{hc_0/n\lambda kT} - 1]} \qquad (2)$$

In the equation, k is Boltzmann's constant (1.3806×10^{-23} J/K), n is the refractive index of the medium, λ is the wavelength (μm), T is the source temperature (K), c_o is the speed of light (km/s), and h is Planck's constant (6.626×10^{-34} J · s).

Wien's displacement law gives the wavelength when emissivity of the radiation is at its maximum.

$$\lambda_{\max} = \frac{2898}{T} \tag{3}$$

T is the temperature of the source and λ_{max} is the maximum wavelength. When the maximum wavelength is known, λ_{max} can be derived from equation (3) (Jun et al. 2011).

The radiation flux energy from a body is described as e_λ (T) W/m^2 according to the Stefan-Boltzmann law:

$$e_\lambda(\lambda, \mathrm{T}) = \frac{\partial e(\lambda,\mathrm{T})}{\partial\lambda} \quad \text{or} \quad e_\lambda(\lambda, \mathrm{T}) = \int_0^\lambda e_\lambda(\lambda, \mathrm{T})\, \partial\lambda \tag{4}$$

$e_\lambda(\lambda,T)$ is the distribution function of radiative flux in λ where the description is called monochromatic emissive power. Stephan described the relationship between $e_\lambda(T)$ and T for black body in 1879 and Boltzmann explained this relationship in thermodynamic terms in 1884. The Stephan-Boltzmann law is:

$$e_b(T) = \sigma T^4 \quad (5$$

σ is the Stephan-Boltzmann constant, 5.67036x10^{-8} W/m^2.K^4 , and T is the absolute temperature (Lienhard and Lienhard 2016). Stefan–Boltzmann's law is used to estimate total amount of heat flux with integration of Planck's law at a given source temperature (Jun et al. 2011).

Infrared Heating Applications

In the past, the main focus of infrared heating was the drying of food products (Ginzburg 1969). However, recently, the relevant areas of food processing with IR are blanching, thawing, pasteurization and other applications like roasting, cooking and frying (Kirmaci 2015).

Kirmaci and Singh (2016) used radiant wall oven (RWO) (Pyramid Food Processing Equipment Manufacturing Inc., RWO-12-36, Tewksbury, MA) paired with steam processing to produce reduced fat baked potato strips. The potato strips were pre-cooked in a steam chamber for 75 or 90 s and then heated in RWO at different temperatures: 450 C for 3 or 3.5 min, at 500 C for 2.5 or 3 min, at 550 C for 1.5 or 2 min. The potato strips baked in RWO were compared to the deep-fried samples at 177 C for 3 min. RWO baked pre-cooked potato strips at 500 C for 3 min and the control group had more similarities than other RWO baked pre-cooked potato strips in terms of texture, chroma, shrinkage and yield, yet contained 86.8% less fat.

Hebbar and others (2004) used a mid-infrared heater (MIR) combined with a hot air heating system to dry vegetables. Drying occurred by convective heat transfer under hot air flow. Drying potatoes and carrots in a combined dryer at 40 C and 80 C with air at a velocity of 1 m/s decreased the drying time by about 48% by consuming less energy, around 63%. Also, it was investigated that combination drying has better results than infrared heating alone (38% energy saving).

Pan and others (2005) used mid and far-infrared heating for blanching and dehydration of various fruits and vegetables. In their study, water and steam were not used because a catalytic infrared blancher/drier was used to blanch and dehydrate fruits and vegetables. For the blanching study, the fruits and vegetables (pears, baby carrots, sweet corn and french fries) were blanched with a radiation energy intensity of 5.7 kW/m^2. After blanching, the vegetables and fruits had a good appearance. For dehydration study, pear cubes were dehydrated with a radiation energy intensity of 2.7 kW/m^2 after the blanching. The texture and appearance were excellent compared with the control samples produced by steam blanching and heated air drying. Additionally, the time saving was about 43.9%.

Particle Size

Particle size is an important parameter for quality of flours and it affects processing and the quality of the products made from flours (Sullivan et al. 1960). There are different techniques for determination of particle sizes for powders including sieve analysis, microscopy, laser diffraction, etc. (Hareland 1994). For particle size measurements of flours, ASABE standards are commonly used (Patwa et al. 2014). Differentiation in particle size affects conductivity, taste, surface reactions mechanical bulk density etc. (Grzechnik and Pitsch 2004). It also affects absorption of the powders. Myers and others (2015) investigated the effect of different particle sizes on spectral properties for inorganic (calcium carbonate, ammonium sulfate, sodium sulfate) and organic compounds (lactose). They found that the reflectance of light generally increased by increase in particle size.

Radiant Wall Oven (RWO)

Radiant Wall Oven (RWO) is a gas-fired IR heater. The RWO is an elliptical tube made of stainless alloy and it emits IR radiation to the product in the far-infrared (FIR) region. The gas flow was automatically controlled to adjust the temperature. The total length of the oven is 113 cm including entrance and exit zone (Fig. 2.1). The wavelength at which maximum emission occurs during RWO processing was 4.54 – 5.15 µm in this study. It heats rapidly while having lower penetration depth of IR radiation. There has not been much research on the radiant wall oven. Kirmaci and Singh (2016) used the RWO to determine product quality of potato strips.

The strips were steamed in a chamber at 99.4 ± 0.3 ºC for 75 or 90 s. Then they fried potato strips at 450 – 550 ºC for 1.5 – 3.5 min and compared to immersion oil fried potato strips. The research resulted that the RWO baked products had similar texture, chroma, shrinkage and yield compared to fried ones.

References

Adedeji, A. A., & Ngadi, M. O. (2011). Microstructural properties of deep-fat fried chicken nuggets coated with different batter formulation. International Journal of Food Properties, 14(1), 68-83.

Albert, A., Salvador, A., Hough, G., & Fiszman, S. (2014). Influence of outer layer formulation on the sensory properties of microwaved breaded nuggets. International Journal of Food Properties, 17(4), 829-841.

Antonova, I. (2001). Determination of crispness in breaded fried chicken nuggets using ultrasonic technique (Doctoral dissertation, Virginia Tech).

Barbut, S. (2015). Principles of meat processing. The science of poultry and meat processing. Univ. Guelph, Guelph, Ontario, Canada.

Barrett, D.M., Beaulieu, J.C., Shewfelt, R. 2010. Color, flavor, texture, and nutritional quality of fresh cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. Critical Reviews in Food Science and Nutrition 50(5):369-89.

Barutcu, I., Sahin, S., & Sumnu, G. (2009). Acrylamide formation in different batter formulations during microwave frying. LWT-Food Science and Technology, 42(1), 17-22.

Burge, R. (1990). Functionality of corn in food coatings. Batters Breadings Food Process., 29-49.

Carabasa, M., & Ibarz, A. (2000). Kinetics of colour development in aqueous glucose systems at high temperatures. Journal of Food Engineering, 44, 81–189.

Chen, R. Y., Wang, Y., & Dyson, D. (2016). Breadings—what they are and how they are used. Batters and Breadings in Food Processing, 169.

Davis, A. (1983). Batter and breading ingredients. Batter and Breading Technology, 16-18.

Dogan, S. F., Sahin, S., & Sumnu, G. (2005). Effects of batters containing different protein types on the quality of deep-fat-fried chicken nuggets. European Food Research and Technology, 220(5-6), 502-508.

Fiszman, S., Sanz, T., & Guerrero-Legarreta, I. (2010). Battering and breading: principles and system development (pp. 35-45). John Wiley and Sons, Hoboken, NJ.

Ginzburg, AS. (1969). Application of infrared radiation in food processing. Chemical and Process Engineering Series. London, U.K.: Leonard Hill.

Gokce, R., Akgun, A. A., Ergezer, H., & Akcan, T. (2016). Effects of Different Batter Formulation on Some Quality Characteristics of Deep-Fat Fried Chicken Nuggets.Tarim bilimleri dergisi Journal of Agricultural Sciences, 22(3), 331-338.

Grzechnik, E. & Pitsch, H. (2004). The Basic Principles of Sieve Analysis [Brochure]. Author. Retrieved February 2018, from http://www.ninolab.se/fileadmin/Ninolab/pdf/retsch/documents/af_sieving_basics_2004_en.pdf

Hareland, G. A. (1994). Evaluation of flour particle size distribution by laser diffraction, sieve analysis, and near-infrared reflectance spectroscopy. J. Cereal Sci., 20(2), 183-190. http://dx.doi.org/ 10.1006/jcrs.1994.1058.

Hebbar, H. U., Vishwanathan, K. H., & Ramesh, N. M. (2004). Development of combined infrared and hot air dryer for vegetables. Journal of Food Engineering, 65(4) 557–563.

Jukanti, A. K., Gaur, P. M., Gowda, C. L. L., & Chibbar, R. N. (2012). Nutritional quality and health benefits of chickpea (Cicer arietinum L.): a review. British Journal of Nutrition, 108(S1), S11-S26.

Jun, S., Krishnamurthy, K., Irudayaraj, J., & Demirci, A. (2011). Fundamentals and Theory of Infrared Radiation. In Z. Pan & G. G. Atungulu (Eds.), Infrared Heating for Food and Agricultural Processing (pp. 1–18). New York, USA: CRC Press.

Kettler, K., Adhikari, K., & Singh, R. K. (2017). Blanchability and sensory quality of large runner peanuts blanched in a radiant wall oven using infrared radiation. Journal of the Science of Food and Agriculture, 97(13), 4621-4628.

Kirmaci, B. (2015). Characterization of Baked Potato Strips Processed in Radiant Wall Oven. The University of Georgia.

Kirmaci, B., & Singh, R. K. (2016). Quality of the pre-cooked potato strips processed by Radiant Wall Oven. LWT - Food Science and Technology, 66, 565–571.

Lawless HT, Heymann H. 2010. Color and appearance. Sensory evaluation of food. Second ed: Springer. p. 283-301.

Lienhard, J. H., IV, & Lienhard, J. H., V. (2016). A Heat Transfer Textbook (Fourth ed.). Cambridge, Massachusetts: Phlogiston Press.

Maskat, M. Y., & Kerr, W. L. (2002). Coating characteristics of fried chicken breasts prepared with different particle size breading. Journal of Food Processing and Preservation, 26(1), 27-38.

McGuire RG. 1992. Reporting of objective color measurements. HortScience 27(12):1254-5.

Myers, T. L., Brauer, C. S., Su, Y. F., Blake, T. A., Tonkyn, R. G., Ertel, A. B., ... & Richardson, R. L. (2015). Quantitative reflectance spectra of solid powders as a function of particle size. Applied Optics, 54(15), 4863-4875.

Ngadi, M., Li, Y., & Oluka, S. (2007). Quality changes in chicken nuggets fried in oils with different degrees of hydrogenatation. LWT-Food Science and Technology, 40(10), 1784-1791.

Olewnik, M., & Kulp, K. (1990). Factors affecting performance characteristics of wheat flour in batters. Batters and breading in foods processing. Minnesota: American Association of Cereal Chemistry, 93-116.

Pan, Z., Olson, D. A., Amaratunga, K. S. P., Olsen, C. W., Zhu, Y., & McHugh, T. H. (2005). Feasibility of using infrared heating for blanching and dehydration of fruits and vegetables. In 2005 ASAE Annual Meeting (p. 1). American Society of Agricultural and Biological Engineers.

Patwa, A., Malcolm, B., Wilson, J., & Ambrose, K. R. (2014). Particle size analysis of two distinct classes of wheat flour by sieving. Transactions of the ASABE, 57(1), 151-159.

R. L. (2015). Quantitative reflectance spectra of solid powders as a function of particle size. Applied Optics, 54(15), 4863-4875.

Rahimi, D., Kashaninejad, M., Ziaiifar, A. M., & Mahoonak, A. S. (2018). Effect of infrared final cooking on some physico-chemical and engineering properties of partially fried chicken nugget. Innovative Food Science & Emerging Technologies, 47, 1-8.

Sakai, N., & Hanzawa, T. (1994, November). Applications and advances in far-infrared heating in Japan. Trends in Food Science & Technology, 5, 357-362.

Sasiela, R. J. (2016). Food coating troubleshooting. Batters and Breadings in Food Processing, 301.

Suderman, D. R., & Cunningham, F. E. (1983). Batter and Breading. AVI Pub. Co.

Sullivan, B., Engebreston, W. E., & Anderson, M. L. (1960). The relation of particle size of certain flour characteristics. Cereal Chem., 37(4), 436-455.

Toledo, R. T. (2007). Fundamentals of Food Process Engineering (Third ed.). New York, NY: Springer Science Business Media, 579.

Table 2.1: Characterizations of electromagnetic waves and their wavelengths (Lienhard and Lienhard 2016)

Characterization	Wavelenght
Cosmic rays	<0.3 pm
Gamma rays	0.3-100 pm
X rays	0.01-30 nm
Ultraviolet light	3-400 nm
Visible light	0.4-0.7 µm
Near infrared radiation	0.7-30 µm
Far infrared radiation	30-1000 µm
Millimeter waves	1-10 mm
Microwaves	10-300 mm
Shortwave radio & TV	300 mm- 10 m
Longwave radio	100 m-30 km

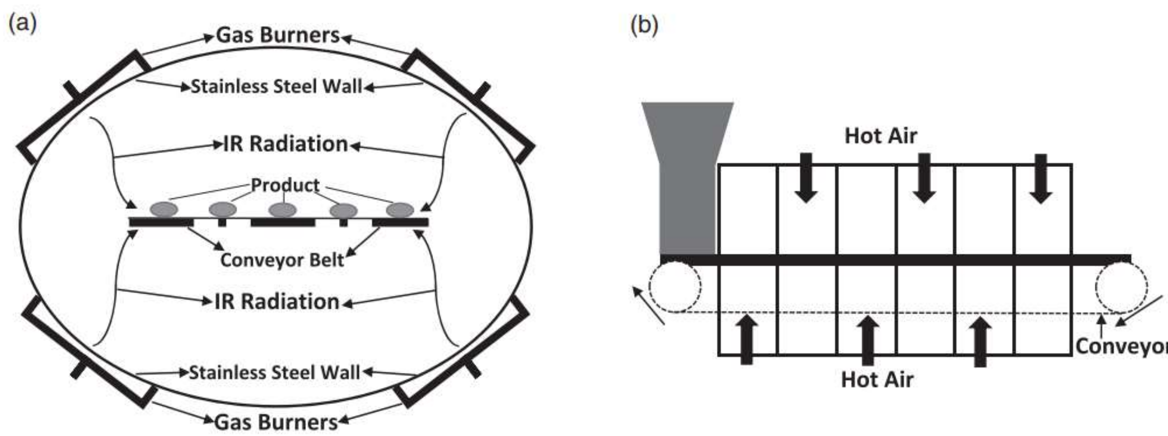

Figure 2.1: Schematic illustration of (a) infrared heating of the radiant wall oven and (b) hot air flow of the oven (Kettler et al. 2017).

CHAPTER 3

HEAT TRANSFER IN BREADED AND NON-BREADED CHICKEN NUGGETS BAKED IN AN RADIANT WALL OVEN[1]

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[1]: Ozen, E. and R.K. Singh. To be submitted to *Journal of Food Engineering*.

Abstract:

A Radiant Wall Oven (RWO) was used to bake chicken nuggets with the different coatings. The overall and radiant heat transfer coefficients were determined for each nugget from the experimental temperature and the heat flux measurements. The baking temperatures ranged between 347ºC and 407ºC with different processing time. The non-breaded nuggets had the highest heat flux and radiant heat transfer coefficients, 46897 ± 429 W/m^2 and 151.1 W/m^{2}K, compared to breaded nuggets. Corn breaded nuggets had higher heat transfer values than chickpea breaded nuggets because the corn flour has greater absorptivity than chickpea flour. A correlation was found between temperature and heat flux for non-breaded and corn breaded chicken nuggets.

Keywords: Infrared Heating, chicken nugget, radiant heat transfer coefficient, heat flux

Practical Application:

Radiant Wall Oven (RWO), an infrared oven was used to bake breaded and non-breaded chicken nuggets and allowed the measuring of heat transfer and evaluate effect of coating type on heat transfer. The non-breaded chicken nuggets at 407ºC had the higher heat transfer. After some improvements, RWO baking can be an alternative to the immersion frying.

Introduction

Fried foods are very popular around the world. The fried chicken nugget is one of the most acceptable fried foods in the United States (Ngadi 1997). It was introduced by the fast-food industry in the late 1970s. It has importance and high consumption rate compared to other poultry products. Therefore, it has one of the biggest success stories in the poultry industry. In order to manufacture this product, heat treatments, such as immersion frying and baking are key processes to improve sensory characteristics (texture and color) of the nugget (Barbut 2012).

Battered and breaded foods have been popular for a long time. Coating meat, poultry, vegetables, and seafood were popular generally for homemakers, food processors and commercial food companies. The importance of coating food products has shifted from homemakers to the restaurants and to the fast food industry. Each batter and breading ingredient affects the product's characteristics; they make important contributions to color, taste, texture, juiciness, and acceptability of the coated food products (Suderman 1983). Predust is used to cover food materials before breading or applying the batter. Predust refers to dry fine material dusted onto the surface of food. This kind of material can be used in water suspension as a batter. Predust can be a mixture of starch, flour, egg whites and gums (Dyson 1990).

Heat is transferred by three different modes: conduction, convection, and radiation. For chicken nuggets in RWO, heat is mostly transferred by radiation in the far infrared region (FIR). The FIR heating is common in non-food industries, such as in the electronic industry for heating and drying. FIR is a new technology for the food industry and is used for baking, drying, pasteurization, and thawing. This heating method is both economical and rapid for producing highly nutritional food products (Sakai and Hanzawa 1994). Radiation heat transfer is independent of convection heat transfer (Toledo 2007). A heater emits the radiation through the air to the food, and the energy is absorbed by the product. When the infrared energy interacts with the food molecules on the surface, it is converted into heat energy. Then, it passes from surface layer of food to the inside by conduction (Sakai and Hanzawa 1994). FIR heating is a processing technique for the food industry and has been adopted by the food industry because of advantages regarding cost and the quality of the food products. Heat is supplied to the food product by electromagnetic waves from the FIR heater. The temperature difference between the heater and the surface of the food determines the rate of energy transferred to the product (Sakai and Hanzawa 1994).

There have been recent efforts to apply infrared heating to the food products and calculation of heat transfer. Nelson III and others (2013) suggested Fryless 100 K radiant fryer with ten heating zones, each zone consists of two-5000 W halogen emitters, as an alternative to the deep fat frying for breaded chicken patties. The product achieved lighter color, 16% less oil and 19% more moisture compared to the immersion frying. Kirmaci and Singh (2016) used Radiant Wall Oven (RWO), an elliptical tube stainless alloy gas-fired infrared heater that produced infrared radiation at 4.54-5.15 μm wavelength bake frozen par-fried potato strips. RWO baked potato strips had dramatically lower fat content and similar texture compared to deep-fat fried ones, but they had different color and moisture content. It was found that overall and radiant heat transfer coefficients had a negative correlation with the texture of baked potato strips. Melito and Farkas (2013) measured quality parameters of gluten-free donuts by comparing infrared baked nuggets to fried ones. The heater was an IR based on quartz halogen radiant emitters. They reported that IR baked donuts had a similar texture to fried donuts but had lower fat content. Kettler and others (2017) used a radiant wall oven working in 4 – 6 μm wavelength to blanch peanuts as an alternative to conventional hot air method. The RWO baked peanuts at 343°C for 1 and 1.5 min, at 316°C for 1.5 min, and at 288°C for 1.5 min did not have a significant difference to the conventional method.

Furthermore, the RWO blanched peanuts had a lower number of split kernel and did not indicate any flavor difference.

Different materials and particle sizes have different absorption in the different wavelengths. Xue and others (2017) measured the spectra of untreated corn flour, and Bashir and Aggarwal (2016) determined spectra of the untreated chickpea flour. It was found that the corn flour has higher absorptivity than chickpea flour in the FIR region. The reflectivity dropped when the particle sizes increased, but the reflectance was stable for large particles (≥ 150 µm) (Myers et al. 2015).

A Radiant Wall Oven (RWO) was used to bake breaded and non-breaded chicken nuggets to calculate heat transfer parameters in this study. The oven is an elliptical stainless alloy that emits infrared radiation to the food products by a gas-fired IR heater in the far-infrared (FIR) region. The wavelength which maximum emission is reached was between 4.54 – 5.15 µm for this study. The surface of the product in RWO was rapidly heated because of the lower penetration depth of the infrared radiation. Therefore, the brown color crust on the product surface was formed. The heat fluxes and the heat transfer coefficients can assist an understanding of which temperature and time is the best for baking chicken nuggets and which coating influence heat transfer. The objectives of this study were (i) to experimentally determine heat flux, overall and radiation heat transfer coefficients of RWO baking of chicken nuggets (ii) to study the effect of temperature and the breading ingredients on heat flux and the heat transfer coefficients, (iii) to evaluate influence of coating particle size on heat transfer parameters.

Material and Methods

Sample Preparation

Boneless and skinless chicken meat (breast and thigh meat) obtained from a local supplier were used to prepare chicken nuggets. The meat was thawed at 10ºC for 4 h in a refrigerator prior to starting the experiment. The nuggets formulation constituted of 48% breast meat, 42% boneless thigh meat, 9.1% water, 0.5% salt and 0.4% phosphate. The breast and thigh meat were seperately grounded by 10 mm diameter grinding plates in a grinder (A200, Hobart Co. Troy, OH). The ground chicken meat was blended in a mixer for 2 min. Water, salt, and phosphate were added one by one and each mixed for 2 min before adding the next ingredient. The whole mixture was stored at -18ºC until it reached -2.2ºC to shape the meat dough. The samples were manually cut into nuggets by a circular cutting mold that had a 4.1 cm diameter and 1.5 cm thickness. Each nugget was weighed, 17.7 ± 1.1 g, before it was coated.

Wheat flour (Gold Medal All trumps wheat flour, General Mills, Minneapolis, MN), corn flour (Whole Grain Corn Flour, Bob's Red Mill Natural Food Inc., Milwaukie, OR), chickpea flour (Garbanzo Bean Flour, Firebird Artisan Mills Inc., Harvey, ND) and pre-dust (Kerry Inc., Beloit, WI) were used for coating and breading of nuggets. The protein content of corn and chickpea flour was 8.6 % and 22.4 %, and the total fat content of corn and chickpea flour was 4.4 % and 6.7 %, respectively. Coating formulations were composed of 1:1 corn flour to wheat flour, and 1:1 chickpea flour to wheat flour. The flours were weighed and mixed in a mixer (Professional 600, Kitchen Aid Inc., OH) for 2 min. The nuggets were dipped in a beaten egg white for 10 s and allowed to drip for 10 s. Then, they were coated with the flour mixtures for 5 s on each side and stored at -40 ºC until it was time to cook them. The chicken nuggets were 4.28 ± 0.003 cm in diameter and 1.72 ± 0.1 cm in thickness and weighed 20.01 ± 1.13 g after adding the corn-wheat flour breading and were 4.41 ± 0.03 cm in diameter and 1.99 ± 0.1 cm in thickness and weighed 22.76 g after adding the chickpea-wheat flour breading.

Experimental Design

The chicken nuggets were baked in RWO (Pyramid Food Processing Equipment Manufacturing, Tewksbury, MA) at four different temperatures (347, 367, 387 and 407 ºC) for three different times (4, 5.5 and 7 min) (Table 3.1). The processing temperatures were selected based on preliminary experiments. Every treatment was randomly replicated three times.

The Heat Transfer Calculation

Heat flux and heat transfer coefficients (radiation, natural convective and total) were experimentally determined. The heat transfer coefficients were calculated by the heat flux to the nuggets, the wall temperature of the RWO, the surface and the center temperature of the product, and the air temperature of the surroundings.

The air temperature surrounding the product, the temperature at the center, and the wall temperature of the oven were monitored by K thermocouples insulated glass fiber (XCIB-K-4-6, Omega Engineering Inc., Stamford, CT) using a portable data logger (RDXL121-D, Omega Engineering Inc., Stamford, CT). The surface temperature of the product was measured by a temperature sensor on the heat flux sensor with a portable data logger (RDXL121-D, Omega Engineering Inc., Stamford, CT) during the processing. The heat flux from the RWO wall to surface were measured by the heat flux sensor with the data logger.

The overall heat transfer coefficient (U_{RWO}) of the RWO was be determined by the equation (1) (Jaluria, 2003):

$$U_{RWO} = \frac{q"}{T_{wall} - T_{surface}} \quad (1)$$

Where q” is the heat flux from the RWO wall to the product surface (W/m2) and T_{wall} and $T_{surface}$ are the wall temperature of the RWO and the surface temperature of the chicken nuggets (ºC), respectively. The calculation of the natural convective heat transfer coefficient (h_{conv}) for the RWO is calculated by the Equation (2) (McAdams 1954):

$$h_{conv} = 1.3683x\left(\frac{T_{air} - T_{surface}}{d}\right)^{0.25} \quad (2)$$

Where d is the diameter of the chicken nuggets and T_{wall} and $T_{surface}$ are the wall temperature of the RWO and the surface temperature of the chicken nuggets (ºC), respectively.

The radiant heat transfer coefficient was calculated by the Equation (3) (Jaluria 2003; Ibarz and Barbosa-Cánovas 2003):

$$h_{rad} = U_{RWO} - \frac{h_{conv}\left(T_{air} - T_{surface}\right)}{\left(T_{surface} - T_{wall}\right)} \quad (3)$$

Particle Size Distribution

The particle size of wheat, corn and chickpea flour were measured by ASABE Standard S319.4 (*ASABE Standards*, 2008). One hundred gram of flour was placed on the topmost sieve. The sieves (U.S series) from US sieve number 4 (sieve opening: 4.75 mm) to sieve number 270 (sieve opening: 0.053 mm) were used. The set of the sieves were vibrated for 10 min in a sieve shaker (Tyler Inc., Mentor, OH, USA). Each sieve was weighed before and after experiment to calculate the amount of flour retained in undersize Equation (4) and (5) (Sonaye and Baxi 2012):

$$\%\,Retained = \frac{W_{Sieve}}{W_{Total}}x100\% \quad (4)$$

$$\%Cumulative\ Pasing = 100\% - \%\ Cumulative\ Retained \quad (5)$$

Where W_{sieve} is the flour weight in each sieve, W_{total} is total weight of the flour.

Statistical Analysis

The effect of temperature change to heat transfer parameters were compared using Microsoft Excel 2016.

Results and Discussion

The chicken nuggets were successfully baked in the RWO by exposing the product to the infrared energy in the far infrared region. The working wall temperatures were controlled by an automatic valve that adjusted the natural gas flow in the RWO. The mean wall temperatures were 346.0 ± 4.7, 364.8 ± 2, 387.3 ± 1.3 and 406.0 ± 2.9 ºC for the non-breaded chicken nuggets, 347.3 ± 1.6, 367.7 ± 1.3, 388.1 ± 0.6 and 403.0 ± 7.2ºC for chicken nuggets coated with the corn flour, and 347.1 ± 0.9, 367.2 ± 1.0, 387.4 ± 0.4 and 406.9 ± 0.8ºC for the chicken nuggets coated with chickpea flour. The processing times were 4, 5.5, and 7 min for each treatment. The inlet and outlet zone of the RWO were 11.1 cm at both ends. The samples for every treatment were placed in the middle of the RWO on a perforated tray. The tray reached the middle section of the RWO in 30 s, stayed in the middle and exited after 30 s. The effective heat zone for the experiments was the middle of the RWO (60 cm) because every treatment stayed at the same distance from the entrance and the exited the RWO (Figure 3.1). The monitored temperatures indicated that center, surface, and air temperatures increased until the effective heat zone (60 m) then the temperatures went down. The wall temperature stayed constant around the RWO.

The Effect of Temperature and Coating on Heat Flux and Heat Transfer Coefficients

The heat fluxes and the temperature differences between the wall and the surface were calculated for all samples. All of the calculations were averaged from corresponding as the nuggets entered and exited the RWO. The temperature differences and heat flux correlation for the same processing times have been shown in Figure 3.2, 3.3 and 3.4.

For non-breaded chicken nuggets, the temperature differences between the product surface and wall were 281.3 ± 14.7, 291.0 ± 13.8 and 307.1 ± 17.9ºC for set temperatures 347, 367, 387 and 407ºC, respectively. The highest heat flux, 46897±429 W/m^2, was measured where the nuggets baked at 407ºC for 4 min. On the other hand, the nuggets baked in the RWO at 347ºC for 5.5 min had the lowest heat flux, 31910±197 W/m^2. For all of the different lengths of time, there was a positive linear relationship between temperatures and heat fluxes for the non-breaded chicken nuggets (Figure 3.2).

The temperature differences for corn breaded chicken nuggets between the wall and surface were 371.6 ± 15.1, 286.2 ± 15.2, 294.7 ± 26.9 and 298.9 ± 20.4ºC for set temperatures 347, 367, 387 and 407 ºC, respectively. The heat flux to nuggets increased with increase in the temperature difference between the wall of RWO and the surface of nuggets. The highest flux of 40652 ± 500 W/m^2 was measured at the highest temperature difference of 327ºC, and the lowest heat flux of 31662 ± 175 W/m^2 was measured at the lowest temperature difference of 254ºC. The increase in the heat flux with increase in the temperature difference showed the similar trend for 4 min and 7 min process times. The chicken nuggets baked for 5.5 min had the same heat flux even at increasing temperature difference. This might be related to changes in the breading characteristics with temperature and the processing time. Moreover, the precise reason for constant heat flux values for the corn breaded chicken nuggets baked for 5.5 min is not known (Figure 3.3).

The chickpea breaded chicken nuggets had the lower heat flux compared to un-breaded and corn breaded nuggets. The difference in temperature between the wall and the nugget surfaces were 254.9 ± 22.9, 273.8 ± 19.4, 264.8 ± 13.1 and 281.9 ± 15.3ºC for wall temperatures ranging from 347 to 407ºC. The chickpea flour breaded nuggets had the lowest heat flux, 24734 ± 98 W/m^2, at 347ºC for 5.5 min and the highest heat flux, 31850 ± 152 W/m^2, at 407ºC for 5.5 min.

The heat flux of the nuggets increased with the temperature difference between the oven wall and the surface temperature. When the temperature difference reached higher than 265ºC, the heat flux was high and fairly constant (Figure 3.4).

Overall and radiant heat transfer coefficients have a similar correlation with heat flux change with the temperature. There was no significant difference between overall and radiant heat transfer coefficients for the same time and the same temperature treatments. The range of overall coefficient was 115.9 W/m^2K at 347ºC– 154.9 W/m^2K at 407ºC and radiant heat transfer coefficients between 111.5 W/m^2K at 347ºC – 151.1 W/m^2K at 407ºC for non-breaded nuggets, the results implicated correlation between temperature and the heat transfer coefficients. The relationship between each heat transfer coefficient and temperature had positive linear trend (Figure 3.5 and Figure 3.8).

The overall heat transfer coefficients were between 116.0 W/m^2K and 145.8 W/m^2K and the measured radiation heat transfer coefficients between 111.5 W/m^2K and 143.6 W/m^2K for corn breaded chicken nuggets. There was a slight increase in the coefficients with the temperature change when the corn breaded nuggets were baked for 5.5 and 7 min. There is a positive linear correlation between the heat transfer coefficients and the temperature difference when the nuggets were baked for 4 min. (Figure 3.6 and 3.9).

The calculated overall and radiant heat transfer coefficients were between 100.4 W/m^2K – 120.4 W/m^2K and 97.7 W/m^2K – 118.1 W/m^2K for chickpea breaded chicken nuggets. The heat transfer coefficients had the similar trend with the heat flux of chickpea breaded chicken nuggets. The coefficients increased with the temperature difference. When the temperature difference reached 265ºC, the heat transfer coefficients decreased with the increase in temperature difference. (Figure 3.4 and 3.10).

The highest radiant and overall heat transfer coefficient was measured at the highest temperature difference, and the lowest radiant and overall heat transfer were calculated at the lowest temperature difference.

Overall, higher temperature differences resulted in higher heat flux and heat transfer coefficients. This change in the flux and the coefficients with temperature difference was due to the energy flow (Equation 1). When the results were compared to other processing with radiant heating, chicken nuggets had higher heat fluxes, the overall heat transfer coefficients and the radiant heat transfer coefficients. Kirmaci (2015) measured lower heat flux 10.2 ± 0.8 kW/m^2-20.0 ± 0.8 kW/m^2, overall heat transfer coefficient 61.1 – 81.7 W/m^2K and radiant heat transfer coefficient 57.1 – 75.7 W/m^2K when the potato strips were fried at different temperatures 290°C – 365°C in a radiant wall oven. Nelson III and others (2013) measured the heat flux of a radiant fryer that ranged from 2.4 to 4.6 W/m^2 to reach 107 ± 5°C surface temperature of chicken patties. These differences occurred when the different products or different radiant heaters were used.

The corn breaded chicken nuggets had higher heat transfer values because corn flour has higher absorbance than chickpea flour in FIR (Bashir and Aggarwal 2016; Xue et al. 2017). The difference in absorbance was related to the flour composition such as, fat, moisture and protein content because proteins and fat absorb infrared radiation between the wavelengths of 3.25 and 5.92 µm that includes the RWO working wavelength (Rosenthal 1992).

Effect of Particle Size Distribution on Heat Flux and Heat Transfer Coefficients

In this study, particle size analysis results were compared for the three different flours within percent cumulative undersize (%). The cumulative particle size distributions of wheat, corn and chickpea flours are presented in Figure 3.11. There were differences among the particle size range for all flour types. More than 80% of wheat flour between was 25 - 300 µm, corn flour between 150-600 μm, and chickpea flour between 300 - 850 μm (Figure 3.11). Wheat flour and corn flour had the lowest and the highest particle size distribution, respectively. Although wheat flour had the lowest particle size distribution, it did not affect the correlation of heat flux measurements between corn and chickpea coated chicken nuggets because wheat flour was used for both breading mixes in the same amount. When corn and chickpea flours were compared, corn flour had lower particle size than the chickpea flour. Corn flour breaded chicken nuggets had higher heat fluxes, overall heat transfer coefficients and radiant heat transfer coefficients. Myers and others (2015) reported that particle size (150 - 500 μm) of an organic compound (lactose) did not significantly affect the reflectance in FIR region used in the RWO.

Conclusions

RWO baked non-breaded nuggets had the highest heat flux, the overall and the radiant heat transfer coefficients but chickpea flour breaded nuggets had lowest values. The radiant heat transfer coefficient ranged between 111.5 – 151.1 W/m^2K for non-breaded chicken nuggets, 111.5 – 143.6 W/m^2K for corn breaded nuggets and 97.7 – 118.1 W/m^2K for chickpea breaded nuggets in the RWO. Overall, there is a correlation between temperature and the heat transfer. The flours have different absorptivity and different particle size distributions. The effects of particle sizes and flour types were compared to understand which parameter affects heat transfer. The chickpea flour breaded chicken nuggets had lowest heat transfer parameter. On the other hand, the particle size of the flours used in experiments was around 150 – 500 μm. There is no effect of this particle size on reflectance in FIR.

References:

Barbut, S. (2012). Convenience breaded poultry meat products-New developments. Trends in Food Science & Technology, 26, 14–10. doi:10.1016/j.tifs.2011.12.007

Bashir, K., & Aggarwal, M. (2016). Effects of gamma irradiation on the physicochemical, thermal and functional properties of chickpea flour. LWT-Food Science and Technology, 69, 614-622.

Chen, R. Y., Wang, Y., & Dyson, D. (2016). Breadings—what they are and how they are used. Batters and Breadings in Food Processing, 169.

Ibarz A, Barbosa-Cánovas GV. 2002. Unit operations in food engineering. Boca Raton: CRC Press.

Jaluria, Y. (2003). Natural Convection. In A. Bejan & A. D. Kraus (Eds.), Heat Transfer Handbook (pp. 525–571). the United States of America.

Kettler, K., Adhikari, K., & Singh, R. K. (2017). Blanchability and sensory quality of large runner peanuts blanched in a radiant wall oven using infrared radiation. Journal of the Science of Food and Agriculture, 97(13), 4621-4628.

Kirmaci, B. (2015). Characterization of Baked Potato Strips Processed in Radiant Wall Oven. The University of Georgia.

Kirmaci, B., & Singh, R. K. (2016). Quality of the pre-cooked potato strips processed by Radiant Wall Oven. LWT - Food Science and Technology, 66, 565–571.

McAdams, WH. (1954). Heat transmission. 3rd edition. New York: McGraw-Hill Book Co.

Melito, H. S., & Farkas, B. E. (2013). Effect of infrared finishing process parameters on physical, mechanical, and sensory properties of par-fried, infrared-finished gluten-free donuts. Journal of Food Engineering, 117(3), 399-407.

Myers, T. L., Brauer, C. S., Su, Y. F., Blake, T. A., Tonkyn, R. G., Ertel, A. B., ... & Richardson, R. L. (2015). Quantitative reflectance spectra of solid powders as a function of particle size. Applied Optics, 54(15), 4863-4875.

Nelson III, L. V., Keener, K. M., Kaczay, K. R., Banerjee, P., Jensen, J. L., & Liceaga, A. (2013). Comparison of the FryLess 100 K Radiant Fryer to oil immersion frying. LWT-Food Science and Technology, 53(2), 473-479.

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.

Rosenthal I. 1992. Electromagnetic radiations in food science. Berlin, Heidelberg: Springer-Verlag.

Sakai, N., & Hanzawa, T. (1994). Applications and advances in far-infrared heating in Japan. Trends in Food Science & Technology, 5(11), 357-362.

Sonaye, S. Y., & Baxi, R. N. (2012). Particle size measurement and analysis of flour. lung, 2(3).

Suderman, R.D. (1983). Use of batters and breadings on food products: A Review. Batter and breading technology, 1-14.

Toledo, R. T. (2007). Fundamentals of food process engineering. Springer Science & Business Media.

Xue, P., Zhao, Y., Wen, C., Cheng, S., & Lin, S. (2017). Effects of electron beam irradiation on physicochemical properties of corn flour and improvement of the gelatinization inhibition. Food Chemistry, 233, 467-475.

Table 3.1: Experimental Design of RWO processing

Treatment#	Set Temperatures[1] (ºC)	Total Processing Time[2] (min)
1	347	4
2	347	5.5
3	347	7
4	367	4
5	367	5.5
6	367	7
7	387	4
8	387	5.5
9	387	7
10	407	4
11	407	5.5
12	407	7

[1]: Mean temperatures were 346.0 ± 4.7, 364.8 ± 2, 387.3 ± 1.3 and 406.0 ± 2.9 ºC for non-breaded chicken nuggets, 347.3 ± 1.6, 367.7 ± 1.3, 388.1 ± 0.6 and 403.0 ± 7.2 ºC for corn breaded chicken nuggets, and 347.1 ± 0.9, 367.2 ± 1.0, 387.4 ± 0.4 and 406.9 ± 0.8 ºC for chickpea breaded chicken nuggets for the set temperatures 347 ºC, 367ºC, 387ºC and 407ºC.
[2]: The deviation in processing times was 0.02 – 0.05 min.

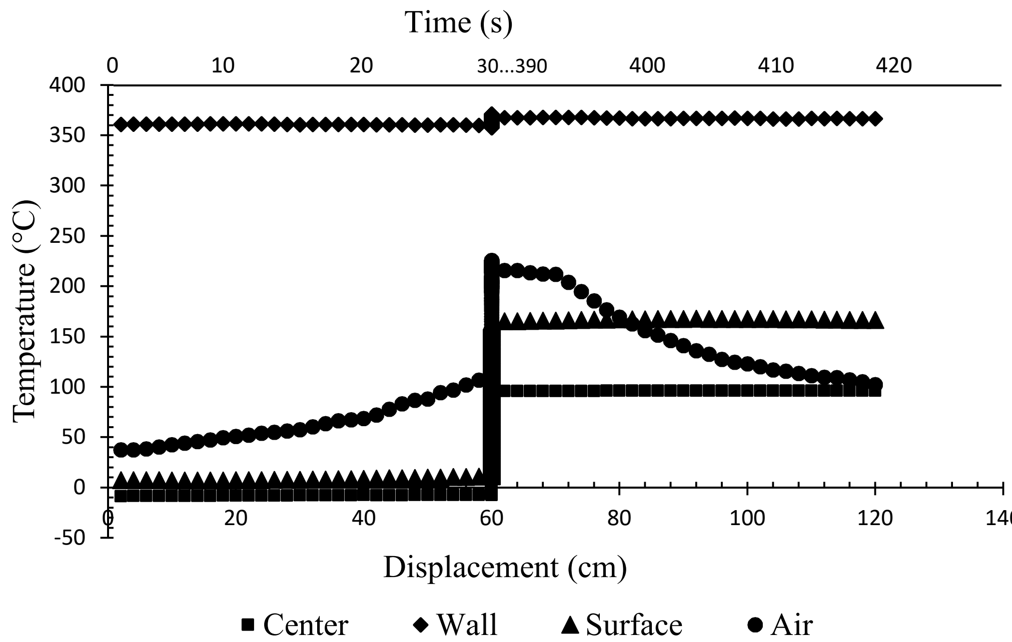

Figure 3.1: Temperature (ºC) vs. displacement (cm) graph with time (s) for non-breaded chicken nuggets processed at 367 °C for 7 min in the RWO.

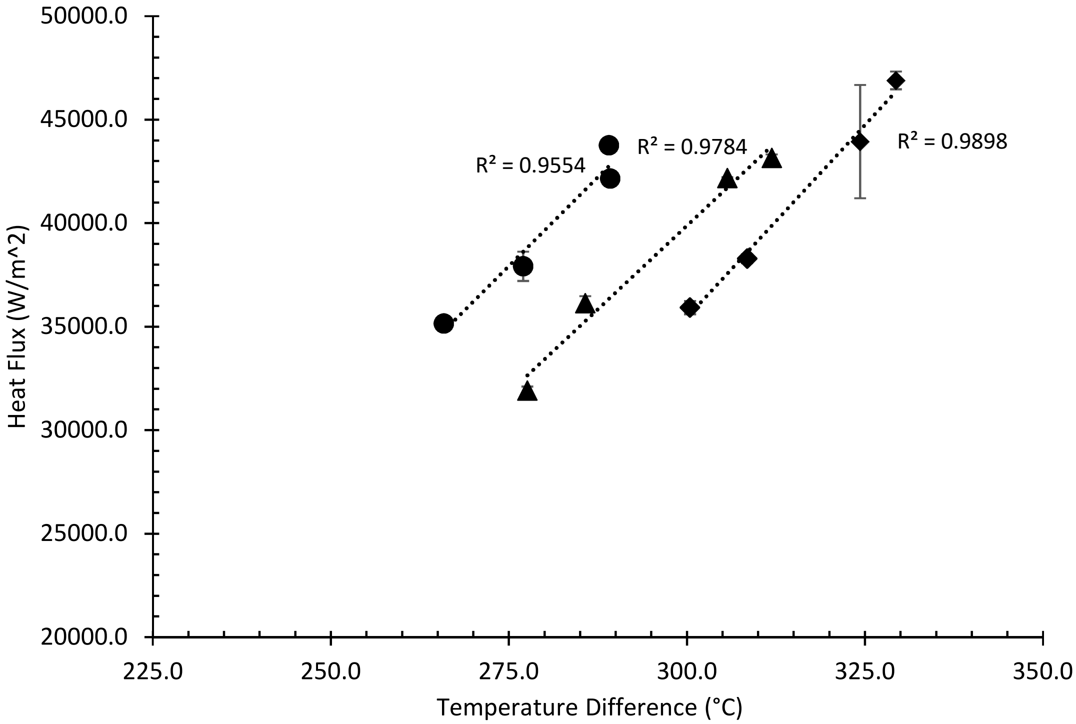

Figure 3.2: Heat flux of non-breaded chicken nuggets during RWO baking for 4 min (●), 5.5 min (▲) and 7 min (◆).

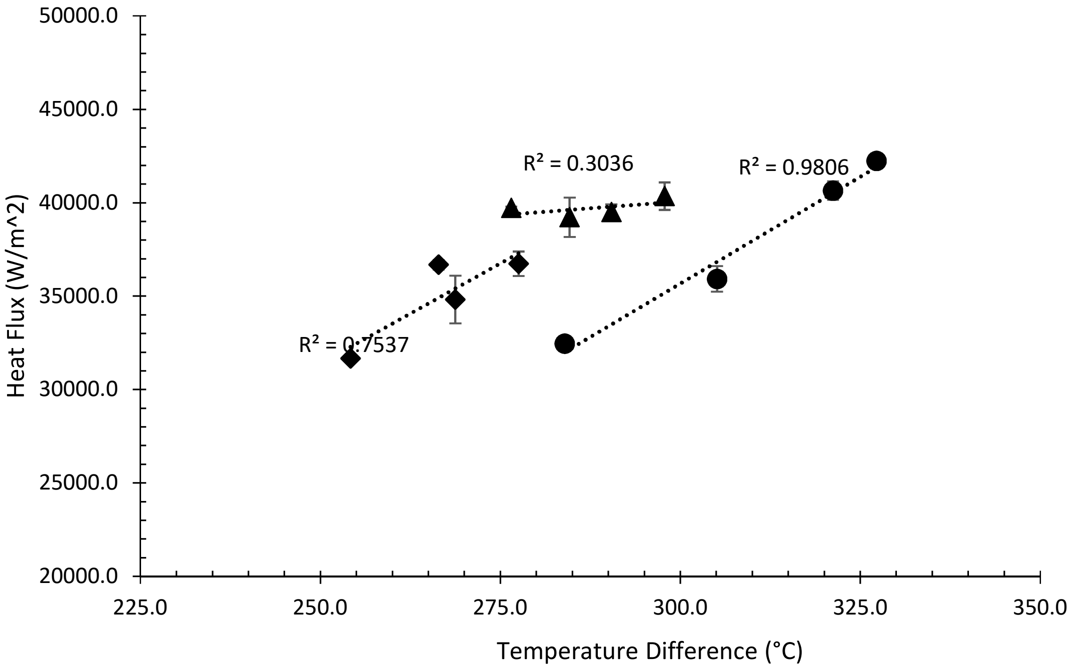

Figure 3.3: Heat flux as function of temperature difference for corn breaded chicken nuggets during RWO baking for 4 min (●), 5.5 min (▲) and 7 min (◆).

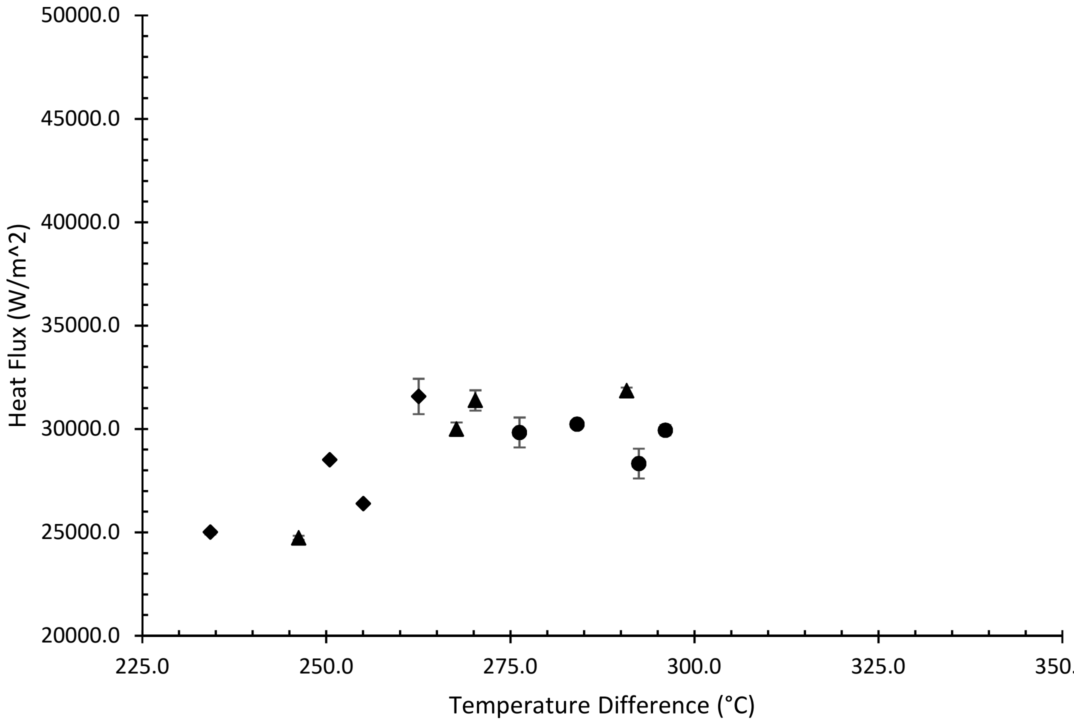

Figure 3.4: Heat flux versus temperature difference for chickpea breaded chicken nuggets during RWO baking for 4 min (●), 5.5 min (▲) and 7 min (◆).

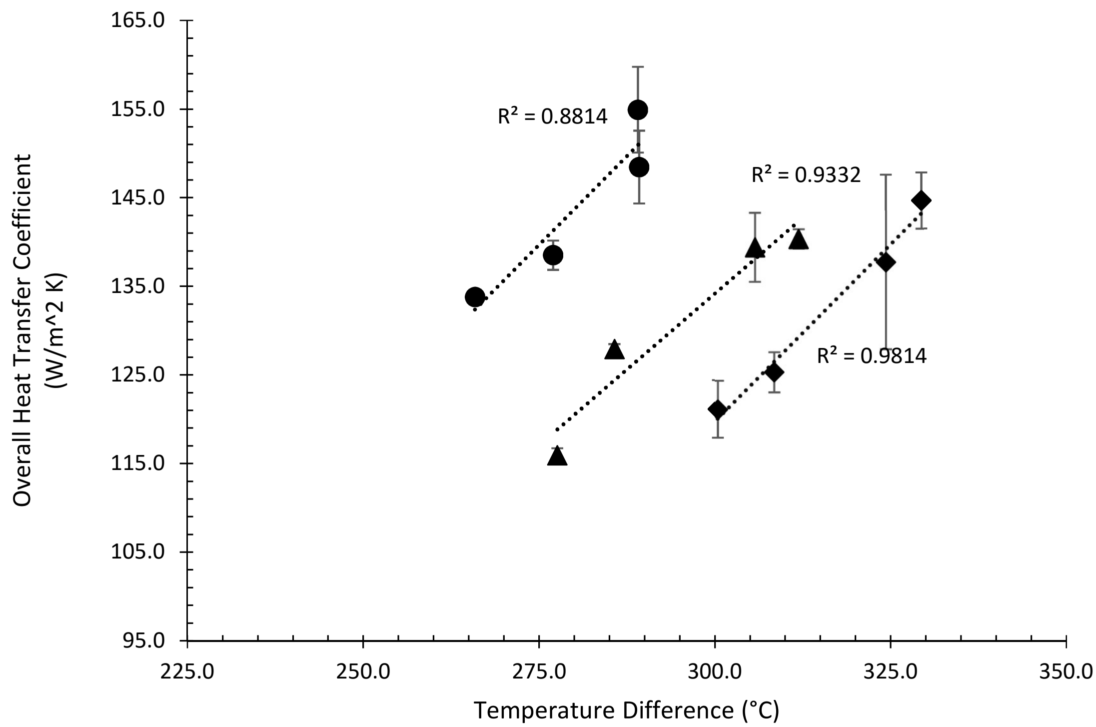

Figure 3.5: Overall heat transfer coefficients of non-breaded chicken nuggets during RWO baking for 4 min (●), 5.5 min (▲) and 7 min (◆).

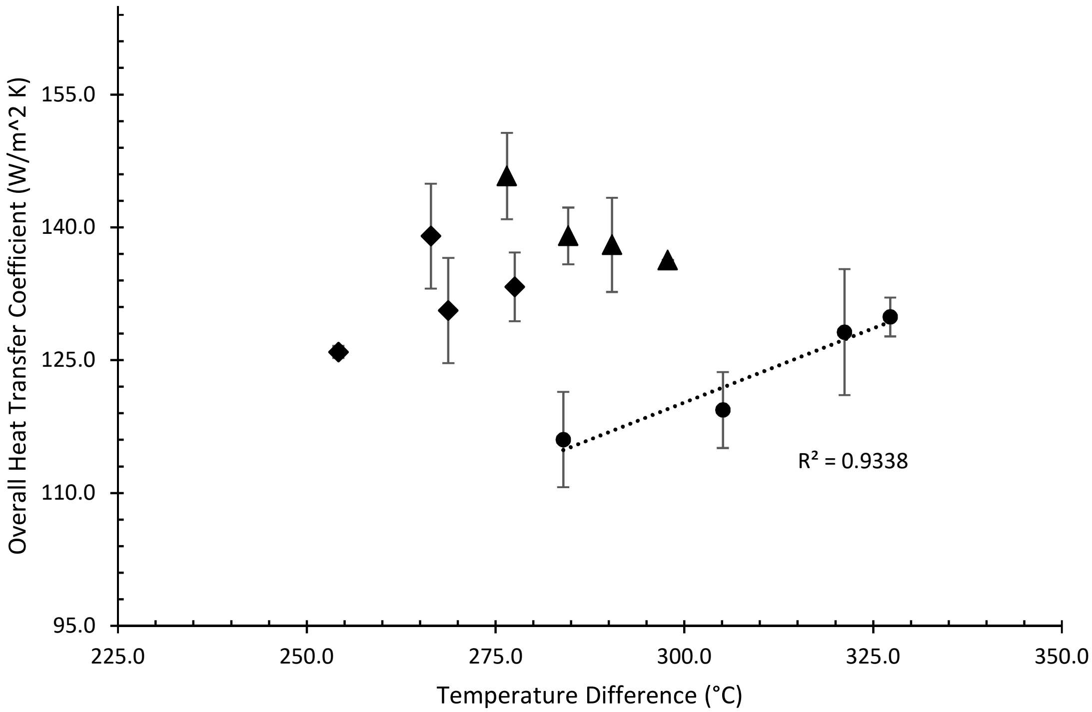

Figure 3.6: Overall heat transfer coefficients of corn breaded chicken nuggets during RWO baking for 4 min (●), 5.5 min (▲) and 7 min (◆).

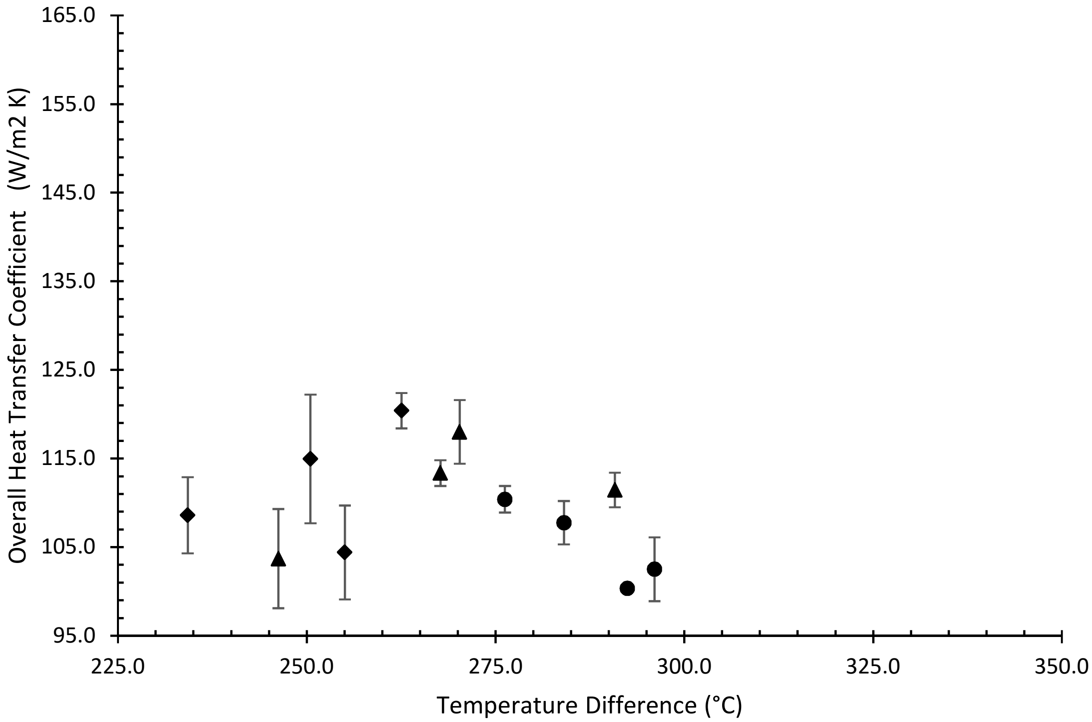

Figure 3.7: Overall heat transfer coefficients of chickpea breaded chicken nuggets during RWO baking for 4 min (●), 5.5 min (▲) and 7 min (◆).

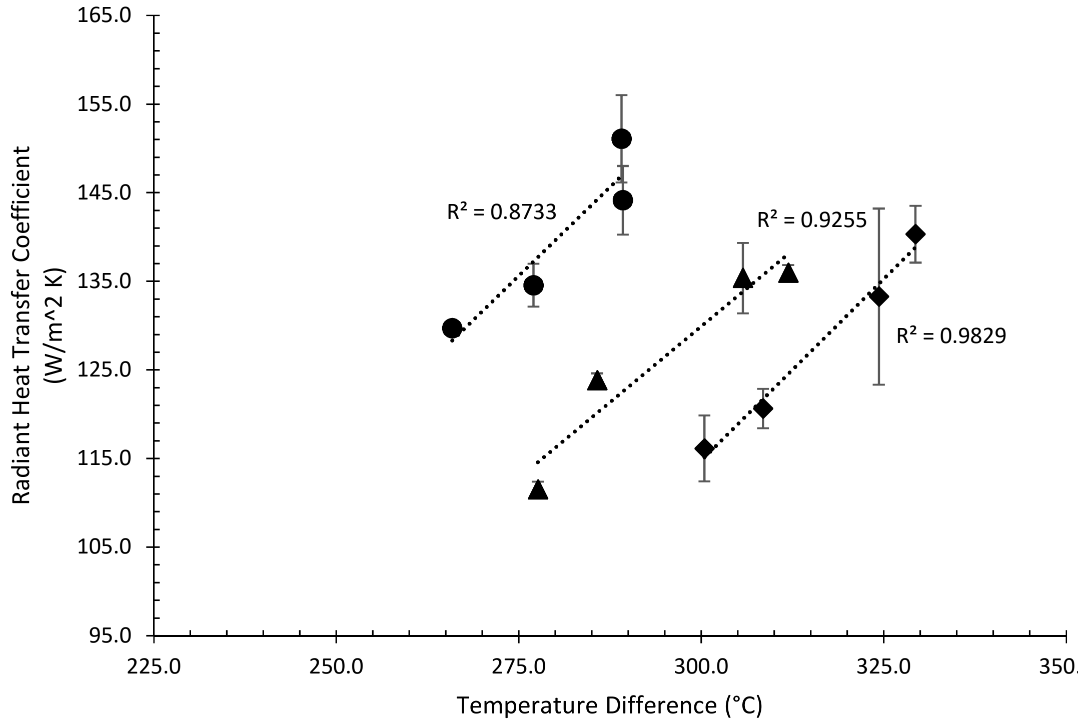

Figure 3.8: Radiant heat transfer coefficients of non-breaded chicken nuggets during RW baking for 4 min (●), 5.5 min (▲) and 7 min (◆).

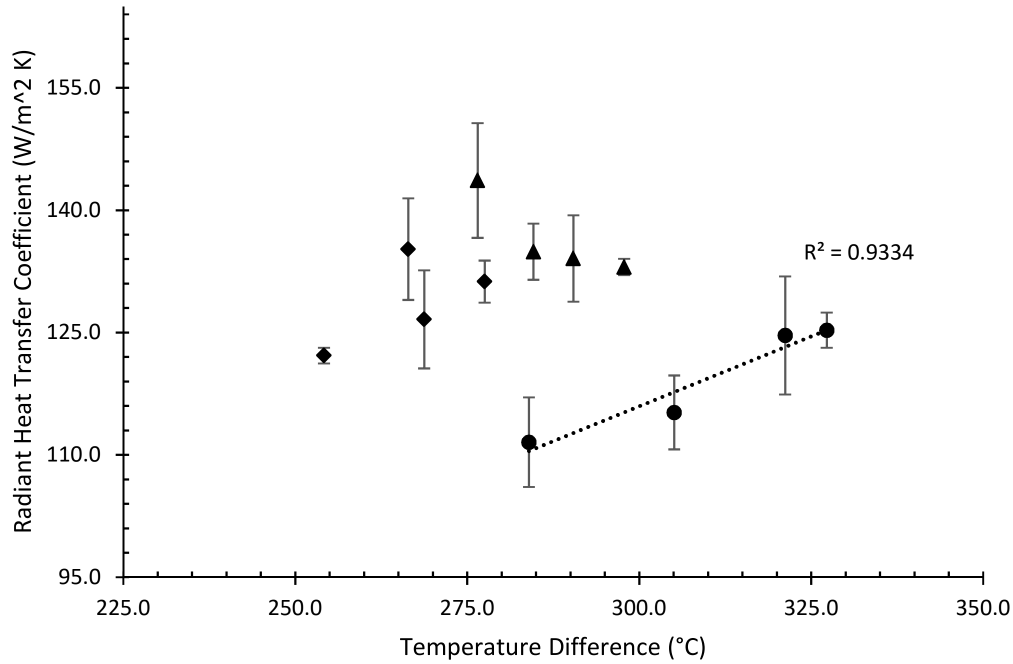

Figure 3.9: Radiant heat transfer coefficients of corn breaded chicken nuggets during RW baking for 4 min (●), 5.5 min (▲) and 7 min (◆).

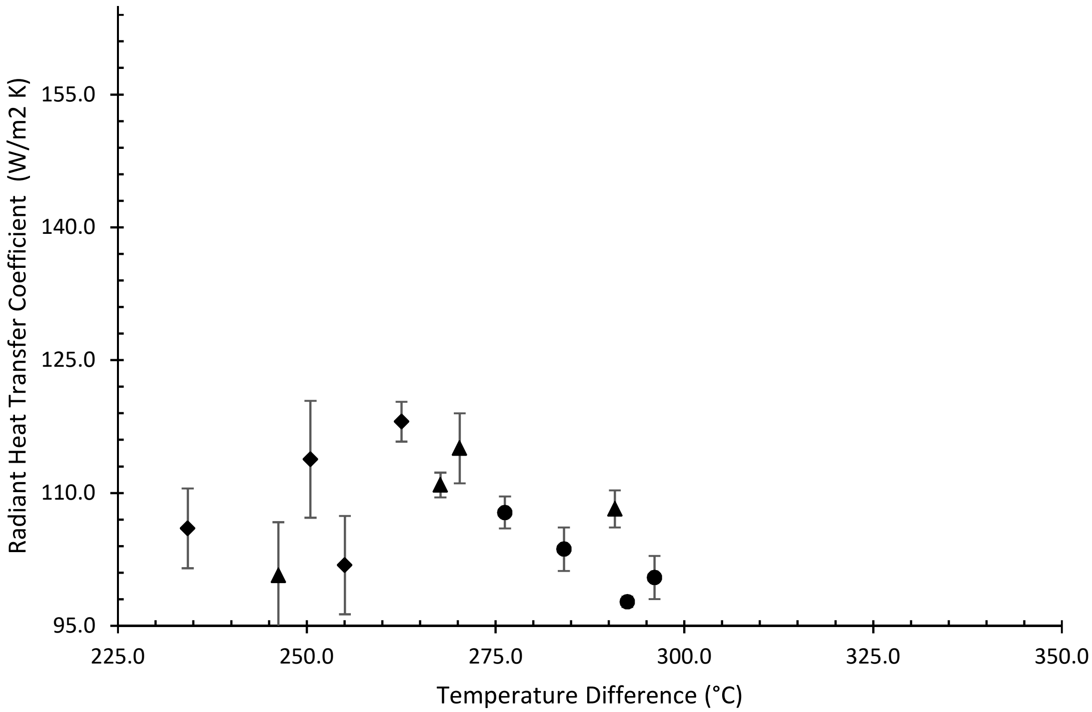

Figure 3.10: Radiant heat transfer coefficients of chickpea breaded chicken nuggets during RW baking for 4 min (●), 5.5 min (▲) and 7 min (◆).

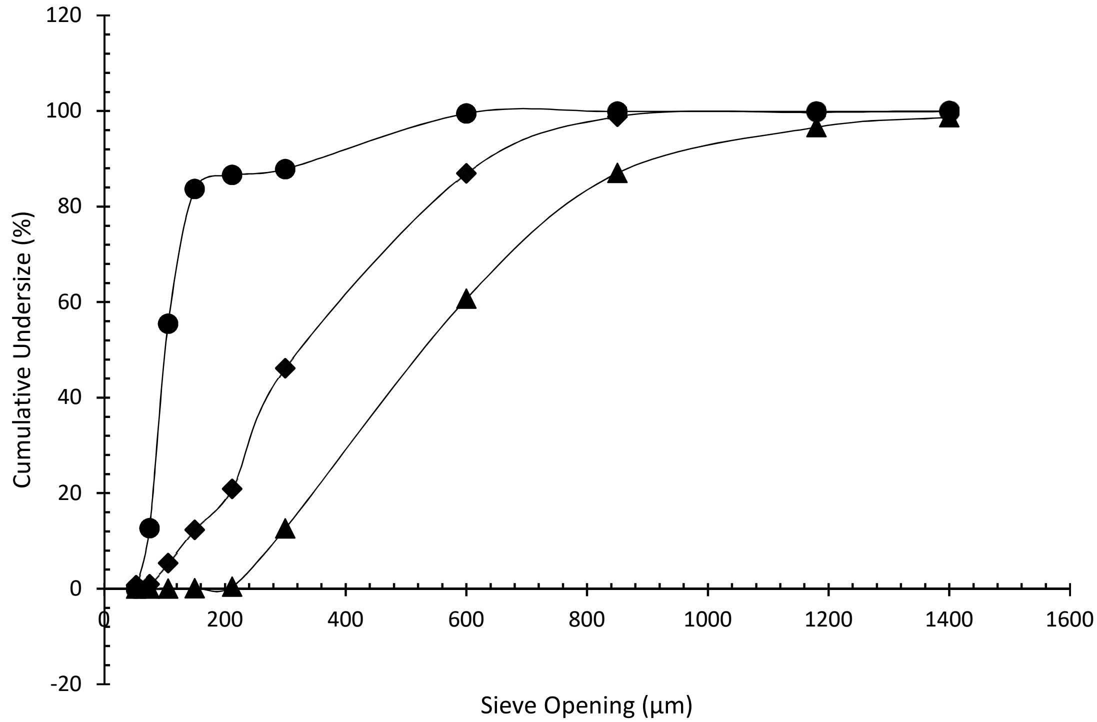

Figure 3.11: Cumulative particle size distribution of wheat (●), corn (◆) and chickpea flour (▲).

CHAPTER 4

QUALITY EVALUTION OF BREADED AND NON-BREADED CHICKEN NUGGETS BAKED IN AN RADIANT WALL OVEN[1]

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[1]: Ozen, E. and R.K Singh. To be submitted to *International Journal of Food* Properties.

Abstract

Instrumental quality characteristics of breaded and non-breaded chicken nuggets baked in a Radiant Wall Oven (RWO) was measured and compared to deep-fat fried and conventional oven (CO) baked samples. Overall, the breaded chicken nuggets had similar lightness with control treatments. The RWO baked chicken nuggets had similar crispness with fried and conventional oven baked controls. Breaded nuggets had significantly lower fat content compared to fried nuggets because of the high oil uptake of the coating. The moisture content of the breaded chicken nuggets was similar with the control treatments while non-breaded nuggets had lower moisture than controls. This moisture difference is because the coating prevents moisture loss from coated products.

Keywords: Color, chicken nuggets, infrared heating, texture.

Introduction

Chicken nuggets are widely consumed as a breaded food product in the United States. The term of breading covers a wide range of cereal-based coatings (Dyson 1983). The breading is a general term for a group of a ground coating. To prepare chicken nuggets for consumption, frying and baking are used for heat treatments (Barbut 2012). Frying is the most popular food preparation method because it is easy to use for preparing tasty product, but the method incorporates high-fat content. As the product diversity of food market becomes more complex, the consumers pay more attention to what they eat because of the health issues. They expect menu options that are appropriate to their dietary habits no matter where they are eating. This attitude caused food industry to focus on the ingredients used in production of various foods (NRA 2017). Brunner and others (2007) advised the participants to lower fat intake, and found that the lowering fat intake affected the cardiovascular risk of the participants in short-term. Hooper and others (2012) reported that lowering fat intake helps to decrease body weight and body mass index. Therefore, some processing methods were introduced to manufacture products with lower fat content. Some researchers have studied new processing methods; Rami and others (2018) used infrared, and pre-fried infrared cooked chicken nuggets, Kirmaci and Singh (2016) used radiant wall oven to bake potato strips of lower fat content to achieve similar quality as with deep fat fried strips with higher fat content. Some researchers have varied the coating or breading formulations of nuggets (Dogan et al. 2005; Sahin et al. 2005; Atlunakar et al. 2006) while others have changed formulation of the nuggets (Devetkal et al. 2009) to achieve similar quality characteristic to fried.

Breaded or coated chicken nuggets with a batter formulation prevents moisture loss, thus the nuggets keep their juiciness as desired for a meat product. The coating also improves flavor, texture, and appearance of the nuggets (El-Dirani 2002). The use of breading for pre-fried food products began only in the middle of 1950s. When the ingredients are mixed with water, the mixture is referred as a batter. On the other hand, the mixture with no water is named by breading (Chen et al. 2016). Before coating the nuggets generally, a layer of pre-dust is used. Pre-dusts are used to prepare of the coated food surface for batter adhesion. They dust onto the moist surface of the frozen products or fresh food before coating (Burge 1990).

Crispness is the most important quality parameter of chicken nuggets. The crispness product can be objectively measured by instrumental analysis. Different kinds of methods have been used to determine crispness of the chicken nuggets. Maskat and others (2002) used 28 mm diameter probe and a condenser microphone to measure the degree of jaggedness for crispness of chicken nuggets. Altunakar and others (2007) used 0.04 m conical probe to count he peak force to assess crispness of chicken nuggets and Albert and others (2013) used a light knife blade and an acoustic detector counted the number of peaks for crunchiness. Objectives of this study were (i) To analyze color and texture of breaded and non-breaded chicken nuggets baked in RWO (ii) To compare color and texture of the chicken nuggets baked RWO with chicken nuggets baked in convection oven and with fried chicken nuggets and (iii) to compare the quality characteristic of chicken nuggets with different coting in the same processing conditions.

Materials and Methods

Sample Preparation

Breast and thigh meat were obtained from a local supplier to make chicken nuggets. The skin and bone were removed from thigh meat after thawing chicken meat at 10ºC for 4 hours in a refrigerator. About 48% breast meat, 42% boneless thigh meat, 9.1% water, 0.5% salt and 0.4% phosphate were used for preparation of the chicken nuggets. The breast meat and thigh meat were ground and passed through a 10 mm diameter plate in a grinder (A200, Hobart Co. Troy, OH), separately. Ground breast and thigh meats were mixed for 2 minutes. Water, salt and phosphate were mixed for 2 minutes and then added to the ground meat. The mixture was stored at -18 ºC until it reached -2.2 ºC. A circular mold was used to cut samples 4.1 cm diameter and 1.5 cm thickness. The average nugget weight was 17.7 ± 1.1 g.

Pre-dust (Kerry Inc., Beloit, WI) was used before coating the nuggets with wheat flour (Gold Medal All trumps wheat flour, General Mills, Minneapolis, MN), corn flour (Whole Grain Corn Flour, Bob's Red Mill Natural Food Inc., Milwaukie, OR), chickpea flour (Garbanzo Bean Flour, Firebird Artisan Mills Inc., Harvey, ND). The protein levels for corn flour and chickpea flour were 8.7 % and 22.4%, respectively according to the supplier's data sheet. The breading formulations consisted of 1:1 corn flour with wheat flour or 1:1 chickpea flour with wheat flour. The flour combinations were mixed in a mixer (Professional 600, Kitchen Aid Inc., OH) for 2 minutes. Egg whites were beaten, and the nuggets were dipped in the egg for 10 seconds and allowed to stay for 10 seconds to remove excess liquid. They were coated with flour mixes for 5 seconds on each side and stored at -40 ºC until cooking. The chicken nuggets were 4.28 ± 0.003 cm in diameter and 1.72 ± 0.1 cm in thickness and weighed 20.01 ± 1.13 g after adding the corn-wheat flour mix breading and were 4.41 ± 0.03 cm in diameter and 1.99 ± 0.1 cm in thickness and weighed 22.76 g after adding the chickpea-wheat flour breading.

Experimental Design

Radiant Wall Oven (Pyramid Food Processing Equipment Manufacturing, Tewksbury, MA) was used to bake chicken nuggets at different temperatures (347, 367, 387 and 407 ºC) for three different times (4, 5.5 and 7 min) (Table 4.1). The temperatures and the times were selected based on RWO operation temperatures and preliminary experiments. The frying experiments for chicken nuggets were done in an immersion fryer (GE Model 168997, General Electric Company, Fairfield, CT) at 190 ºC for 2 min with 5 L vegetable oil and the baking was done in a conventional oven (Alto-Shaam CTP7 – 20E, Inc., Menomonee Falls, WI) at 225 ºC for 10 minas control treatments. The fried and baked chicken nuggets were transferred to the food warmer before texture and color analysis. Each treatment was randomized and replicated three times.

Moisture and Fat Content

To homogenize all randomized replications in the same processing conditions, liquid nitrogen was used to freeze the nuggets and a coffee grinder (A200, Hobart Co. Troy, OH) was used to grind the frozen nuggets. Frozen grinded samples were stored at -18ºC for moisture and fat analysis. The moisture content of the samples was measured based on AOAC standard method (AOAC, 1986). About 2 – 3 g wet samples were placed into dry thimbles and dried in an oven (VWR Model 1430MS, VWR Scientific) at 105ºC for 24 h. The sample was weighed after drying using a balance. The moisture content on dry basis (db) was calculated by dividing the weight difference between the wet sample and after the drying by the weight of dry material. The fat content was determined by AOAC Method 960.39 (AOAC 1990). The fat of samples was extracted by petroleum ether using a Pyrex Distillation Unit. The fat content of each sample was calculated on dry basis (db). The analysis was replicated three times.

Texture

Texture of the samples was measured to calculate linear distance of every nugget. A texture analyzer (TA-XT2, Stable Micro Systems Ltd., Hamilton, MA) was used with a 50 kg load cell, 1.00 mm/s test speed and 10 mm displacement. A razor probe was used to cut the samples placed on the HDP/90 Heavy Duty Platform. The upper and lower side of every nugget were cut with the razor and linear distance were calculated by the Texture Exponent 32 software. The analyzer was calibrated prior to analysis. The experiment was repeated three times for every nugget.

Yield

The yield of fried, conventional oven baked and the RWO baked chicken nuggets were gravimetrically calculated by moisture loss. The weight of the samples was measured by analytical balance in triplicate. The percentage of yield was calculated by equation (1) after every processing:

$$\%Yield = 100 - \frac{W_1 - W_2}{W_1} x100 \quad (1)$$

W_1: Weight of chicken nuggets before cooking process (g)

W_2: Weight of chicken nuggets after cooking process (g)

Color

The color of the chicken nuggets was measured after every cooking process and method. The color determination was quantified by CIELAB color space by a colorimeter (Model# CR-410, Konica Minolta Sensing Inc., Ramsey, NJ). The lightness (L), chroma (C_{ab}) and hue Angle (H_{ab}) were determined by recommendation of the Commission Internationale de L'Eclairage (CIE 2004). The surface color was averaged from the both sides of nuggets, the side in contact with belt and the opposite surface. The experiment was repeated three times for every nugget. L is referred to lightness of the sample ranged 0-100, Chroma is the saturation of the sample and Hue Angle represent the red-purple and yellow color in range 0^o and 90^o, respectively. The chroma and hue angle were calculated from equation (2) and (3) by a and b values;

$$C^*_{ab} = [(a^*)^2 + (b^*)^2]^{1/2} \quad (2)$$

$$h_{ab} = arctan(b^*/a^*) \tag{3}$$

Statistical Analysis

Data was analyzed by One-Way Analysis of Variance using SPSS for Windows Version 12 (SPSS Inc., USA) to compare fried and conventional oven baked control treatments with the RWO baked ones and to compare the treatments with each other in the same processing conditions. The Tukey Test were used to calculate least significant differences.

Result and Discussion

The RWO processing

The mean wall temperatures of the nuggets baked the RWO were 346.0 ± 4.7, 364.8 ± 2, 387.3 ± 1.3 and 406.0 ± 2.9 ºC for non-beraded nuggets, 347.3 ± 1.6, 367.7 ± 1.3, 388.1 ± 0.6 and 403.0 ± 7.2 ºC for the corn flour breaded chicken nuggets, and 347.1 ± 0.9, 367.2 ± 1.0, 387.4 ± 0.4 and 406.9 ± 0.8 ºC for the chickpea flour coated chicken nuggets. Every nugget reached in the middle of the RWO from entrance in 30 seconds and exited in 30 seconds.

Color

The color changes occur in the chicken nuggets due to the high temperature that contributed to the brown color in the presence of reducing sugars and amines present in proteins from breading or the nuggets. The reducing sugars combine with amines to form non-enzymatic browning, the Maillard Reaction (El-Dirani 2002). Lightness, chroma, and the hue angle of the RWO baked, deep-fat fried, and conventional oven baked chicken nuggets are given in Table 4.2, 4.3 and 4.4. Lightness of the non-breaded chicken nuggets are significantly higher than deep fat fried chicken nuggets. On the other hand, there is no significant difference in lightness between treatment #1 and oven baked un-breaded nuggets. The intensity of color, the chroma of the samples is significantly lower than fried chicken nuggets. The chroma of treatment # 4 and #7 are only significantly different from oven baked control treatment. The hue of treatment #6 is significantly higher than control1 and treatment #1 is significantly lower than control 2. Overall non-breaded chicken nuggets baked in the RWO looked darker and less intense in color than those of control treatments. They were closer to yellow color similar to those of the control treatments (Table 4.2). The color of the corn breaded chicken nuggets has been given in Table 4.3. The statistical results for instrumental color analysis showed not significantly differences in lightness, chroma and hue (º) between conventional oven baked and the RWO baked corn breaded chicken nuggets. The chroma value of treatments #3, #5, #6 and #10 was not significantly different than that of fried chicken nuggets, and the hue angle of the treatment #2, #4, #5, #7 and #10 were significantly higher than that of fried chicken nuggets.

Overall, lightness of the RWO baked chickpea breaded chicken nuggets was not significantly different from control treatments like corn breaded chicken nuggets. This result is in agreement with Albert and others (2009) for fried and conventional oven baked battered fish nuggets. They reported that cooking method in high temperatures causes the Maillard reaction because of the high temperatures. Chroma of the samples was significantly lower than fried chicken nuggets but similar to conventional oven baked nuggets. The hue angle of the RWO baked nuggets was around 90º, yellowish color, and like control treatments (Table 4.4). There are no effects of times and temperatures on color parameters in the RWO processing.

The color measurements for different coating type in the same processing condition were compared in Table 4.6. The Chickpea breaded chicken nuggets had darker colors compared to non-breaded and corn breaded chicken nuggets. The darker color is related to the protein content of the flours. The high amount of proteins undergoes a high level of Maillard reactions result in a darker color (Dogan et al. 2005), but this lightness was not significantly different. The chroma and hue (°) of the nuggets in the same processing condition were significantly the same.

Yield

The yield of the RWO baked non-breaded chicken nuggets, corn breaded, and chickpea breaded chicken nuggets was shown in table 4.2, 4.3 and 4.4 and they ranged 65.6 – 94.1%, 78.9 – 95.3% and 82.6 – 97.5%, respectively. Deep fat frying resulted in 54.4, 86.7 and 95.5% yield for plain, corn breaded and chickpea breaded nuggets because of moisture loss and fat absorption. The RWO baked non-breaded nuggets had significantly higher yield than fried nuggets. Nuggets with treatments #9 and #12 were no different than fried chicken nuggets because of high temperature and long time. The yield due to treatments #6, #9, #11 and 12 were not different from conventional oven baked nuggets (Table 4.2). The yield of RWO baked corn breaded nuggets were not significantly different from fried and conventional oven baked nuggets (Table 4.3). Yields of all chickpea breaded nuggets (except treatment #12) were significantly lower than that of fried and not different than conventional oven baked nuggets (Table 4.4). There was no significant effect of different coating types on the yield of nuggets (Table 4.6).

Texture

The linear distance was calculated from the force-deformation curve of the nuggets for the RWO baked treatments with fried and conventional oven baked nuggets because it is the best way to objectively measure mechanical texture of the chicken nuggets in terms of crispness. The jagged response in the curve occurred when the crispier products were cut. The response caused larger linear distance in the curve. The calculated linear distance of the all treatments were given in table 4.2, 4.3 and 4.4. The linear distance was not different from the control treatments. Albert and others (2009) reported that the linear distance of oven baked, and fried chicken nuggets had similar jagged response, but microwave oven baked nuggets had less jagged response to the cutting force. While the RWO baked chicken nuggets had the similar results with the oven baked and fried control groups, it can be concluded that the RWO baked chicken nuggets can be alternative to the conventional oven baking and frying processes. The nuggets with different coatings and baked at 407°C for 5.5 min had similar linear distance, which meant that there was no effect of coating on crispness of chicken nuggets in this study (Table 4.6).

Moisture and Fat Content

The moisture absorption of breading is a function of porosity of breading, particle size of the coating and gelatinization (Dyson 1983). The moisture content of the chicken nuggets ranged from 74.5 ± 0.4 to 56.2 ± 0.1% for non-breading, 81.4 ± 1.6 to 71.1 ± 0.4% for corn breading and 81.5 ± 1.4 to 74.4 ± 3.3% for chickpea breading (Table 4.5). The moisture content of the fried and conventional oven baked un-breaded nuggets was significantly lower than those of the RWO baked nuggets ($p<0.05$).

Increasing the processing time decreased the moisture content of the RWO baked non-breaded chicken nuggets within the same temperature. The moisture content of the corn breaded fried chicken nuggets was not significantly different than the RWO baked treatments (except treatment #3). The treatment #2, #3, #7 and #10 had higher moisture than conventional oven baked corn breaded control group. Chickpea breaded fried chicken nuggets had higher moisture than the treatment #5 and #6 and there is no significant different between the treatments and conventional oven baked ones. Overall, the processing time did not affect the moisture content of corn breaded and chickpea breaded chicken nuggets.

While the fat content of non-breaded fried chicken nuggets (except treatment #6) were not significantly different than the RWO baked plain chicken nuggets, it was significantly higher when the nuggets were coated because the coating provided porosity to the product and it was resulted high oil uptake during frying (Sahin et al. 2005). The conventional oven baked chicken nuggets had similar fat content with non-breaded and corn breaded treatments. The Chickpea breaded treatments #2, #8, #9 and #10 had higher fat content than conventional oven baked control (Table 4.5).

The non-breaded, corn breaded, and chickpea breaded chicken nuggets baked at 407°C for 5.5 minutes were compared in terms of moisture and fat content (Table 4.6). Corn breaded chicken nuggets had significantly higher fat content than plain and chickpea breaded chicken nuggets, the non-breaded chicken nuggets had lower moisture content than the breaded nuggets because Coating not only made contribution to appearance but also prevented moisture and weight loss from the products. It behaved like a sealant to limit the natural juices from flowing out (Cunningham, 1983).

Conclusions

Texture and lightness of the RWO baked chicken nuggets were not significantly different than that of deep-fat fried and conventional oven baked samples. However, the fat content of chickpea and corn breaded chicken nuggets were higher than fried chicken nuggets. Although the moisture content of the RWO baked non-breaded chicken nuggets were significantly higher, the moisture content of breaded chicken nuggets was the similar with control treatments.

References:

[NRA] National Restaurant Association. 2017. 2014 Restaurant industry outlook. Available from: https://www.restaurant.org/Downloads/PDFs/News-Research/2017_Restaurant_outlook_summary-FINAL.pdf. Accessed 2018 March 11.

Albert, A., Perez-Munuera, I., Quiles, A., Salvador, A., Fiszman, S. M., & Hernando, I. (2009). Adhesion in fried battered nuggets: performance of different hydrocolloids as predusts using three cooking procedures. Food Hydrocolloids, 23(5), 1443-1448.

Altunakar, B., Sahin, S., & Sumnu, G. (2006). Effects of hydrocolloids on apparent viscosity of batters and quality of chicken nuggets. Chemical Engineering Communications, 193(6), 675-682

AOAC (1986). Moisture content. Approved methods of the American Association of Chemists. St Paul, MN: AACC.

AOAC (1990). Official methods of analysis. Washington, DC: Association of Official Analytical Chemists.

Barbut, S. (2012). Convenience breaded poultry meat products-New developments. Trends in Food Science & Technology, 26, 14–10. doi:10.1016/j.tifs.2011.12.007

Brunner, E. J., Rees, K., Ward, K., Burke, M., & Thorogood, M. (2007). Dietary advice for reducing cardiovascular risk. Cochrane Database Syst Rev, 4(4), CD002128.

Burge, R. M. (1990). Functionality of corn in food coatings. Batters and breadings in food processing, 29-49.

Chen, R. Y., Wang, Y., & Dyson, D. (2016). Breadings—what they are and how they are used. Batters and Breadings in Food Processing, 169.

CIE. (2004). Technical report colorimetry (3rd ed.). Commission Internationale de l' Eclairage Central Bureau.

Cunningham, F. E. (1983). Application of batters and breadings to poultry. Batter and Breading. Westport, CT: AVI Publishing, 33-60.

Devatkal, S. K., Kadam, D. M., Naik, P. K., & Sahoo, J. (2011). Quality characteristic of gluten-free chickenuggets extended with sorghum flour. Journal of Food Quality, 34(2), 88-92.

Dogan, S. F., Sahin, S., & Sumnu, G. (2005). Effects of soy and rice flour addition on batter rheology and quality of deep-fat fried chicken nuggets. Journal of Food Engineering, 71(1), 127-132.

Dyson, D. V. (1983). Breadings. Batter and breadiry. Westport, CT: AVI Publishing, 24-32.

El-Dirani, K. (2002). Textural and mass transfer characteristics of chicken nuggets during deep fat frying and oven baking (Doctoral dissertation, McGill University Libraries).

Hooper L, Abdelhamid A, Moore HJ, Douthwaite W, Skeaff CM, Summerbell CD. 2012. Effect of reducing total fat intake on body weight: systematic review and meta-analysis of randomised controlled trials and cohort studies. BMJ: British Medical Journal 345.

Kirmaci, B. (2015). Characterization of Baked Potato Strips Processed in Radiant Wall Oven. The University of Georgia.

Kirmaci, B., & Singh, R. K. (2016). Quality of the pre-cooked potato strips processed by Radiant Wall Oven. LWT - Food Science and Technology, 66, 565–571.

Maskat, M. Y., & Kerr, W. L. (2002). Coating characteristics of fried chicken breasts prepared with different particle size breading. Journal of food processing and preservation, 26(1), 27-38.

Olewnik, M., & Kulp, K. (1990). Factors affecting performance characteristics of wheat flour in batters. Batters and breading in foods processing. Minnesota: American Association of Cereal Chemistry, 93-116.

Sahin, S., Sumnu, G., & Altunakar, B. (2005). Effects of batters containing different gum types on the quality of deep-fat fried chicken nuggets. Journal of the Science of Food and Agriculture, 85(14), 2375-2379.

Table 4.1: Experimental Design of RWO processing

Treatment#	Set Temperatures[1] (ºC)	Total Processing Time[2] (min)
1	347	4
2	347	5.5
3	347	7
4	367	4
5	367	5.5
6	367	7
7	387	4
8	387	5.5
9	387	7
10	407	4
11	407	5.5
12	407	7

[1]: Mean temperatures were 346.0 ± 4.7, 364.8 ± 2, 387.3 ± 1.3 and 406.0 ± 2.9 ºC for non-breaded chicken nuggets, 347.3 ± 1.6, 367.7 ± 1.3, 388.1 ± 0.6 and 403.0 ± 7.2 ºC for corn breaded chicken nuggets, and 347.1 ± 0.9, 367.2 ± 1.0, 387.4 ± 0.4 and 406.9 ± 0.8 ºC for chickpea breaded chicken nuggets for the set temperatures 347 ºC, 367 ºC, 387 ºC and 407 ºC.

[2]: The deviation in processing times was 0.02 – 0.05 min.

Table 4.2: Color, linear distance and yield of RWO baked, fried and conventional oven baked non-breaded chicken nuggets (n=3)

	Color				
Treatments #	Lightness	Chroma	Hue (°)	Linear Distance	Yield (%)
1	70.9 ± 0.1^{bA}	16.3 ± 0.7^{bA}	62.7 ± 1.4^{aB}	20.6^{aA}	94.1^{bB}
2	78.7 ± 0.4^{bB}	15.8 ± 0.1^{bA}	77.8 ± 1.8^{aA}	16.6^{aA}	88.2^{bB}
3	80.9 ± 0.0^{bB}	19.2 ± 0.7^{bA}	83.6 ± 0.0^{aA}	15.1^{aA}	84.9^{bB}
4	75.2 ± 1.1^{bB}	13.9 ± 0.1^{bB}	69.9 ± 2.8^{aA}	14.1^{aA}	94.3^{bB}
5	82.3 ± 0.4^{bB}	17.1 ± 0.9^{bA}	78.9 ± 1.8^{aA}	13.8^{aA}	88.6^{bB}
6	78.8 ± 0.7^{bB}	19.5 ± 0.6^{bA}	84.9 ± 0.7^{bA}	15.8^{aA}	81.8^{bA}
7	77.0 ± 1.2^{bB}	15.3 ± 0.4^{bB}	75.2 ± 3.1^{aA}	14.7^{aA}	91.0^{bB}
8	77.9 ± 2.9^{bB}	19.7 ± 1.1^{bA}	81.2 ± 0.2^{aA}	15.8^{aA}	85.1^{bB}
9	74.0 ± 0.3^{bB}	20.8 ± 0.8^{bA}	79.4 ± 1.9^{aA}	16.5^{aA}	71.9^{aA}
10	78.8 ± 0.4^{bB}	12.6 ± 3.2^{bA}	72.7 ± 4.6^{aA}	15.2^{aA}	91.2^{bB}
11	76.0 ± 0.9^{bB}	19.5 ± 0.4^{bA}	81.8 ± 0.2^{aA}	15.5^{aA}	79.4^{bA}
12	70.7 ± 0.4^{bB}	19.9 ± 0.2^{bA}	80.2 ± 0.1^{aA}	14.4^{aA}	65.6^{aA}
Control1[1]	63.5 ± 1.8^{a}	29.9 ± 1.4^{a}	72.2 ± 1.2^{a}	16.9^{a}	54.4^{a}
Control2[2]	67.7 ± 1.0^{A}	22.1 ± 1.4^{A}	77.1 ± 1.2^{A}	16.0^{A}	61.7^{A}

[1]: Deep fat fried chicken nuggets at 190 °C for 2 min.

[2]: Oven baked chicken nuggets at 225 °C for 10 min.

^{a,b}: Mean values followed by same letters within the same column show not significant difference with control1 treatment ($p<0.05$).

^{A,B}: Mean values followed by same letters within same column show not significant difference with control2 treatment ($p<0.05$).

Table 4.3: Color, linear distance and yield of RWO baked, fried and conventional oven baked corn flour mix breaded chicken nuggets (n=3)

Treatments #	Color			Linear Distance	Yield (%)
	Lightness	Chroma	Hue		
1	82.4±0.9^{aA}	23.4±0.6^{bA}	88.6±0.9^{aA}	94.2^{aA}	95.2^{aA}
2	88.1±0.1^{aA}	29.2±1.0^{bA}	93.3±0.1^{bA}	16.3^{aA}	95.3^{aA}
3	88.0±1.9^{aA}	30.2±0.8^{aA}	88.3±2.8^{aA}	13.5^{aA}	88.1^{aA}
4	89.4±5.1^{aA}	26.8±0.9^{bA}	90.7±4.5^{bA}	11.6^{aA}	95.3^{aA}
5	91.7±3.2^{aA}	30.6±0.7^{aA}	93.1±1.4^{bA}	15.0^{aA}	90.5^{aA}
6	81.5±5.3^{aA}	31.9±0.7^{aA}	79.9±4.3^{aA}	15.9^{aA}	86.0^{aA}
7	88.0±2.3^{aA}	25.7±0.7^{bA}	93.1±2.7^{bA}	13.7^{aA}	93.1^{aA}
8	90.3±6.6^{aA}	28.0±1.5^{bA}	89.5±3.5^{aA}	15.6^{aA}	83.3^{aA}
9	70.2±3.1^{aA}	28.2±3.6^{bA}	75.6±4.3^{aA}	16.2^{aA}	78.9^{aA}
10	89.6±0.6^{aA}	31.1±1.7^{aA}	91.2±2.7^{bA}	13.3^{aA}	92.7^{aA}
11	77.8±4.7^{aA}	26.9±2.6^{bA}	77.3±3.4^{aA}	12.6^{aA}	88.4^{aA}
12	76.0±4.8^{aA}	27.1±0.3^{bA}	79.2±1.7^{aA}	15.2^{aA}	81.4^{aA}
Control1	66.6±2.0^{a}	40.8±2.5^{a}	73.9±1.2^{a}	15.1^{a}	86.7^{a}
Control2	80.6±7.3^{A}	32.5±4.0^{A}	85.2±3.4^{A}	15.1^{A}	68.2^{A}

[1]: Deep fat fried chicken nuggets at 190 °C for 2 min.

[2]: Oven baked chicken nuggets at 225 °C for 10 min.

[a,b]: Mean values followed by same letters within the same column show not significant difference with control1 treatment (p<0.05).

[A,B]: Mean values followed by same letters within same column show not significant difference with control2 treatment (p<0.05).

Table 4.4: Color, linear distance and yield of RWO baked, fried and conventional oven baked chickpea flour mix breaded chicken nuggets (n=3)

Treatments #	Color			Linear Distance	Yield (%)
	Lightness	Chroma	Hue		
1	81.3±2.4^{aA}	15.4±0.6^{bA}	80.3±4.2^{aA}	14.2^{aA}	95.6^{aB}
2	85.6±6.7^{aA}	17.2±1.2^{bA}	86.0±9.9^{aA}	13.0^{aA}	93.1^{aB}
3	95.5±2.0^{aA}	22.1±1.3^{bA}	91.5±0.4^{aA}	14.7^{aA}	90.9^{aB}
4	84.9±1.4^{aA}	15.5±1.1^{bA}	88.2±2.0^{aA}	13.2^{aA}	92.6^{aB}
5	92.3±0.2^{aA}	22.1±0.1^{bA}	89.4±1.5^{aA}	14.7^{aA}	97.5^{aB}
6	105.0±1.9^{bA}	20.8±0.5^{bA}	93.2±0.7^{aA}	13.1^{aA}	93.2^{aB}
7	91.4±3.3^{aA}	12.7±3.8^{bB}	94.0±8.1^{aA}	12.7^{aA}	95.2^{aB}
8	76.6±4.1^{aA}	24.5±0.8^{bA}	79.5±0.7^{aA}	13.2^{aA}	87.5^{aB}
9	88.4±1.1^{aA}	24.3±1.2^{bA}	85.4±0.8^{aA}	14.5^{aA}	84.8^{aB}
10	95.5±1.6^{aA}	18.4±0.3^{bA}	92.3±1.2^{aA}	13.4^{aA}	87.3^{aB}
11	78.2±8.9^{aA}	24.7±3.6^{bA}	79.0±1.2^{aA}	13.3^{aA}	88.7^{aB}
12	71.1±1.1^{aA}	23.1±0.8^{bA}	77.3±1.2^{aA}	14.8^{aA}	82.6^{bA}
Control1	79.8±0.9^{a}	43.2±2.0^{a}	79.6±0.8^{a}	16.2^{a}	95.5^{a}
Control2	85.7±1.3^{A}	22.2±0.5^{A}	82.3±0.1^{A}	15.3^{A}	72.2^{A}

[1]: Deep fat fried chicken nuggets at 190 °C for 2 min.

[2]: Oven baked chicken nuggets at 225 °C for 10 min.

[a,b]: Mean values followed by same letters within the same column show not significant difference with control1 treatment ($p<0.05$).

[A,B]: Mean values followed by same letters within same column show not significant difference with control2 treatment ($p<0.05$).

Table 4.5: Moisture and fat content of RWO baked, fried and conventional oven bake chicken nuggets with different coating (n=3)

	Non-Breaded Chicken Nuggets		Corn Breaded Chicken Nuggets		Chickpea Breaded Chicken Nuggets	
Treatments #	Moisture Content (%)	Fat Content (%) (Dry Basis)	Moisture Content (%)	Fat Content (%) (Dry Basis)	Moisture Content (%)	Fat Content (%) (Dry Basis)
1	74.5±0.3^{bB}	10.7±3.5^{aA}	78.3±0.5^{aA}	11.4±1.1^{bA}	77.3±0.6^{aA}	10.5±0.3^{bA}
2	73.4±0.5^{bB}	11.0±0.4^{aA}	79.6±0.0^{aB}	12.1±0.7^{bA}	74.3±0.7^{aA}	10.9±0.4^{bB}
3	72.3±0.5^{bB}	10.2±1.7^{aA}	81.4±1.6^{bB}	15.1±1.4^{bA}	74.9±1.1^{aA}	9.3±0.4^{bA}
4	74.5±0.4^{bB}	13.9±1.7^{aA}	77.9±7.1^{aA}	15.7±1.8^{bA}	76.3±0.8^{aA}	9.3±1.5^{bA}
5	72.9±0.3^{bB}	15.0±1.0^{aA}	77.3±1.2^{aA}	11.0±0.4^{bB}	73.2±0.2^{bA}	8.8±0.8^{bA}
6	70.9±0.0^{bB}	18.8±0.9^{bB}	78.2±1.2^{aA}	10.9±1.0^{bB}	73.2±1.1^{bA}	7.6±0.7^{bA}
7	73.6±0.4^{bB}	12.0±0.7^{aA}	78.7±0.7^{aB}	15.4±1.0^{bA}	77.2±1.7^{aA}	15.0±1.5^{bA}
8	72.3±0.5^{bB}	15.5±0.3^{aA}	78.2±0.7^{aA}	14.7±0.8^{bA}	77.1±1.4^{aA}	16.4±0.8^{bB}
9	66.6±0.4^{bB}	14.2±1.1^{aA}	75.8±1.0^{aA}	12.2±0.9^{bA}	77.7±0.8^{aA}	15.7±0.5^{bB}
10	73.6±0.4^{bB}	15.1±0.5^{aA}	79.8±0.8^{aB}	14.1±1.1^{bA}	81.5±1.4^{aB}	14.0±0.1^{bB}
11	70.4±0.5^{bB}	8.2±1.1^{aA}	77.5±0.3^{aA}	14.5±1.2^{bA}	78.4±0.9^{aA}	10.2±0.9^{bA}
12	63.5±0.3^{bB}	9.5±0.3^{aA}	75.5±0.4^{aA}	15.2±1.7^{bA}	76.1±1.5^{aA}	9.4±1.4^{bA}
Control1	56.2±0.1^{a}	11.6±0.8^{a}	73.7±0.5^{a}	29.3±1.6^{a}	78.5±1.4^{a}	21.3±1.1^{a}
Control2	61.3±0.2^{A}	12.3±0.6^{A}	71.1±0.4^{A}	15.4±0.4^{A}	74.4±3.3^{A}	7.2±1.5^{A}

[1]: Deep fat fried chicken nuggets at 190 °C for 2 min.

[2]: Oven baked chicken nuggets at 225 °C for 10 min.

[a,b]: Mean values followed by same letters within the same column show not significant difference with control1 treatment ($p<0.05$).

[A,B]: Mean values followed by same letters within same column show not significant difference with control2 treatment ($p<0.05$).

Table 4.6: Comparison of quality characteristic for breaded and non-breaded nuggets at the same temperature and time (n=3)

Nuggets Type[1]	Lightness	Croma	Hue (°)	Yield (%)	Linear Distance	Moisture Content (%)	Fat Content (%) (Dry Basis)
Non-Breaded	76.0±0.9[a]	19.5±0.4[a]	81.8±0.2[a]	79.4[a]	15.5[a]	70.4±0.5[b]	8.2±1.1[a]
Corn Breaded	77.8±4.7[a]	26.9±2.6[a]	77.3±3.4[a]	88.4[a]	12.6[a]	77.5±0.3[a]	14.5±1.2[b]
Chickpea Breaded	78.2±8.9[a]	24.7±3.6[a]	79.0±1.2[a]	88.7[a]	13.3[a]	78.4±0.9[a]	10.2±0.9[a]

[1]: The all nuggets baked in the RWO at set temperature 407°C for 5.5 min.

[a,b]: Mean values followed by same letters within the same column show not significant difference between the treatments ($p<0.05$).

CHAPTER 5

CONCLUSIONS

The non-breaded chicken nuggets had the highest heat flux and radiant heat transfer coefficient compared to corn breaded and chickpea breaded chicken nuggets. The heat flux and radiant heat transfer coefficient of corn breaded chicken nuggets were higher than chickpea breaded nuggets. A correlation between temperature and heat transfer have been found for the RWO baked nuggets. The particle size for each flour type was measured, and the effect of the particle size and flour type were compared to understand their effect on the radiant heat transfer. It has been found that particle size did not affect the heat transfer of the RWO baked chicken nuggets.

The RWO processed breaded chicken nuggets had dramatically lower fat content. Instrumental analysis indicated that non-breaded and breaded chicken nuggets had similar lightness and texture regarding crispness when compared to fried and conventional oven baked chicken nuggets. The moisture content of breaded nuggets was similar to the moisture content of fried and conventional oven baked nuggets.