DEVELOPMENT OF CRISPINESS IN BATTER COATED CHICKEN NUGGETS DURING POST FRYING HOLDING

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ABSTRACT

Loss of crispiness and the high fat content of deep-fried foods are two major challenges facing the fried food services industry. Crispiness is one of the key quality attributes that determines consumer's acceptance and preference for fried products. Likewise, Public awareness of the harmful effect of consumption of high amounts of fat has driven the industry to explore alternative and strategic approaches for the reduction of fat content in fried foods. Therefore, maintaining both crispiness and low-fat quality of fried products without forfeiting one for the other is of huge interest. This study was then undertaken to investigate the potential of hydrocolloids, ultrasound treatment and frying method to significantly minimize fat uptake during frying and prevent crispiness loss during post-frying holding under heat lamp.

In the first phase of this study, 1% concentration of hydrocolloid (pectin (P), locust bean gum (LB), guar gum (GG), xanthan gum (XG), methylcellulose (MC), and hydroxypropyl methylcellulose (HPMC)) was integrated into a pre-dust and batter system. Chicken nugget was coated with the different formulated batters and subjected to either air frying or deep fat frying. Various quality attributes such as moisture loss, fat uptake and crispiness were measured after keeping the fried samples under heat lamp for 0, 10, 20, 30, 40 and 50 min. In a second study phase, the batters were subjected to ultrasound treatment before they were used to coat the chicken nugget and subsequent deep fat fried or air fried. Crispiness and other quality attributes were measured similar to the first phase of the study.

The inclusion of hydrocolloids in the batter formulation significantly reduced the fat content of chicken nuggets subjected to both frying methods. In particular, hydrocolloids reduced the fat content of deep-fried samples by 27.08 to 59.92%. Likewise, post frying holding time under heat

lamp caused a significant ($p < 0.05$) reduction in the moisture content of the crust, core, and overall moisture content of fried chicken nuggets. The effect of hydrocolloids on the crispiness was well pronounced in both frying methods with air fried samples having the highest crispiness under heat lamp. Most importantly, the control sample showed the highest cutting force at almost every holding time for both frying methods while xanthan gum presented samples with the lowest crispiness that ranged between 1.91 to 4.90 N for deep fried nuggets, and 3.38 to 8.43 N for air fried nuggets held under heat lamp. Compared to the control (batter with no hydrocolloid and ultrasound treatment), the overall fat content of ultrasound treated batters decreased by 11.5, 39.0, 60.9, 64.1, 65.7, 65.0, and 62.87% for control, P, LB, GG, HPMC, MC, and XG, respectively. Additionally, ultrasonicated samples produced the highest crispiness when compared with non-ultrasound treated samples.

This study added to the scientific understanding of the usefulness of hydrocolloids in suppressing moisture migration in food materials during deep fat frying and air frying. The combination of hydrocolloids and ultrasound treatment has significant benefits in terms of nutritional and quality preservation, and it can be used in both domestic and commercial deep fat frying processes.

RÉSUMÉ

La perte de croustillance et la teneur élevée en gras des aliments frits sont deux défis majeurs auxquels est confrontée l'industrie des services alimentaires frits. La croustillance est l'un des principaux attributs de qualité qui détermine l'acceptation et la préférence des consommateurs pour les produits frits. De même, La sensibilisation du public aux effets néfastes de la consommation d'une grande quantité de matières grasses a poussé l'industrie à explorer des approches alternatives et stratégiques pour réduire la teneur en matières grasses des aliments frits. Par conséquent, maintenir à la fois le croustillant et la qualité faible en gras des produits frits sans renoncer à l'un pour l'autre est d'un grand intérêt.. Cette étude a ensuite étudié le potentiel des hydrocolloïdes, du traitement par ultrasons et de la méthode de friture pour réduire considérablement l'absorption des graisses pendant la friture et prévenir la perte de croustillance pendant la tenue après la friture sous une lampe à chaleur.

Dans la première phase de l'étude, une concentration d'hydrocolloïdes de 1 % (pectine (P), gomme de caroube (LB), gomme de guar (GG), gomme de xanthane (XG), méthylcellulose (MC) et hydroxypropyl méthyl cellulose (HPMC)) a été intégrée dans le système. La pépite de poulet a ensuite été enrobée des différentes pâtes formulées et soumise à la friture à l'air et à la friture. Divers attributs de qualité tels que la perte d'humidité, l'absorption de graisse, et croustillant ont été mesurés après le stockage sous lampe à chaleur pendant 0, 10, 20, 30, 40, et 50 min. Dans la deuxième phase de l'étude, les pâtes ont été soumises à un traitement par ultrasons avant d'être utilisés pour enrober la pépite de poulet suivie de friture profonde. Le croustillance et d'autres attributs de qualité ont ensuite été mesurés de la même façon que la première phase de l'étude.

L'inclusion d'hydrocolloïdes dans la préparation de la pâte a considérablement réduit la teneur en gras des pépites de poulet soumises aux deux méthodes de friture. En particulier, les

hydrocolloïdes ont réduit la teneur en matières grasses des échantillons frits de 27,08 à 59,92. De plus, le temps de maintien après friture sous la lampe à chaleur a entraîné une réduction importante ($p < 0,05$) de la teneur en humidité de la croûte, du noyau et de la teneur en humidité globale des pépites de poulet frites. L'effet des hydrocolloïdes sur la croustillance était bien prononcé dans les deux méthodes de friture avec des échantillons frits ayant la plus grande croustillance sous lampe à chaleur. Plus important encore, l'échantillon de contrôle a montré la force de coupe la plus élevée à presque tous les temps de maintien pour les deux méthodes de friture, tandis que la gomme de xanthane a présenté des échantillons avec le croustillant le plus faible, allant de 1,91 à 4,90 N pour les pépites frites et de 3,38 à 8,43 N pour les pépites frites à l'air. tenu sous la lampe chauffante. Par rapport au témoin (pâte sans hydrocolloïde ni traitement par ultrasons), la teneur globale en matières grasses des pâtes traitées par ultrasons a diminué de 11,5, 39,0, 60,9, 64,1, 65,7, 65,0 et 62,87 % pour le témoin, P, LB, GG, HPMC, MC et XG, respectivement. Comparés aux échantillons non traités aux ultrasons, les échantillons traités aux ultrasons ont produit le croustillant le plus élevé. De plus, les échantillons ultrasoniques ont produit le croustillant le plus élevé par rapport aux échantillons non traités aux ultrasons.

Cette étude a permis de mieux comprendre l'utilité des hydrocolloïdes pour la suppression de la migration de l'humidité dans les matériaux alimentaires lors de la friture et de la friture à l'air. La combinaison d'hydrocolloïdes et de traitement par ultrasons a des avantages significatifs en termes de conservation nutritionnelle et de qualité, et il peut être utilisé dans les processus de friture tant domestiques que commerciaux.

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THESIS FORMAT

This thesis is submitted in the format of papers suitable for journal publication. This thesis format has been approved by the Faculty of Graduate and Postdoctoral Studies, McGill University, and follows the conditions outlined in the Guidelines: Concerning Thesis Preparation, which are as follows:

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2. The thesis must be more than a collection of manuscripts. All components must be integrated into a cohesive unit with a logical progression from one chapter to the next. In order to ensure that the thesis has continuity, connecting texts that provide logical bridges between the different papers are mandatory.

3. The thesis must conform to all other requirements of the "Guidelines for Thesis Preparation" in addition to the manuscripts. The thesis must include the following:

(a) A table of contents.

(b) An abstract in English and French;

(c) An introduction which clearly states the rational and objectives of the research.

(d) A comprehensive review of the literature (in addition to that covered in the introduction to each paper);

(e) A final conclusion and summary;

4. As manuscripts for publication are frequently very concise documents, where appropriate, additional material must be provided (e.g., in appendices) in sufficient detail to allow a clear and precise judgment to be made of the importance and originality of the research reported in the thesis.

5. In general, when co-authored papers are included in a thesis, the candidate must have made a substantial contribution to all papers included in the thesis. In addition, the candidate is required to make an explicit statement in the thesis as to who contributed to such work and to what extent. This statement should appear in a single section entitled "Contributions of Authors" as a preface to the thesis. The supervisor must attest to the accuracy of this statement. Since the task of the examiners is made more difficult in these cases, it is in the candidate's interest to clearly specify the responsibilities of all the authors of the co-authored papers".

CONTRIBUTION OF AUTHORS

The contribution and role performed by the different authors are as follows: **Mr. Dare Oloruntoba** is the primary author of this work. He is the M.Sc. candidate in Bioresource Engineering who prepared, designed and conducted all the experiments, data analysis, and writer of the work submitted. All experiments were carried out in the Food and Bioprocess Engineering Laboratory, Department of Bioresource Engineering, Macdonald Campus of McGill University. The thesis supervisor is **Dr. Michael O. Ngadi**, he supervised the candidate design and implementation of the experiments and data analysis during the production of the above-mentioned work. The entire manuscript was also corrected and examined by **Dr. Michael O. Ngadi**. **Dr. Josephine Ampofo** graduated from the Food and Bioprocess Engineering Laboratory, McGill University, Macdonald Campus, she is currently a postdoctoral researcher at the University of Sainte Anne. She reviewed chapter 4 of this thesis. The following manuscript has been prepared for publication in food and bioprocess engineering-related journals.

1. ***Dare Oloruntoba*** and Michael Ngadi 2020. "Crispiness of fried product: current status and challenges"
2. ***Dare Oloruntoba*** and Michael Ngadi 2020. "A Comparative study of the impact of hydrocolloids on the crispiness of deep fat fried and air fried chicken Nugget"
3. ***Dare Oloruntoba*** and Michael Ngadi 2020. "Combined effect of ultrasound and hydrocolloid formulated batter on qualities of fried chicken nuggets during post frying holding"

Signed: Dare Oloruntoba

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NOMENCLATURE

DSC	Differential scanning calorimeter
XG	Xanthan gum
MC	Methylcellulose
HPMC	hydroxypropyl methylcellulose
GG	Guar gum
LB	Locust beans gum
P	Pectin
C	Control
CMC	Carboxymethylcellulose
USXG	Ultrasonicated xanthan gum
USMC	Ultrasonicated Methylcellulose
USHPMC	Ultrasonicated hydroxypropyl methylcellulose
USGG	Ultrasonicated guar gum
USLB	Ultrasonicated locust beans gum
USP	Ultrasonicated pectin
USC	Ultrasonicated control
$_{C}P$	Centipoise
R^2	Coefficient of determination
DF	Deep fat fried
AF	Air fried
/s	Per second
T	Temperature
k	Consistency coefficient
n	Flow behavior index
γ	Shear rate
N	Newton (unit of force)
τ	Shear stress
Pa.s	Unit of consistency coefficient
T_e	Peak temperature
T_C	Conclusion temperature
T_O	Onset temperature of gelatinization
ΔH	Gelatinization enthalpy
db	Dry basis

°C	Celsius degrees
L*	Lightness
a*	Redness-greenness dimensions (CIE L, a*, b* colorspace)
b*	Yellowness-blueness dimensions (CIE L, a*, b* colorspace)
ΔE	Equally weighted combination of L, a*, and b* variances
ΔH_m	Enthalpy of melting
US	ultrasonicated
NUS	Non-ultrasonicated
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
C.I.E	Commission Internationale de l'Eclairage
GLM	General linear model
min	Minute
mg	Milligram
SAS	Statistical analysis software
PROC GLM	Generalized linear model procedure

CHAPTER ONE

1. GENERAL INTRODUCTION

1.1 Background

In recent years, the need to produce healthy fried foods with improved crispiness and other organoleptic properties has become a major concern to the world's growing population. Deep fat frying is the best known and most frequently used method for the preparation of fried foods with a desirable appearance, flavor and crispiness. The crispy crust and the moist core of deep-fried foods are some of the key quality attributes that influence consumers' acceptability and palatability of fried products (Luyten et al., 2004). In this regard, improved frying methods and modern techniques are essential for the reduction of fat uptake and the improvement of fried foods crispiness, thus reducing the quality of fried foods.

Various approaches and emerging techniques have been utilized in combating the high fat absorbed during deep fat frying. These techniques include 1) pre-treatment activities, such as pre-drying, pre-dusting, pre-cooking, battering, ultrasonic treatment, and addition of additives, 2) frying techniques modification (vacuum frying, air frying, and deep fat frying), 3) modification of frying parameters, and 4) post frying activities such as centrifugation, blotting through a paper towel, and exposure to infrared heat lamp. However, these methods have faced distinct drawbacks, given the high cost of purchase and/or the failure to produce fried food with organoleptic properties that imitate conventional deep fat frying (Santos *et al.*, 2017). In recent decades, the use of additives such as hydrocolloids has been studied to enhance the crispiness and reduce oil absorption in different fried foods (Ojagh et al., 2016).

Hydrocolloids, when heated in their hydrous state go through recoverable gelation with a unique property that helps in increasing the batter pickup and creating a barrier that resists oil absorption and moisture loss during and after frying (Mellema, 2003). Some hydrocolloids are known and widely used because of their thermal gelling properties. Such properties can influence the quality of fried products during and after frying. The most used hydrocolloids in the fried food industry are hydrocolloids from the cellulose derivatives such as methylcellulose (MC) Carboxymethyl cellulose (CMC) and hydroxypropyl methylcellulose (HPMC) (Phule & Annapure, 2013). This is due to their themo-gelling property and film forming ability. However, due to the manufacturing process and chemical-sounding names of cellulose derived hydrocolloids, focus is been shifted to the functionality of natural hydrocolloids due to consumers' preference for natural and fresh ingredients. In this regard, various natural hydrocolloids such as Pectin, guar gum, locust bean gum, xanthan gum, and others have found considerable application in the food industry. There is, however, a lack of information about how these hydrocolloids and other frying parameters impact various fried food properties during post frying activities.

In addition, ultrasound pretreatment has been listed among the latest technologies used in cooking to reduce the high fat content in fried foods (Sani et al., 2018). Ultrasound treatment is a novel technology used in the food industry. It is a non-thermal technology that transmits sound waves of around 20 KHz and above to induce agitation in liquid media. This technology is gaining ground in food processing owing to its nutrients preservation, less processing time, low material usage, energy saving, and increase in mass transfer (Oladejo et al., 2017). The impact of ultrasound has been reported to reduce fat content in fried foods like fried sweet potato by up to 75% (Oladejo et al., 2017) and potato strip (Dehghannya et al., 2018; Mohammadalinejhad et al., 2018). However, there is a shortage of information on the effect of ultrasound on the crispiness of fried foods. In addition, post frying practices also play important role in the quality of fried foods, new technologies that can help reduce the fat content while maintaining the crispness of fried foods are still needed.

Several of the batter-coated fried foods are usually par-fried or partly fried. It can then be finished fried with other techniques, namely deep-fat frying, oven baking, air frying, and cooking with a microwave. Recently, there has been increased utilization of air frying in the fried food industry mainly because of the less oil used and organoleptic properties that are similar to conventional deep fat frying (Zaghi et al., 2019). While fried products made with air fryers have comparable properties to those made with traditional deep fat frying, certain products, such as batter-coated fried products, require a par-frying process to ensure batter adhesion to the substrate before being finished fried in a hot air fryer, this often leads to higher oil absorption due to the par-frying process.

One of the most prevalent problems associated with batter-coated fried products is the inability to suppress the loss of crispiness during post frying period (periods after frying) (Luyten et al., 2004a). Crispiness is a textural attribute that is well appreciated and easily perceived by consumers. It is the most important textural attribute of fried products, this sensation occurs as a result of heat and mass transfer process which includes the loss of moisture as a result of the high temperature transferred from the hot oil during frying (Miranda & Aguilera, 2006). Therefore, new innovations and techniques to improve and maintained the crispiness by limiting moisture migration between different portions of the food are of utmost importance. The application of hydrocolloids as water binder have been documented. The unique characteristics of hydrocolloids, which inhibit moisture migration by means of their themo-gelling and water-binding capacity in frying could inhibit the rate of crispiness lost during post frying holdings.

1.2 Hypothesis

Based on available literatures on the application of hydrocolloids, ultrasound-assisted treatment, pre-dusting, and frying methods in influencing various properties of fried products, it is hypothesized that incorporation of various hydrocolloids into the pre-dust and batter system will cause a significant reduction in fat content and also lead to improvement/maintenance of the crispiness of the fried battered chicken nuggets during post frying holding time under heat lamp. It is also further hypothesized that a combination of hydrocolloids and ultrasound treatment will help in improving the nutritional and textural properties of the fried chicken nuggets during post-frying holding under heat lamp.

1.3. Research Objectives

The objective of this research was therefore to study the effect of ultrasound pretreatment and the inclusion of hydrocolloids in batter formulation on the properties of deep-fried and air-fried chicken nuggets during post frying holding times under heat lamp. Specifically, the objectives include.

1. To determine the effect of hydrocolloids and ultrasound treatment on the thermal and rheological properties of wheat flour- corn starch batter.
2. Investigate the effect of different hydrocolloids and two frying methods (deep fat frying and air frying) on properties of fried chicken nuggets during post-frying holdings.
3. To determine the combined effect of ultrasound treatment and hydrocolloids on nutritional and textural properties of deep-fried chicken nuggets during post frying holding under heat lamp.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Deep Fat Frying

Deep fat frying is the most popular and oldest method used in preparing fried foods due to its affordability and rapid preparation process, it is a multifaceted method used in producing food products with improved textural attributes, flavor, and attractive appearance (Ziaiifar et al., 2010; Vitrac et al., 2000; Saguy & Dana, 2003). Deep-frying, also known as immersion frying, is a thermal food processing method through which food is subjected to oil at a temperature between 150 and 200 ºC. A lot of chemical changes occurs during this process due to the simultaneous heat and mass transfer of oil and moisture, thereby, leading to moisture loss, fat uptake, starch gelatinization, oil polymerization, crust formation, hydrolysis or oxidation, and color changes through Maillard reactions (Mir-Bel *et al.*, 2012). In addition, the development of crusts is due to a higher evaporation rate in the coated portion of food relative to the migration of moisture within the center, thereby, presenting a product with a moist core and crispy crust. Apparently, the batter coated surface to a greater extent would determine the quantity of oil absorbed during and after the frying process (Van Koerten *et al.*, 2015; Ziaiifar *et al.*, 2010). However, due to public awareness and apprehension regarding high fat content deposited in deep-fat fried foods, which also contributes to multiple cardiovascular disorders such as diabetes, obesity, and high blood pressure (Saguy & Dana, 2003), recent studies are directed at the use of new fried food technologies that ensure a fried product with reduced oil absorption, such as hot air frying, vacuum frying, and microwave frying. However, little is established about the versatility of these modern frying methods to improve or maintain the crispness of fried foods.

2.2 Frying Process

Frying is a concurrent heat and mass transfer mechanism that causes major changes in the microstructure of a fried product. Diverse chemical reactions happen during frying as a result of heat transfer, including the gelatinization of starch, denaturation of protein, crust formation, vaporization, and color development (Mir-Bel et al., 2009). However, amid growing consumer understanding of the relationship between food, diet, and wellbeing, frying continues to be one of the major cooking methods at both domestic and industrial level due to its ability to create in the final product, an amalgam of color, flavor, and textural attributes that are desirable and palatable to consumers (Shaker, 2015). Fried foods exist in different forms, shapes, and compositions. According to Kulp (2016), fried foods with multi-domain moisture content could be described as having three zones during frying. These zones are namely:

1. The boundary between food and oil
2. The portion that contains most of the oil (crust)
3. The inner portion that is moist and mostly oil-free (core).

Figure 2.1 depicts the mechanism of heat and mass transfer during deep fat frying. At the inception of the frying process, there is rapid evaporation of moisture. However, at this stage, the transfer of heat from the oil surface to the food is mainly due to convection, while conduction depicts the heat distribution through the crust layer. During the deep-fat frying process water in the crust is evaporated and removed. Enough water would have to pass from the food core to the crust to allow the migration of vapor and to stay permeable to the crust. The fact that the vapor creates a cavity for fat to penetrate later is the reason why the fat absorption is primarily dictated by the moisture content of the product (Oke et al., 2018). Heat transmission by means of conduction takes place in the food, while transfer by convection takes place between food and frying oil. Water evaporation is fast at the preliminary frying stages and the water leaving from the core hits the crust. The escaped water comes into contact with the frying oil and forms bubbles that travel rapidly in the oil, causing agitation across the oil. The bubbling water at the surface, therefore, affects the coefficient of heat transfer by rising turbulence. As a result of lowered moisture levels inside the product, the amount of water vapor bubbles that escape from the food decreases with increasing frying time.

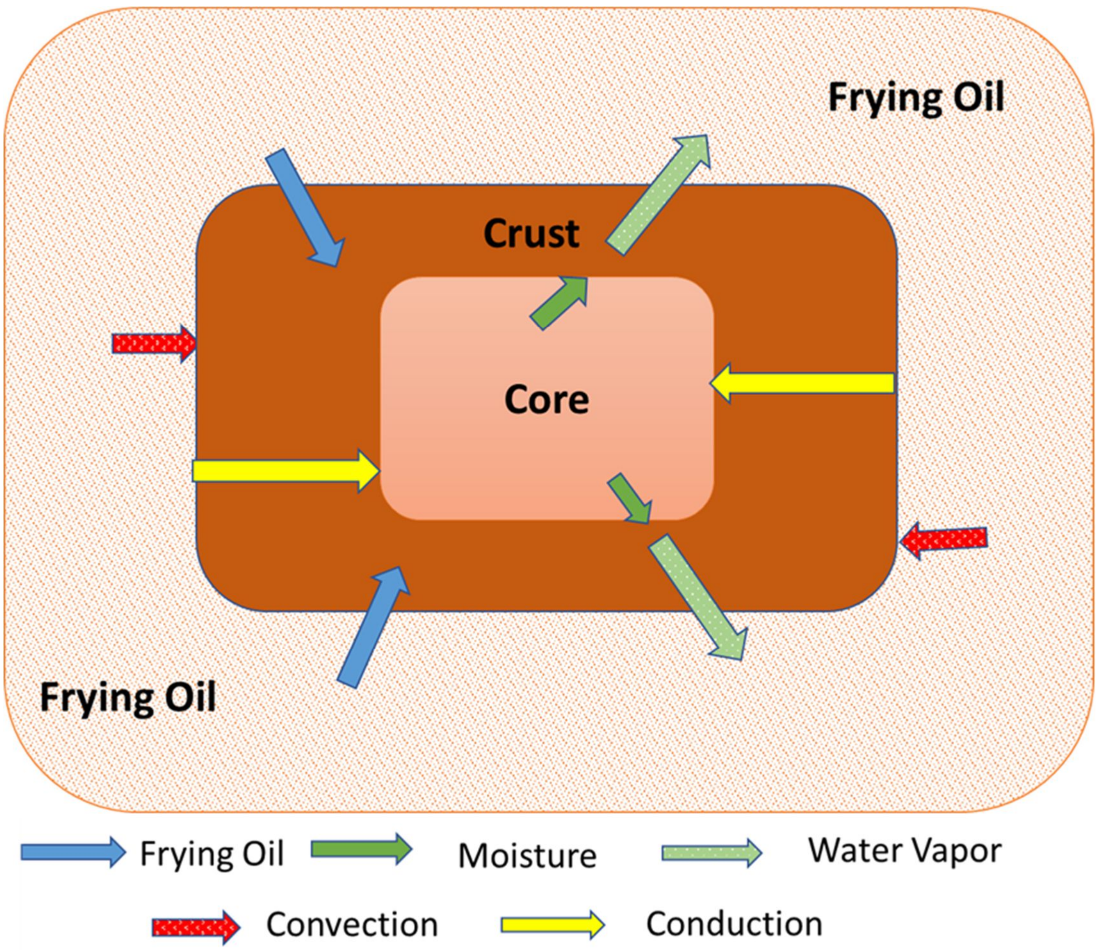


Fig. 2.1: Heat transfer and mass transfer mechanism during deep fat frying

2.3 Pre–Treatments and their Influence on Quality Attributes of Fried Products

Proper pre-treatment of foods could dramatically reduce the absorption of oil and also improve the organoleptic properties of fried foods. Certain pretreatment processes, such as pre-dusting, pre-drying, pre-cooking, battering, and ultrasonic pretreatment have been commonly utilized to reduce the oil content of fried foods such as chicken nuggets, potato chips and French fries.

2.3.1 Pre-drying

Various authors have reported the correlation between the initial moisture content and fat absorption of fried foods (Krokida et al., 2001; Tran et al., 2007). According to Debnath et al. (2003), the amount of water removed during the pre-drying process could reduce the gradient of the moisture and oil transfer. Most importantly, they stated that the decrease in the moisture content of snack food made from a blend of modified starch and chickpea flour by first pre-drying in the oven helped lower the final fat absorption by up to 54%. Lumanlan et al. (2020) also observed that pre-drying of fried chips at 90 min resulted in a decrease of about 20% in fat uptake which was attributed to the low moisture content of pre-dried chips (8.76%) relative to control chips (25.04%). A study by Moyano and Pedreschi (2006) on the impact of blanching with hot water (85 °C, 3.5 min) and a combinative effect of blanching (85 °C, 3.5 min) and drying to achieve a moisture content of 60 g/100 g (wet basis) prior to deep fat frying of potato slices resulted in lower oil absorption for samples treated with the combination of blanching and drying. Conversely, the blanched potato slices absorbed more oil when compared to the control sample without blanching and drying. Dehghannya et al. (2016) investigated the impact of ultrasound treatment, air-drying (8 and 15 min), and a combination of the pre-treatments on the moisture content and fat uptake attributes of potato strips. Specifically, prior to frying, Pre-treated samples with a 40 kHz frequency and a drying time of 15 min resulted in a moisture loss of 31.2 %. However, the samples showed a moisture loss of 28.7% only when 15 min drying time was used as pre-treatment. Consequently, after frying, the pre-treated samples with a 40 kHz frequency and a drying time of 15 min resulted in a moisture loss of 38.5% and fat reduction of 19.4%. Apparently, the samples also showed a moisture loss of 33.4% and fat reduction of 16.3% only when drying for 15 min was used as pre-treatment. According to Oladejo et al. (2018), the decrease in oil absorption through pre-drying pre-treatment operation may be influenced by the initial solidity and structural hardening of substrates before frying, which then prevents oil absorption during the frying process. Although pre-drying operations have been established to facilitate the reduction in fat content due to low moisture, there is still, however, a need to investigate the impact of pre-drying operations on the crispiness of fried products.

2.3.2 Pre-cooking

The initial moisture content of fried products is the most crucial characteristic that influences oil absorption. High porosity development and fat absorption occur in fried food due to the high moisture loss in samples with higher initial moisture content thereby providing a pathway for oil to penetrate the product (Soorgi et al., 2012). Various precooking operations such as steaming, boiling, blanching, microwave heating, and simmering have been shown to influence the adhesive properties of batter coating. Microwave heating as a pre-treatment has many advantages which include short cooking time, energy-saving, improved microstructure, and improvement in product uniformity (Amiryousefi et al., 2012). For instance, Soorgi et al. (2012) evaluated the effect of microwave pre-treatment on the mass transfer of fried chicken nuggets. Precisely, the chicken nuggets were subjected to 3.7 and 7.4 W/g power densities to cause a reduction in the moisture content prior to frying. It was reported that as the power density increased the fat absorption also increased. Likewise, the moisture reduction in the final fried chicken nugget increased with frying time. Microwave power density of 3.7 W/g had no significance on the moisture content. Similarly, Adedeji et al. (2009) study on the effect of microwave precooking temperature and time on mass transfer of chicken nuggets (core and crust) reported that samples precooked at 6.7 W/g produced a chicken nugget with lower oil content at all frying temperatures. Adedeji et al. (2009) were able to reduce the fat absorption in fried chicken nuggets by reducing the initial moisture content through microwave heating at 14.1 W/g for 1 and 2 min. The authors concluded that increasing the microwave precooking time leads to a reduction in the moisture content prior to frying and subsequent reduction in the fat absorption after frying.

2.3.4 Pre-dusting

Pre-dust is a fine, dry ingredient that is applied to the surface of a moist food substrate prior to further coating application. Generally, ingredients used for pre-dusting are starches, proteins, and hydrocolloids (Albert et al., 2009; Varela & Fiszman, 2011). Application of batter to the surface of a moist substrate could lead to batter slipping off the surface of the substrate, thus, providing partial coverage and a thin layer to the substrate. On the order hand, the addition of pre-dust on dry or frozen substrates could result in the dust being deposited in the batter system due to non-adherence, thereby resulting in high viscosity and batter pickup of the substrate (Fiszman, 2008). One of the key techniques of achieving the desired texture in fried foods is the sequential inclusion of different layers of pre-dust, batter, and breading. For example, Usawakesmanee et al. (2008) study on the influence of pre-dusting mix on fat absorption, moisture content, and consumer acceptability of breaded shrimps revealed that the inclusion of methylcellulose gum (MC) and hydroxypropyl methylcellulose (HPMC) in the pre-dust of breaded shrimps caused a decrease in the fat uptake and enhanced moisture loss. Furthermore, MC inclusion provided the sample with a reduced hardness value of 182.51 N compared with the control (without pre-dusting) 205.59 N.

Sensory evaluation showed similar rating for other quality attributes such as color, appearance, flavor, and taste for both pre-dusted shrimp and the control. Additionally, Albert et al. (2009) stated that pre-dusting a fish nugget with hydrocolloids such as xanthan gum, HPMC, and starch does not improve the batter pickup, color, and crispiness of battered fish nuggets when compared with the control (wheat flour).

2.3.5 Battering and breading

Over the past decades, the producers of batter mix only applied wheat flour with intuition without studying the functionality of the batter during frying. However, recent studies have focused on the development of batter systems and the interaction of the ingredients within the batter system. According to Kulp (2016), to achieve practical and economic benefit in fried products, different food substrates could be modified effectively through the application of batter and breading coating. For instance, with the inclusion of inexpensive coating materials, substrates may be modified to improved sensory properties, the resulting foods are always distinctive, making them more desirable to expanded customer numbers in appearance and even certain less-appealing substrates can be enhanced and flavored by the use of coatings. A sample of the widely batter-coated product is shown in Table 2.1.

Table 2. 1 Commonly coated products

Ingredient	Product
Fish	Nuggets
	Sticks
	Fillets
Poultry/Chicken	Nuggets, whole muscle-formed
	Breasts, boneless and skinless
	Breasts, boneless and skin-on
	Tenders
	Bone-in
	Breasts
	Drumsticks
	Wings
	Thighs
	Nine-cut
	Eight-cut
Vegetables	Onions
	Zucchini
Cheese	Sticks

Source: Kulp (2016)

Battering and breading remains the most useful ways of improving the crispiness of fried products. The usability of different batter formulations and breading has helped in creating or improving the crispiness and flavor of fried foods (Brannan *et al.*, 2014; Xue & Ngadi, 2007). Batter is a mixture of ingredients/ flour and water applied to the surface of a food product to enable a crispier crust and serve other purposes like the prevention of moisture loss, offering a golden-yellow crust, and reduction in fat uptake during deep-fat frying by protecting the juiciness of the product (Sahin *et al.*, 2005; Zhang *et al.*, 2014). The quality of the edible crust could be influenced by different factors such as batter formulations, frying methods, and other parameters (frying temperature, frying time, and heating method) (Altunakar et al., 2004; Baixauli et al., 2003; Zhang et al., 2014). Other ingredients are added to batters in other to improve the functionality of the batter during further processing, these ingredients range from, egg, leavening agent, salt, hydrocolloids, starches, and others (Yılmaz *et al.*, 2017). Furthermore, batter serves another purpose by forming a layer where breading can adhere wholly (Sousa *et al.*, 2019). Battering and breading have been one of the methods used in attaining a crispier product during frying. This is because, the crispiness of batter coated, or breaded products greatly depend on the structure of the outer crust of the product. Zhang et al. (2014) stated that the ratio of amylose content in starches can improve the crispness of fried products, in their research on the physicochemical properties of starches it was established that amylomaize, corn, waxy maize, and pregelatinized tapioca starch could increase the crispness of deep-fried chicken nuggets (Altunakar *et al.*, 2004). Ketjarut and Pongsawatmanit (2015) emphasized that the viscosity of batter is essential in the coating of fried foods as properties like batter pickup, appearance, and crispiness are influenced by the batter formulation. Furthermore, Van de Noort (2017) highlighted the impact of battering on the quality of fried products to be the adhesion, freeze-thaw tolerance, emulsification, fat uptake, crispiness development, and barrier creation during frying.

2.3.6 Hydrocolloid

Hydrocolloids are colloidal compounds with an affinity for water. They are macromolecular hydrophilic compounds from a chemical perspective. Some of them are water-soluble and form colloidal solutions; others can only swell in water and can be spread through the application of shear force. In water, hydrocolloids transform into a viscous solution, gels, or pseudo-gels. The diverse group is majorly composed of protein and polysaccharides (Wüstenberg, 2015).

The main explanation behind the widespread use of hydrocolloids in food is their ability to influence the rheology of food systems. This concerns two fundamental characteristics of food systems namely flow behavior (viscosity) and mechanical property (texture). The alteration of food texture and/or viscosity drastically alters their sensory properties, so hydrocolloids are used for this particular purpose as essential food additives (Milani et al., 2012). Basically, hydrocolloids can be applied to batter coated products in three distinct ways. The first is directly on the substrate surface as a pre-dust powder. The second, hydrocolloid solution is sprayed on the surface of the substrate or the substrate is pre-dip in the solution. Thirdly, the hydrocolloid is incorporated into the batter coating or is applied to the breading by different techniques in order to enhance adherence and barrier properties of the batter. However, the most commonly used methods are pre-dusting and inclusion in batter systems. According to Manzoor et al. (2020), hydrocolloids could be divided into four major groups according to their sources (Figure2.2). These include;

1. Hydrocolloids obtained from plants
2. Hydrocolloids from animals
3. Microbial origins hydrocolloids (fermentation)
4. chemically modified Plant-derived hydrocolloids (synthetic gums)

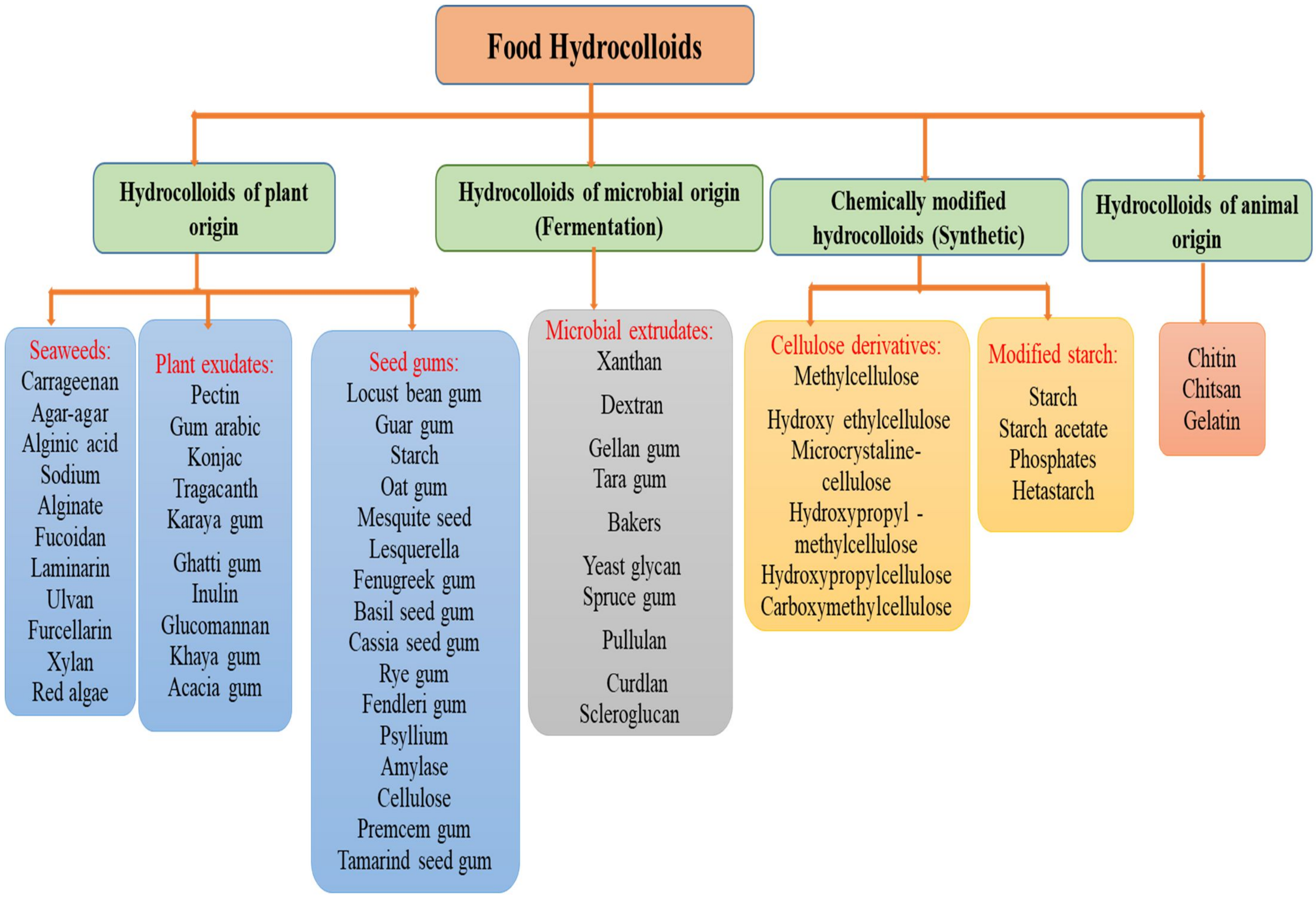


Fig. 2.2: Classification of food hydrocolloids based on origin

Hydrocolloids from plant sources are the largest and cheapest amongst other classes because they need less refining whereas synthetic hydrocolloids are the costliest if processed using advanced equipment from expensive materials. Due to the limitations of synthetic hydrocolloids (toxicity, high cost, non-biodegradability, and environmental pollution during manufacturing), more studies are geared towards the use of hydrocolloids from natural sources to improve the properties of fried foods. The addition or inclusion of hydrocolloids in food serve various functions such as fat reduction, fat replacer, gelling agent, stabilizers, thickener, emulsifier, flocculating agents, clarifying agents, clouding, and whipping agents (Pongsawatmanit *et al.*, 2018; Varela & Fiszman, 2011). Recently, new emerging areas of applicability of hydrocolloids are being discovered. Yemenicioğlu et al. (2020) stated that food hydrocolloids could serve other purposes such as nutritive value and health benefits owing to their prebiotic activity and effects on chronic diseases and metabolic. In this regard, various studies have been conducted on the usage of hydrocolloids such as b-glucan, inulin, pectin, and resistant starch in food formulations with health assertions (Viebke et al., 2014)

Hydrocolloids from cellulose derivatives are polysaccharides materials obtained through chemical modification and have found considerable application in the food industry. The popularly used polysaccharides for food coatings are the hydrocolloids from cellulose derivatives such as Carboxymethyl cellulose (CMC), methylcellulose (MC) Hydroxypropyl methylcellulose (HPMC), and hydroxypropyl cellulose (HPC) (Albert & Mittal, 2002). Cellulose derived hydrocolloids exhibit thermogelation; thus, they form a gel when suspensions are heated, whereas when cooled, they return to their initial consistency. The recent trend towards a clean label of foods and consumers' appreciation of ingredients from natural sources has led to less acceptance of cellulose-derived hydrocolloids owing to their chemical-sounding names and chemical modifications (Pegg, 2012). In any case, each of the hydrocolloids from cellulose derivatives has a valuable property that is challenging to be substituted with other hydrocolloids. Natural hydrocolloids on the other hand are considered as hydrocolloids from plant and animal sources, these ranged from but are not limited to locust beans gum, alginate, pectin, guar gum, gum Arabic, konjac, oat gum, etc. However, there is still no clear categorization of where xanthan gum belongs, some researchers, however, believed that since it is a result of fermentation it could be categorized under natural hydrocolloids (Demirkesen et al., 2010).

2.3.6.1 Effects of hydrocolloid on oil reduction

The tendency of hydrocolloids to serves as a protective layer against fat absorption has been studied. Some edible coatings are a good barrier against fats and oils, especially those based on hydrophilic polymers. In frying batter coated foods, the film prevents the uptake of the fat, improves the quality of the food, and limits the calories and fat content of the finished product (Varela & Fiszman, 2011). The efficiency of food hydrocolloids in reducing the fat uptake in fried food strongly depends on the concentration of the hydrocolloid, the film formation tendency, and other properties of the substrate. Some hydrocolloids, due to their thermo-gelling properties create a film barrier that prevents oil penetration when heated. For instance, Garmakhany et al. (2008) reported about 65% reduction in the fat content of fried potato when xanthan gum was incorporated into the coating. The less oil absorbed was attributed to the reduction in the porosity of the formed crust and improvement in quality attributes such as high batter pickup, moisture retention, and adherence of batter to the substrate. Different hydrocolloids provide variants in the amount of oil absorbed and also influenced other quality attributes of fried products due to differences in batter thickness, adhesion of batter to the substrate, frying parameters, and surface features. For instance, Garmakhany et al. (2008) reported that the inclusion of 0.3% guar gum, 1% CMC, 0.5, and 1% xanthan gum resulted in fat reduction in potato chips by 55, 57, 56, and 50%, respectively. Similarly, Ojagh et al. (2016) studied the effect of hydrocolloid (CMC, HPMC, xanthan, and zedo gum) on coated shrimp. The authors reported a reduction in the oil content of all the treatments containing hydrocolloids. Specifically, the sample coated with 1.5% concentration of HPMC showed the highest moisture content and fat content compared to other treatments. The absorption of oil usually happens as a result of moisture removal from food products. It has been posited that higher fat absorption results from a higher initial moisture content. If the original moisture content is low, the internal amount of food that could be occupied by oil during frying would decrease and the frying period would also be reduced. The degree of oil absorption and the loss of moisture may be influenced by food additives such as natural hydrocolloids and cellulose-derived hydrocolloids (Asokapandian et al., 2020).

2.3.6.2 Effects of hydrocolloid on moisture retention

The key role of an edible film is to prevent moisture migration. This is especially important to keep the best quality of multi-phase fried foods (Chidanandaiah Keshri et al., 2005). Water holding capability is the tendency of food to retain its own or additional water during the application of force, centrifugation, pressure, or heating. Water holding capacity is also the ability of food to hold water against gravity and has been demonstrated to play a vital role in the development of food texture (Gyawali et al., 2016). Hydrocolloid inclusion in batter is one of the most effective ways of reducing the fat content of batter coated food products, these gums possess properties that enable retardation of oil absorption while still retaining the moisture content in the core of the battered product (Aydinli & Tutas, 2000). In an extensive study of the effect of hydrocolloids on the quality of deep fried shrimps, Izadi et al. (2015) reported a significant increase in the moisture content of samples coated with CMC and guar gum when compared to the control samples. Specifically, the moisture content ranged from 60.15 to 62.43% and 61.25 to 65.92% wb for samples coated with 0.5, 1, and 1.5% concentration of CMC and guar gum, respectively, while the control sample had a moisture content of 51.25% wb. Similarly, Ojagh et al. (2016) study on the effect of hydrocolloid (CMC, HPMC, xanthan, and zedo gum) on coated shrimp reported an increase in the moisture content of all the treatments containing hydrocolloids. Specifically, the moisture content for 1.5% concentration of CMC, HPMC, xanthan gum, zedo gum, and control were 64.26, 66.74, 65.38, 55.07, and 51.25% wb, respectively.

2.3.6.3 Effect of hydrocolloid on the textural property of fried food

The texture of fried foods could be improved with the inclusion of hydrocolloids in deep-fried foods. As stated by Sahin *et al.* (2005), hydrocolloids help in improving the consistency of batter systems and have a higher water-binding capability that aids the trapping of gas with the aid of leavening agents. Furthermore, hydrocolloid provides a batter with a thin and invisible film which helps in the reduction of the oil content, increase batter viscosity, batter pickup, adhesiveness, and mechanical resistance to the crust of the fried products, it is also a useful way of controlling the stability of freeze/thaw processes and maintaining the crispiness of fried battered and breaded products (Varela & Fiszman, 2011; Sousa et al., 2019). To enhance the texture and other quality attributes of fried foods, hydrocolloids such as gums and proteins have been used as additives. It has been shown that the addition of xanthan gum decreased the crumb hardness of fresh and stored bread made from rice flour (Lee & Lee, 2006). Likewise, Izadi et al. (2015) reported lower hardness values for samples coated with CMC and Guar gum when compared to the control samples of shrimps. Specifically, the hardness value ranged from 4.12 to 4.95 N and 3.98 to 5.05 N for samples coated with 0.5, 1, and 1.5% of CMC and guar gum, respectively while the control sample had a hardness value of 5.85 N. These hydrocolloids are capable of holding water and forming a gel-like structure. A search of the literature, however, showed a lack of comprehensive knowledge on the interaction of moisture content and the water holding capacity of hydrocolloids on the crispiness of fried products during post frying holdings.

2.3.7 Impact of ultrasound treatment on quality attributes of fried foods

Ultrasound is made up of 20 kHz sound waves and beyond. Ultra-sound induces cavitation during food processing that causes physical, mechanical, and chemical alterations in food products, such as dehydration, cutting, mixing, extraction, hydrolysis, extraction, and emulsification (Oladejo et al., 2018). Depending on the processing conditions, Ultrasonic treatment could modify food structure through its chemical and physical effects. This is possible as a result of the cavitation process, which is a process of growth, formation, and disintegration of bubbles when a sound wave is dispersed into a liquid medium (Shiferaw Terefe et al., 2015; Terefe et al., 2016). Ultrasound has found tremendous application in the food industry (Arzeni et al., 2012; Gallego-Juárez & Graff, 2014; Lee & Feng, 2011; Ozuna et al., 2015). Specifically, it has been used in micro-organism and enzyme inactivation, extraction, homogenization, and alteration of batter properties. Furthermore, ultrasound treatment causes various changes in the chemical, physical and functional properties of food products. In fact, it can impact various quality attributes of food systems and help in improving performance and productivity (Carrillo-López et al., 2017; Terefe et al., 2016). Ultrasound is extensively used in the food industry because of its time and energy-saving ability, food nutrient conservation, and low material utilization (Oladejo *et al.*, 2017). The propensity of ultrasound treatment to minimize the high fat content in fried products has been documented in numerous studies (Karizaki et al., 2013; Oladejo et al., 2017). The effectiveness of ultrasound treatment in minimizing fat absorption depends on different factors, such as ultrasonic frequency, power, and ultrasonic duration (Liberty et al., 2019; Qiu et al., 2018). However, there’s a dearth of information on the impact of ultrasonication on the crispiness of fried products.

2.4 Effect of Frying Methods on Quality Attributes of Fried Products

2.4.1 Novel frying techniques

Frying offers numerous enticing quality attributes which include texture (crispiness), flavor, aroma, and appearance. However, the amount of oil absorbed during frying has led to limited consumers' appreciation of fried food. Consumers are well informed about the health risks linked with fried foods and always desire fried products with less fat content and improved crispiness (Usawakesmanee et al., 2008). Although different ingredients of high quality and frying oil can affect different quality attributes of fried food, researchers are harnessing the propensity of frying equipment to improve the nutritional and organoleptic properties of foods (Pankaj & Keener, 2017). Furthermore, Ngadi *et al.* (2007) reported that the crispiness of fried chicken nuggets could be impacted by the type of oil used, higher hardness value was reported for chicken nuggets fried in oil with higher saturation in their research. Therefore, understanding the effect of frying methods/mechanisms on the desired final quality of fried food is important in improving and maintaining the crispiness of fried food.

2.4.1.1 Air frying

Air frying is another novel technology used in the fried food industry because it tends to reduce the high-fat content deposited in deep-fried foods while still maintaining similar characteristics of deep-fried foods (Ghaitaranpour *et al.*, 2018). In fact, air frying has proven to reduce the fat content of French fries by 70% when compared with deep fried products (Santos *et al.*, 2017). Air frying provides a range of benefits relative to traditional frying processes, including less oil usage and fat absorption. Generally, air fryers operate with a heating element and a fan that blows hot air around the fried products. Air frying is a cheaper and more efficient means of making a fried food with healthier outcomes. More research on the functionality of this novel technology has not been explored, although some publications on the application of air fryers only focus on the appearance and other physicochemical changes (Shaker, 2014; Tian *et al.*, 2017). There is little research on the impact of air frying on the crispiness of fried foods. However, Cao *et al.* (2020) compared the impact of air frying and deep frying at different frying times on the crispiness of fried chicken nuggets and reported that the crispiness of the two frying methods was similar for sample air fried for 12 minutes and samples deep fried for 6 minutes. Cao *et al.* (2020) also reported that the frying process also influenced the changes in the outer layer coating of fried chicken nuggets due to water evaporating from the fried food. A major setback in air fried battered and breaded products is the degree of crispiness, they are less crispy compare to deep fat fried products. A proven method to improve the crispiness of these types of products is to par fry prior to air frying (Barbut, 2011; Bechtel *et al.*, 2018). Prior frying steps enable the batter and breading total adhesion to the product and presents acceptable crispiness of the baked products.

2.4.1.2 Pressure frying

Pressure frying is a revamped form of the deep frying method, for which water emitted from the food produces steam within the fryer. Pressure frying has been effective in minimizing cooking time and has culminated in improved textured products. Because of improved moisture preservation and lower oil absorption, pressure fried chicken has been stated to be more tender and juicier. It is also claimed that there was less depletion of oil in pressure frying relative to traditional frying (Pankaj & Keener, 2017). Researchers have recently attempted to combine this strategy with various edible coatings in order to further minimize oil absorption and enhance food quality. For instance, Ballard and Mallikarjunan (2006) studied the effect of pressure on fried chicken nuggets and reported that pressure frying produced a chicken nugget with more juiciness and enhanced color when compared with the traditional deep frying method. In contrast to deep-fried foods, which are mostly greasy on the outside and dry on the inside, pressure frying was reported to produce tender and juicier products. Furthermore, the desired market characteristics can be obtained in the finished product by correctly choosing temperature and pressure in deep-fat frying (Das et al., 2013).

2.4.1.3 Vacuum frying

Vacuum frying enables frying at a lower concentration of oxygen and frying temperature due to the reduction in the boiling point of water. This method thereby retains the natural colors, flavors, and reduce the degradation of oil. Most vacuum fryers are equipped with a centrifuge chamber for de-oiling the fried product immediately after frying (Moreira et al., 2009). Notably, in their research on vacuum fried chicken nuggets, Teruel *et al.* (2014) reported a higher hardness value for vacuum fried chicken nuggets when compared to deep fat frying, this was attributed to the high moisture loss in vacuum fried chicken nuggets. The different quality attributes obtainable in vacuum fried products are consequently due to the different frying equipment used in vacuum frying. Although most of the quality attributes could be improved through pre-treatment operations, the characteristics of the raw material and the desired quality attributes must be put into consideration during treatment (Ayustaningwarno et al., 2018). Microwave vacuum frying (MVF) is a unique type of vacuum frying technique that uses microwave as the heating medium. It has found application in fried fruits, vegetables, and produced fried foods with lower oil content and high textural attribute when compared with vacuum frying (Quan *et al.*, 2014; Su *et al.*, 2016; Su *et al.*, 2018). The application of microwave oven method of heating food is well documented by researchers (Oztop et al., 2007). However, the major limitation to the use of microwave frying is the uneven distribution of heat (Schiffmann, 2017). Su *et al.* (2018) reported a tremendous improvement in the quality of fried potato chips (high crispiness and low-fat content) when an ultrasonic microwave-assisted vacuum frying (USMVF) method was used.

While various new frying innovations have been developed to combat high fat content and enhance the quality of deep-fried foods, there is still a need for a proper basis for comparison with the conventional deep-fat frying process for fat reduction, fat redistribution, crispiness, and other organoleptic properties. For instance, Cao et al. (2020) study on the effect of deep fat frying and air frying at different frying times on the crispiness of chicken nuggets showed that the crispiness of air fried chicken nuggets for 12 minutes was similar to that of deep-fat fried chicken nuggets fried for 6 minutes. Likewise, the impact of other frying methods should be compared with deep fat frying to obtain processing parameters that give the optimum quality and satisfaction.

2.4.3 Crust formation and crispiness development

One of the special and enticing quality attributes of deep fat fried foods is a crispy crust. During frying, the crust is developed on the food surface. A close association between frying media and food surfaces can lead to rapid loss of moisture and the production of crust triggered by other physiochemical reactions. The formation and development of the crust not only changes the heat transfer but there is a wealth of studies that suggested that the structural characteristics of the crust are the most significant element influencing mass transfer during frying (Ghaitaranpour et al., 2018). A variety of findings have reported that oil absorption is concentrated on the crust during deep fat frying (Liberty et al., 2019; Ngadi et al., 2007). Furthermore, the most important textural characteristic of fried food crust is the crispiness. **C**rispiness is a unique sensory attribute of fried products that are well appreciated by consumers (Shaker, 2015). However, this unique sensation is lost within few minutes after frying, owing to the moisture gradient between the various portions of the food (core and crust) (Hirte et al., 2013). The freshness and quality perception of fried products is judged by the consumers through the duration of crispiness maintenance (Hirte et al., 2012). Most fried foods are crispy immediately after frying which ultimately provides consumers with optimum sensory satisfaction. However, one of the greatest challenges associated with fried food apart from the high oil content is the maintenance of their crispy nature after frying (Luyten et al., 2004a). Consequently, consumers' acceptability of deep-fried food is linked to quality attributes like crispiness and juiciness, inability to maintain the crispiness leads to rejection of fried food during delivery to customers. Therefore, latest researches are focused on developing a healthier fried product with optimum quality attributes, improved crispiness, and maintenance of the crispiness during the post-frying period.

2.5 Changes in Fried Food Qualities during Post Frying Holdings

As described above, most batter coated, and breaded products are products with moist core and crispy crust. The major challenge in this industry is the inability to keep fried products crispy after frying. Although the mechanism behind the loss in crispiness is not well known, some researchers postulated that the loss in crispiness could be attributed to rehydration in low moisture foods or due to moisture gradients between the core and the crust in fried products with multi-domain moisture difference (Luyten et al., 2004b). Over time, researchers only consider the effect of water/plasticizers on the crispiness of fried products without considering the distribution of these plasticizers within the food at a molecular and mesoscopic level (Luyten *et al.*, 2004). However, some researchers reported the effect of moisture gradients/plasticizers on the quality of food products. For instance, Chinachoti and Vodovotz (2000) reported that the distribution of water in bread had a great impact on the sensorial and physical properties of food in their research on the staling of bread. Rovedo *et al.* (1999) study on moisture migration in potato starch patty revealed that the moisture content in the crust was very low immediately after frying. However, the moisture content of the crust started increasing due to moisture migration from the core to the crust during post-frying holding time at ambient temperature. Thereafter, a decrease in the moisture content of the core was observed majorly after the first 30 minutes after frying.

2.5.1 Moisture and fat distribution during post frying holding

Moisture content is a quality attribute well appreciated by consumers. In fact, consumers demand a product with high moisture content in the core and low moisture in the crust in order to balance the crispy and juicy nature of deep-fried foods. However, this high moisture content has caused losses in the crispiness of fried food during the post frying period due to non-uniformity of moisture distribution in the core and the crust, thereby rendering crispy fried foods soggy. The effect of moisture redistribution during post frying holding has been described for different products. According to Stear (1990), the crispiness of bread remains the same immediately after baking and the moisture content of the crust was minimal. However, during storage, the moisture content of the core migrates to the crust due to temperature and concentration gradients between the two layers. Likewise, Antonova *et al.* (2001) recorded a decrease in the crispiness of fried chicken nuggets stored at room temperature during different holding times, they concluded that the decrease in the crispiness could be due to the moisture migration between the core and the crust of the chicken nugget. Clara (1999) also studied the effect of post-frying holding conditions on the moisture migration in potato starch patty and discovered that the moisture content of the crust was low immediately after frying and subsequently increase during the post frying holding. Furthermore, the moisture content of the core decreases during the first 30 minutes of post frying holdings. In relation to the textural attributes, the hardness of the crust decreased significantly during the first 30 min of holding time and was correlated with the increase in the moisture content of the crust. However, the hardness continued to increase after 4hrs holding time and this was due to the increase in firmness of both the core and the crust.

2.5.2 Heat lamp exposure

Heat lamp is a promising technique used in the food industry and food services industry to keep food products warm and in some cases to maintain the crispiness and physicochemical properties of such products. The effect of heat lamp exposure on the crispiness of batter coated and breaded products has not been established. Although various studies have been conducted to determine the effect of heat lamps on the crispiness of fried products, there is still a misconception about whether the heat lamp exposure effect is significant or not. For instance, Antonova *et al.* (2003) researched on the crispiness of breaded chicken nuggets revealed that the heat lamp holding time had a great impact on the crispiness of fried chicken nuggets. Specifically, they reported that the hardness value of the chicken nuggets increased with post frying holding time under a heat lamp. This finding was justified by Rahimi et al. (2017) who worked on the effect of heat lamp holding time on the brittleness of potato strips and reported that heat lamp exposure showed an increasing trend in the brittleness of the samples during the first 10 min. However, the brittleness decreased after holding for 10 minutes. In conclusion, there is a need for the validation of the effect of heat lamp exposure on the crispiness of fried products. Several factors could contribute to the loss of crispiness under the heat lamp. These factors include batter pickup or viscosity, frying time, and food additives. Another challenge of heat lamp as related to crispiness is the method used to determine the crispiness, for example, the heat lamp exposure was found to be significant when a sensory panel was used and was insignificant with a mechanical instrument (Antonova *et al.*, 2003).

Various approaches and technologies have been employed in producing a crispier fried product. When developing a crispier product, it is of utmost importance to study the frying parameters and pre-frying operations, this is necessary because the storability of the fried product and quality can be improved or rendered with low quality if not maintained, of most importance is the frying time, the loss in crispiness will depend on the amount of moisture present in the fried products, this moisture can migrate during post-frying holding and render the crispy products soggy. Also, novel technologies that would help in reducing the oil content while still maintaining the crispiness of fried foods after frying are still required, thereby solving the major challenges associated with fried foods (high-fat content and loss of crispiness).

2.6 Measurement and Evaluation of Crispiness

In food quality assessment, food texture is a significant property that defines the quality of foods. The perceived crispiness has a major effect on consumer acceptability and satisfaction in most foods (Jaworska et al., 2008). Efforts have since been made to examine and evaluate the crispiness of fried products using various techniques. Therefore, the crispiness of fried foods can be measured using a range of methods, such as mechanical, acoustic, mechanical-acoustical, ultrasound, and sensory analysis.

Sensory analysis is a predominantly used method of measuring the crispiness of fried foods. The method involves the use of individuals known as sensory panels, and the food sample is introduced to the panel for evaluation of their perceived crispiness based on a ranking system. In the past decades, sensory evaluation is mostly accomplished through the magnitude of estimation approach. In this approach, a food sample is selected as a benchmark and a subjective score is assigned. The panelists are requested to rate the samples in relation to the reference sample. However, descriptive analysis methods have recently become more common and are mainly used for sensory assessment. This approach requires the use of a trained or untrained panel. The different qualities of the crispy product are explained for the untrained panelist and a ranking system is used for their perceived quality attributes. However, the major setback of this strategy is the uncertainty of whether or not untrained evaluators can correctly assess their perceived crispness (Roudaut et al., 2002). According to Saeleaw and Schleining (2011), the descriptive test is one of the commonly used techniques by sensory scientists. Descriptive analysis used for sensory evaluation relies on criteria such as the composition of the intact food, the sound produced at the fracture, the force used to crush the food, collapse of the food at fracture, and the appearance of the sample experienced and interpreted after the fracture. Primo-Martin et al. (2008) observed that the sound quality of crispier foods is higher among panelists. However, owing to the variations in the tasting panels and the failure to provide quantitative measurement of crispiness, this approach is unreliable and less accurate.

Since mastication is a highly destructive mechanism, the most common approach to mimic biting is through mechanical tests. Mechanical property is designed to tell the structural properties of materials with resistance to compression by tensile fixture or a probe that breaks apart the food surface with the aid of a universal testing machine or a texture analyzer (Saeleaw & Schleining, 2011). Instrumental analyses provide easier and cheaper evaluations than sensory evaluations. Mechanically, the crispiness of food products could be determined using various destructive tests such as compression. Puncture, texture profile analysis, shearing, and bending tests. Depending on the type of food product and various parameters obtained through the type of test carried out, properties such as brittleness, hardness, total work, puncture force, maximum force, stress, and area under the curve are often correlated to the crispiness of the product (Tunick et al., 2013). Generally, fried foods are subjected to force deformation with the aid of a probe that mimics the first bite, and the crispiness is determined using quantitative parameters from the force-deformation curve (Miranda & Aguilera, 2006). Mechanical assessments are comparatively faster and easier to perform but have not provided adequate correlation with sensory crispiness. There is also another drawback with the use of mechanical tests; certain crisp foods cannot be tested due to irregularity in size, shape or part of a food that also consists of non-crisp components (Saeleaw & Schleining, 2011).

Recently, the application of the combination of mechanical determination and acoustic measurements to assess the crispiness of food has been explored. It is reported that the combination of mechanical and acoustic measurement was more effective in describing the perception of food sound than the separate techniques (Chauvin et al., 2008; Piazza et al., 2007). Gouyo et al. (2020) reported that the combination of mechanical and acoustic measurement was effective for measuring the textural properties of French fries. Furthermore, they reported that the acoustic parameters such as the linear distance of sound peak, number of sound peaks, the mean sound pressure, and the area under the sound displacement curve were positively correlated with the crispiness of French fries. The acoustic envelope detector can be coupled with a texture analyzer to track sound waves, transmit sound waves to electric signals, and display a graph of sound pressure against time (Dias-Faceto et al., 2020; Taniwaki & Kohyama, 2012). While the amalgam of acoustic and force deformation has provided a great outcome in the evaluation of the crispiness of fried foods, these approaches are still destructive. A non-destructive quantification approach is still required.

CONNECTING TEXT TO CHAPTER THREE

In chapter two, the literature review revealed that batter formulations play a crucial role in improving the crispiness of fried food. It indicated strategic ways of reducing the fat content of fried food products. The review also highlighted the various novel technologies used in improving the quality of fried foods (namely ultrasound treatment, heat lamp exposure, the inclusion of hydrocolloids, and frying methods) and the impact of the combination of these technologies were reviewed. In the next chapter of this thesis, the impacts of six different hydrocolloids on the properties of fried chicken nuggets using deep fat frying and air frying method are reported. Then, the fried chicken nuggets were exposed to different heat lamp holding times and changes in the quality (moisture content, fat content, and crispiness) of chicken nuggets were recorded.

CHAPTER THREE

3. A COMPARATIVE STUDY ON THE IMPACT OF HYDROCOLLOIDS ON THE CRISPINESS OF DEEP FRIED AND AIR FRIED CHICKEN NUGGETS DURING POST FRYING HOLDING.

3.1 Abstract

Loss of crispiness in batter coated fried products such as chicken nuggets has been shown to negatively impact sensory and quality parameters such as color and mouthfeel. According to previous studies, this challenge is associated with the instability of crispiness after frying up to consumption. Thus, this study investigated the impact of different hydrocolloids and frying methods (air frying and deep fat frying) on the crispiness of fried chicken nuggets during post frying holding under heat lamp. Batter was prepared with a blend of wheat flour and corn starch (80% wheat and 20% corn starch). Afterward, edible coatings such as pectin, guar gum, Locust bean gum, methylcellulose, xanthan gum, and hydroxypropyl methylcellulose were added at 1% concentration. Batter pickup, rheological and thermal properties of each batter formulation were studied. Chicken nuggets coated with formulated batter were deep fried (180 °C, 6 min) and air fried (180 °C, 18 min), after which they were kept under heat lamp for 0, 10, 20, 30, 40, and 50 min. The loss in moisture content, fat content, and crispiness after each holding time and temperature were evaluated. The results showed that all treated nuggets held at shorter holding time had significantly higher moisture content than samples held for longer time with each frying method. Likewise, there were significant differences between the fat content of nuggets coated with different hydrocolloid types. When compared to deep fried samples, air fried samples produced the highest crispiness. Most importantly, the control sample showed the highest cutting force at almost every holding time for both frying methods while xanthan gum presented samples

with the lowest crispiness that ranged between 1.91 to 4.90 N for deep fried nuggets, and 3.38 to 8.43 N for air fried nuggets held under heat lamp.

3.2 Introduction

For many years, maintenance of the crispiness of batter coated and breaded fried products have been a great challenge to the fried food industry. Crispiness is the most appreciated textural attribute of batter coated fried foods (Antonova et al., 2003). According to Cao et al. (2020), changes in the crispiness of fried foods during frying are a consequence of protein denaturation, water evaporation, starch gelatinization, and other reactions that occur during frying. Besides the limitation of crispiness, high fat content of deep-fried foods has been linked to risks of developing chronic diseases such as obesity, coronary heart disease, diabetes, cancer, and cardiovascular malfunctions (Ananey-Obiri et al., 2018; Saguy & Dana, 2003; Yang et al., 2020). Thus, the development of new fried foods with duo properties including low-fat content and high crispiness has been a subject of many new studies in the food industry. In fact, according to literature, previous works have been reported on how techniques such as application of starches, composite of starch and flour, frying modifications, and post frying manipulations (i.e., exposure to centrifugation and heat lamp) impact the crispiness of batter coated and breaded products (Matsunaga *et al.*, 2003; Dogan *et al.*, 2005b; Nasiri *et al.*, 2012; Rahimi *et al.*, 2017; Sothornvit, 2011).

Prior to frying, batter (i.e., a mixture of dry flour and water) is applied to different food substrates to control textural modifications, moisture loss, fat uptake, color, and mouth-feel (Sahin *et al.*, 2005). Currently, flours commonly used for batter formulations in the food industry are sourced from wheat, corn, rice, and soy (Xue and Ngadi, 2007). Additionally, Ketjarut & Pongsawatmanit (2015) reported that crispiness and fat reduction among fried foods can be achieved through partial substitution of flours and starches, as well as composite formulations of flours with starches. For instance, Dogan et al. (2005b) reported on fried chicken nuggets coated with batter formulated with soy and rice flour. Furthermore, the application of cellulose derived food hydrocolloids (e.g., hydroxyl propyl methylcellulose, methylcellulose, and carboxyl methylcellulose) and their natural counterpart (e.g., pectin, guar gum, locust bean gum, xanthan gum, etc) for batter coating of fried products have been shown to limit fat uptake while enhancing crispiness, flavor, color, aesthetic, and other sensory qualities (Amboon *et al.*, 2012; Garmakhany *et al.*, 2014; Singthong & Thongkaew, 2009).

In addition to batter composition, the method of frying (i.e. deep fat or air frying) has been shown to greatly influence crispiness and other sensory attributes of fried foods. Contrary to deep fat frying which requires the total immersion of food products in hot oil, air frying involves the use of hot air as the heat transfer medium (Andrés *et al.*, 2013; Ghaitaranpour *et al.,* 2018). Air frying is advantageous compared to deep fat frying, due to its ability to reduce oil uptake during frying (Heredia *et al.,* 2014). For example, Cao et al. (2020) reported a 25% reduction in the fat content of air fried chicken nuggets when compared with deep-fat fried chicken nuggets.

Despite these efforts, there is little knowledge on how batter formulated with hydrocolloid impacts the crispiness of fried chicken nuggets during post frying. Although various studies have been published on the effect of different hydrocolloid types on batter pickup and rheological properties, most of these researches only focused on the ability of hydrocolloids to reduce the oil content in fried products during frying. The availability of such data will help guide the fried foods industry in modulating their process towards the production of fried foods with enhanced consumer acceptance. Therefore, the aim of this work was to investigate the applicability of food hydrocolloids in maintaining crispiness, moisture redistribution, and fat reduction during post frying holding of deep fried and air fried chicken nuggets held under heat lamp.

3.3. Materials and Methods

3.3.1. Materials

Wheat flour (Five Roses White All Purpose Flour), corn starch (Fleischmann's Corn Starch), leavening agent ($Na_2H_2P_2O_7/NaHCO_3$), canola oil (Selection TM/MC, Quebec, Canada), chicken breast, and salt used for the study were obtained from the local store in Montreal. Hydrocolloids (i.e., pectin, guar gum, locust bean gum, xanthan gum, and hydroxypropyl methylcellulose) were obtained from Spectrum Chemical Manufacturing Corporation (New Brunswick, USA) and methylcellulose (2% Solution in Water; viscosity - 3000-5600 CP) was purchased from Fisher Scientific, Canada.

3.3.2. Batter formulations

Batter formulations comprised of wet and dry ingredients. Dry ingredients consisted of 92% wheat flour-corn starch blend (that is 80% wheat flour and 20% corn starch), as detailed in Table 3.1. The ratio of dry ingredients to water was 1:1.3. Each hydrocolloid was weighed (1% of dry ingredients) into a beaker containing water and manually stirred for 5 minutes. The dispersion was kept inside a water bath at 10 °C for 30 min to allow complete hydration of the hydrocolloids. Dry ingredients were subsequently added to form batter as presented in Table 3.1.

Table 3. 1: Batter formulation

Batter formulation	Wheat flour (%)	Corn starch (%)	Salt (%)	Leavening agent (%)	GG (%)	P (%)	LB (%)	CMC (%)	HPMC (%)	XG (%)
Control	78	19.5	2	0.5						
1	77.2	19.3	2	0.5	1					
2	77.2	19.3	2	0.5		1				
3	77.2	19.3	2	0.5			1			
4	77.2	19.3	2	0.5				1		
5	77.2	19.3	2	0.5					1	
6	77.2	19.3	2	0.5						1

C: Control; P: pectin; GG: guar gum; LB: locust bean gum; MC: methylcellulose XG: xanthan gum; HPMC: hydroxypropyl methylcellulose

3.3.3. Rheological properties measurement

Batter viscosity was measured using a controlled stress rheometer (AR2000, TA Instruments, New Castle, Delaware, USA). The instrument was equipped with a 40 mm parallel plate geometry using a gap of 1000 μm. Before placing the sample on the rheometer, the batter slurry was kept at 23 °C for 10 min to ensure a proper blend between hydrocolloids and dry ingredients. Viscosity was measured at 15 °C regulated using a Peltier plate with an accuracy of ±0.1 °C. Excess samples were trimmed using a spatula, and five minutes was allowed for structure recovery. Next, the viscosity of each batter was measured as a function of the shear rate in the range of 0.1 – 100 1/s. Batter flow behavior was evaluated using the power law model (Eqn. 3.1), previously used to model the flow behavior of batters (Dogan et al., 2005).

$$\tau = K\ (\gamma)^n \qquad (3.1)$$

Where τ represents shear stress (Pa), γ represents shear rate (1/s), K represents consistency coefficient (Pa.s^n), and n represents the flow behavior index.

3.3.4. Batter pickup

Batter pickup indicates the degree of adherence of batter to a food surface before frying (Pongsawatmanit et al., 2018). Each chicken nugget was pre-dusted with wheat flour-corn starch blends (Table 3.1) and dipped into formulated batters. Final weights of battered chicken nuggets were measured after the excess batter was allowed to drip off for about 20 seconds. Batter pickup was computed as the percentage of battered chicken nugget weight compared to the initial weight of non-battered chicken nuggets and the average of three replicates of each treatment were recorded.

3.3.5. Determination of thermal properties

The gelatinization temperature of each batter formulation was determined using Differential Scanning Calorimeter (DSC250, TA Instruments, New Castle, Delaware, USA). The instrument was calibrated with an indium standard before sample measurements. 15±2 mg of the batter slurry was weighed into aluminium pans and hermetically sealed with a press. The gelatinization profiles of each sample were evaluated by heating the pans from 25 °C to 110 °C with a heating rate of 2 °C/min. Gelatinization parameters such as onset temperature (T_o), peak temperature (T_p), and conclusion temperature (T_c) were determined from the DSC thermogram according to the method of Xue & Ngadi (2007). The enthalpy of gelatinization (ΔH) was evaluated from the area of the endothermic peak. All measurements were performed in triplicates.

3.3.6. Preparation of chicken nugget

The chicken breast meat was cleaned and placed on a mesh for the water to drip off. After cleaning, it was cut into 20±2 g, and pre-dusted with formulated batter blends.

3.3.7. Frying and post-frying holding

Battered chicken nuggets were fried with a programmable deep fat fryer (De'Longhi, America Inc., Saddle Brooke, NJ 076663, China) and air fryer (model-HD9240É90, PHILIPS, China). Deep fat frying was conducted at 180 °C for 6 min. After frying, samples were placed under heat lamp (Model Sw-2430, Merco Inc., Lakewood, New Jersey., U.S.A) for 10, 20, 30, 40, and 50 min. Also, air fried samples were first parfried in a deep fryer for 1 min and immediately drained of adhering surface oil by gently blotting with a paper towel. After which the Air fryer was pre-set to 180 °C and pre-warm for 20 min. Samples were then fried for 18 min. Next, air-fried samples were then exposed to heat lamp for 10, 20, 30, 40, and 50 min. Each frying experiment was conducted in triplicate.

3.3.8. Moisture loss and distribution

The moisture content of chicken nuggets was measured (105±2 °C, 24 hr) immediately after frying and under each post-frying holding condition according to the method of AOAC (2005). Moisture redistribution between the core and the crust during post frying holding time was determined by separating the crust from the core after holding under heat lamp. Weights of the core, crust, and overall chicken nugget before and after drying were recorded and used to calculate moisture content on a dry basis. Triplicates of each sample were measured.

3.3.9. Fat content determination

Fat content of the different treatments after post frying holding time was determined by using a Soxhlet extraction method (SER 148, Velp Scientifica, Usmate, Italy). Percentage fat content was calculated as the weight of oil extracted from fried chicken nuggets and the total weight of oven-dried sample. Triplicates of each sample were measured (Adedeji et al., 2011).

3.3.10. Color

Color attributes of deep fat fried and air fried chicken nuggets were determined by using Konica Minolta spectrophotometer (Minolta, Spectrophotometer CM-3500d, Japan). CIE L* a* b* system was used to express obtained data. The color parameters L*(blackness/whiteness), a* (greenness/redness), b* (blueness/yellowness), and ΔE (color difference) were obtained. Six measurements were taken at the surface of four coated nuggets for each formulated batch, and one measurement was taken on different sides of each chicken nugget. Net color difference (ΔE) was calculated using Eqn. 3.2.

$$\Delta \boldsymbol{E} = \sqrt{((\boldsymbol{L_0} - \boldsymbol{L_t})^2 + (\boldsymbol{a_0} - \boldsymbol{a_t})^2 + (\boldsymbol{b_0} - \boldsymbol{b_t})^2)} \quad \textbf{(3.2)}$$

Where,

L_0, a_0, b_0 are the L, a, and b values for Chicken nugget coated the control batter (without hydrocolloid)

L_t, a_t, b_t are the L, a, and b values for the chicken nugget coated with the formulated batter at the same frying time

3.3.11. Texture

Textural properties of air fried and deep fat fried chicken nuggets were determined using a texture analyzer (Model: TA-HD plus, Stable micro systems, United Kingdom operating at 500 volt-ampere). Compression test was performed with fried chicken nuggets exposed to heat lamp by using a TA-42 knife blade with 45 °C chisel end. The method of Mah & Brannan (2009) was used with a slight modification. The pre-test, test, and post-test speeds were set at 10, 1, and 10 mm/s, respectively, and the hardness data were recorded. Triplicates of each sample were measured.

3.3.12 Statistical analysis

Analysis of variance was performed on all treatments in triplicate by using SAS system software (Version 9.2, SAS Institute, Inc., 1999, Cary, NC, USA). To determine the effect of the different hydrocolloids and heat lamp exposures on moisture and fat redistribution of the samples, and also to statistically compare the influence of frying methods on the crispiness of the batter coated product during post-frying holdings, Generalized Linear Model (PROC GLM) function was applied. Tukey test was performed for the mean separation at a statistical significance of $P < 0.05$.

3.4. Results and Discussion

3.4.1. Batter pickup

Coating pickup is an important attribute in the food industry and is one of the key parameters that determine the quality of fried foods such as crispiness, redistribution of moisture, microstructure, and other physicochemical properties of fried foods. However, changes in this property is strongly dependent on attributes such as the concentration of hydrocolloids or the batter formulation (Garmakhany *et al.*, 2014). In addition, research has shown that apparent viscosity is closely associated with batter adhesion (Xue & Ngadi, 2007). Figure 3.1 presents the batter pickup for the different batter formulations. The batter pickup value ranged from 38.15 to 86.26% depending on the hydrocolloid type. The inclusion of hydrocolloids in the batter formulations significantly ($p < 0.05$) increased the batter pickup. The highest coating pickup was recorded for the batter formulation containing xanthan gum, the increase in the batter pick-up of xanthan gum could be linked to the high viscosity buildup of the sample and the cleavage of the batter to the chicken nugget. According to Adedeji and Ngadi (2011), the increase in batter pickup of hydrocolloid-containing samples may be attributed to the high water holding capacity and the viscosity building capacity of the hydrocolloids. There was no significant difference ($P < 0.05$) between C, LB, and P. Overall, the viscosity of the hydrocolloid-containing batter increased by 45.81, 0.66, 1.18, 145.41, 60.20, and 40.76% respectively for GG, LB, P, XG, MC and HPMC relative to control (C).

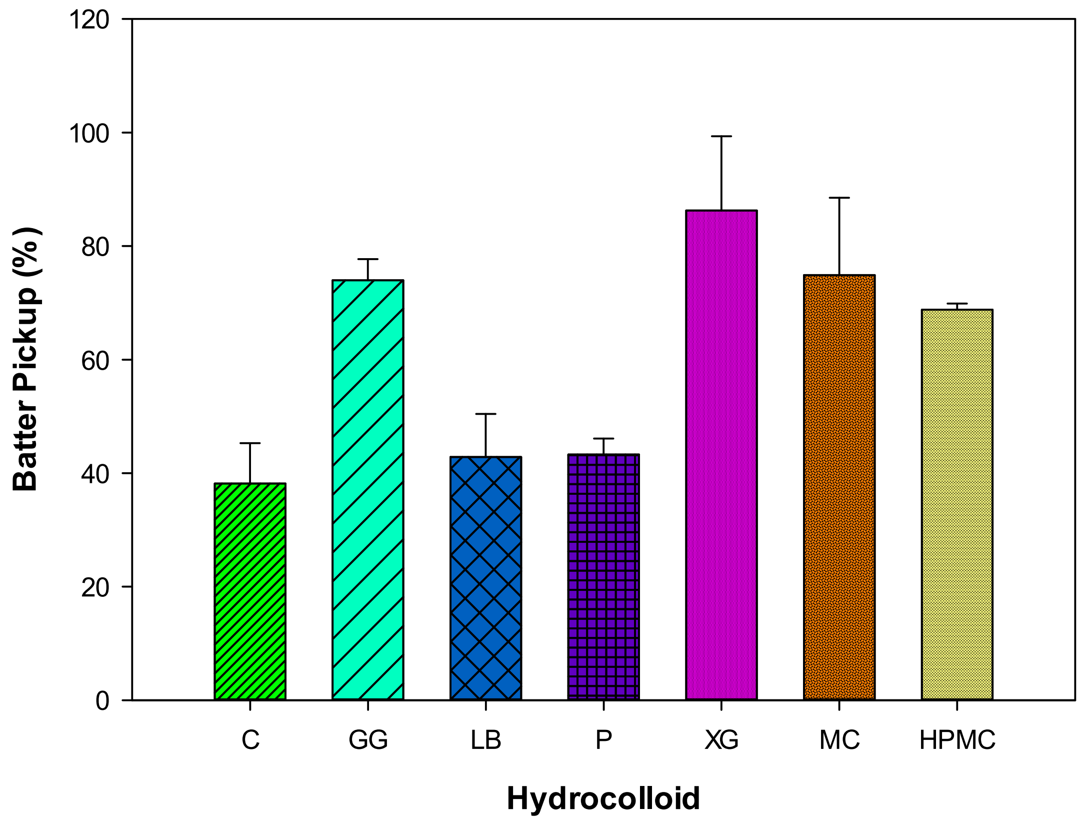


Fig. 3.1: Effects of hydrocolloid formulated batters on the coating pickup of chicken nuggets C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

3.4.2. Impact of hydrocolloids on rheological properties of formulated batter

Figure 3.2 shows the relationship between the apparent viscosity and the shear rate of the different batter formulations. The viscosity of all the samples decreased with an increase in shear rate, depicting shear-thinning characteristics of the batter. Specifically, the control batter had the lowest viscosity whereas xanthan gum presented the highest viscosity at a shear rate below 18 s^{-1} and MC presented the highest viscosity between 18 s^{-1} and 100 s^{-1}. In addition, the viscosity of HPMC, MC, GG, and XG was significantly higher than C, P, and LB. The increase in the apparent viscosities of HPMC, MC, GG, and XG could be attributed to the water-binding capacity of the hydrocolloids, which decreased the quantity of water available and thereby prevent the movement of batter particles. A similar viscosity-building trend of hydrocolloids has been reported by other researchers (Meng & Kim, 2020; Ronda & Roos, 2011). Furthermore, the apparent viscosity of P and LB were similar to the control (C) sample. Guar gum and locust beans gum belong to the same hydrocolloids type group based on the origin of the gums. They are both made from the seeds of carob tree and guar plant, respectively. However, their viscosity building ability is strongly influenced by the concentration of the hydrocolloids in batter system. Higher concentration of locust beans is needed to attain the same viscosity of guar gum which could be the reason for the higher viscosity of guar gum recorded in this research. In addition, the chemical structures of the gums differ as LB has a lower degree of galactose side chain compared to guar gum.

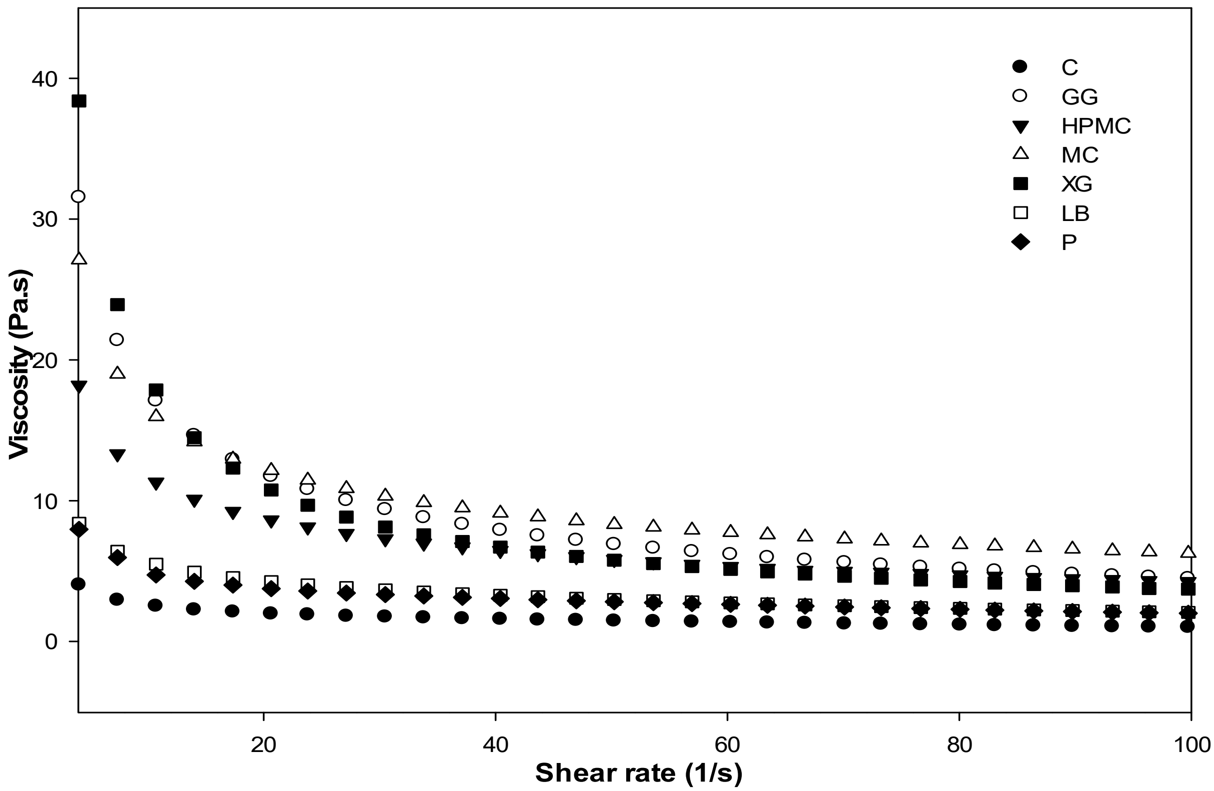


Fig. 3.2: Effects of different hydrocolloids on the viscosity of batter formulations. C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

The different batter formulated with different hydrocolloids were fitted to the power law equation with an R^2 value ranging from 0.99 to 1. The power law model parameters are presented in Table 3.2. Depending on the hydrocolloid type, the consistency coefficient (k) ranged from 7.56 to 91.69 Pa.s^n and was observed to increase with the addition of different hydrocolloids. Specifically, hydrocolloid type had a significant effect ($p < 0.05$) on consistency coefficient (k), with the control (i.e., batter without hydrocolloid) showing the lowest k value (7.56 Pa.s^n) and the k value increased in the following order C>P>LB>HPMC>MC>GG>XG. A similar result of the consistency index was reported by Xue and Ngadi (2006) with k value ranging from 0.46 to 69.2 Pa.s^n for batter samples made from different flour combinations and hydrocolloids. On the other hand, the flow behavior index significantly ($p< 0.05$) reduced for HPMC, LB, GG, and XG but increased for P and MC, relative to the control (C). Specifically, there were no significant differences ($p < 0.05$) between the flow behavior of the C, P, and MC samples. In general, the flow behavior decreased in the order P< MC<C<HPMC<LB< GG<XG.

Table 3. 2: Effect of hydrocolloids on the consistency coefficient (k) and flow behavior index (n) of batter formulations

Sample	K ($Pa.s^n$)	n	R^2
C	7.561 ± 0.24^b	0.573 ± 0.01^a	0.9900
GG	74.695 ± 7.71^c	0.391 ± 0.03^b	1.000
LB	17.44 ± 1.35^d	0.543 ± 0^a	1.000
P	13.77 ± 0.51^{bd}	0.588 ± 0.02^a	0.993
XG	91.69 ± 0.09^a	0.298 ± 0.01^c	0.990
MC	43.625 ± 3.12^e	0.579 ± 3.12^a	1.000
HPMC	33.835 ± 2.6^f	0.55 ± 2.6^a	1.000

C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose. Results are means of triplicate ± standard deviation. Different letters within the same column depict a significant difference ($p < 0.05$)

3.4.3. Thermal properties of different batter formulations as influenced by hydrocolloid type

The thermal properties of the wheat flour – corn starch blend batter was determined with the aid of differential scanning calorimeter (DSC) and the gelatinization profile such as T_o (onset temperature), T_p (peak temperature), T_c (conclusion temperature), and ΔH (enthalpy of gelatinization) were recorded. Hydrocolloid inclusion in the batter formulation delayed the onset of gelatinization by approximately 1 to 2 °C compared to the control sample (Table 3.3). Likewise, there was a significant difference ($p < 0.05$) in the peak temperature of samples containing hydrocolloids and the control. Batter containing P, LB, and XG had the highest peak temperature above the control while other gum peak temperature falls below the control sample. Unlike other researchers that reported two peaks for a blend of wheat flour and other starches; Wheat flour-tapioca starch (Pongsawatmanit *et al.*, 2018), the gelatinization profile of batter formulated with a blend of wheat flour and corn starch showed a single peak. Furthermore, the gelatinization profile of a mixture of wheat flour and corn starch has been reported to occur between 52.83 to 71.90 °C (de Alcântara *et al.,* 2020). In comparison, Xue & Ngadi (2007) recorded a peak gelatinization temperature of 65.45 °C and 68.97 °C for wheat flour and corn flour, respectively. Likewise, in this study, the peak gelatinization temperature occurred at approximately 66 °C. The inclusion of different hydrocolloids in the batter formulation caused a significant reduction in the gelatinization enthalpy, with the control sample having the highest gelatinization enthalpy (3.15 J/g). A similar result has been reported for the effect of hydrocolloids on gelatinization enthalpy of batter mixtures with different hydrocolloids. For instance, Shahzad*, et al.* (2019) reported a decrease in gelatinization enthalpy of chickpea with and without xanthan gum to be 4.00 and 13.25 J/g, respectively. The reduction in the enthalpy of gelatinization could be as a result of the hydrogen bond between the hydrocolloid and amylose percolation that impedes the internal interactions between amylose and amylopectin (Shahzad, Hussain, Alamri*, et al.*, 2019; Tang *et al.*, 2013). Likewise, Lee *et al.* (2002) and Shahzad*, et al.* (2019) stated that the decrease in the gelatinization enthalpy of hydrocolloids containing batters could be associated with the tendency of the hydrocolloids to contend with the water intended for amylose and amylopectin, thereby restricting the movement of the amylopectin chain.

Table 3.3 Thermal properties of the effect of different hydrocolloids on wheat flour-corn starch-based batter.

	T_o	T_p	T_c	ΔH
C	60.23±0.14^{b}	66.525±0.21^{b}	73.42±0.66^{b}	3.150±0.72^{a}
GG	61.835±0.02^{c}	66.51±0.06^{b}	69.93±0.56^{c}	1.608±0.06^{b}
LB	61.43±0.21^{dcb}	66.985±0.02^{c}	74.57±0.24^{b}	2.175±0.21^{ab}
P	62.395±0.04^{ac}	67.225±0.13^{ac}	71.845±0.16^{ba}	1.731±0.11dbac
XG	62.055±0.56^{fcdea}	66.94±0.03^{bca}	71.445±0.68^{dcba}	1.819±0.97^{ebacd}
MC	61.61±0.33^{ecd}	66.035±0.02^{db}	75.75±0.38^{ab}	1.267±0.33^{cba}
HPMC	60.745±0.14^{b}	66.31±0.35^{b}	72.07±0.96^{b}	2.614±0.33^{ab}

C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose. Note: Results are means of triplicate ± standard deviation. Different letters within the same column depict a significant difference ($P<0.05$)

3.4.4. Color evaluation

The effect of different batter formulations on color development of deep fat fried and air fried chicken nuggets is shown in Table. 3.3. The L* value represents the lightness of the product and is one of the first visual assessments made by consumers. Significant differences ($p < 0.05$) were observed for the L* value for samples coated with different hydrocolloids and fried with either deep fat frying or air frying methods. For deep fried samples, the L* value of the samples decreased with different hydrocolloids in the order XG < HPMC < MC < P < C < GG < LB. The crust of the deep-fried samples containing xanthan gum was lighter than the control and other samples. However, air fried samples presented samples with high darkness (lower L* value) compared to the deep fat fried sample, which could be due to the frying time used. For air-fried samples, the L* value decreased in the order LB < C < XG < MC < P < GG < HPMC. Garmakhany, et al. (2014) also reported a decreasing trend in the lightness of deep-fried French fries coated with pectin and guar gum compared to the control. Similarly, Cao *et al.* (2020) obtained a similar L* value for chicken nuggets deep fried for 6 min and air fried sample for 18 min. However, higher L* value was recorded for air fried samples compared to deep fried samples and this was attributed to a slower rate of nonenzymatic browning reaction in air fried samples compared to deep fried chicken nuggets. This is in tandem with our control sample that showed a higher lightness value for air fried sample compared to deep fried sample. However, the hydrocolloid type significantly caused a reduction in the lightness of air-fried samples except for LB.

Table 3. 4: Effect of deep-fat frying and air frying on the color parameters L*, a*. b*, and ΔE of fried chicken nuggets

	Deep Fried				Air Fried			
Hydrocolloid	L*	a*	b*	ΔE	L*	a*	b*	ΔE
C	55.23±2.02^{a}	4.16±0.6^{a}	21.20±1.23^{a}	3.86±2.15^{a}	56.14±0.02^{a}	4.43±0.52^{a}	18.68±0.98^{a}	1.74±0.77^{b}
LB	52.29±2.15^{b}	3.61±1.56^{a}	18.62±3.6^{a}	3.65±2.83^{a}	57.04±0.16^{a}	3.13±0.09^{a}	18.95±1.62^{a}	2.32±0.88^{b}
GG	54.10±0.17^{ab}	3.97±0.36^{a}	19.34±0.12^{a}	1.70±0.13^{a}	49.71±0.01^{b}	5.20±2.14^{a}	14.85±0.79^{b}	7.99±0.33^{c}
P	55.70±1.82^{ab}	3.71±1.17^{a}	19.80±0.47^{a}	0.74±1.04^{a}	52.94±0.26^{dc}	3.14±0.91^{a}	16.09±1.74^{a}	5.02±1.75^{bc}
XG	63.02±2.56^{a}	2.15±0.18^{a}	20.26±1.82^{a}	7.82±2.43^{a}	55.77±0.19^{a}	2.36±0.86^{a}	16.96±1.33^{a}	3.82±1.59^{b}
MC	57.00±0.52^{ab}	2.72±0.22^{a}	18.32±0.1^{a}	2.91±0.46^{a}	53.01±0.07c	3.09±0.06^{a}	15.75±0.11^{a}	5.28±0.14^{bc}
HPMC	57.13±2.78^{ab}	3.04±0.19^{a}	18.88±1.45^{a}	2.47±1.04^{a}	46.98±1.89^{e}	5.16±0.48^{a}	15.77±0.56^{a}	9.67±1.96^{abc}

C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose. Results are means of triplicate ± standard deviation. Different letters within the same column depict a significant difference (P<0.05)

The value a* reflects the redness of the chicken nuggets. There was no statistical significance ($p < 0,05$) of the effect of hydrocolloids on the a* value of deep-fried samples and air-fried samples. However, the method of frying had a significant effect on the redness of fried chicken nuggets. Specifically, a* value for C, GG, XG, MC, and HPMC was lower for deep-fried samples compared to air-fried samples. A similar trend was reported by Cao *et al.* (2020) for deep fried and air fried chicken nugget at 6 min and 18 min frying time, respectively. The value b* represents the yellowness of the fried chicken nuggets. There was no statistical difference between the effects of the hydrocolloid type on the b* value of the deep-fried chicken nuggets. There was, however, a significant difference in the air-fried samples. Explicitly, the b* value of all treatments was higher for the deep-fried product compared to the air-fried sample except for LB. The highest value of ΔE was recorded for the sample with xanthan gum and decreased in the order XG < C < LB < MC < HPMC < GG < P and HPMC < GG < MC < P < XG < LB < C for deep fried and air fried chicken nuggets, respectively.

3.4.5. Moisture redistribution of chicken nuggets under heat lamp

Hydrocolloid type, frying methods, and post-frying heat lamp holding period had a significant ($p < 0.05$) effect on the moisture content of different portions of the chicken nuggets. The moisture content of the crust, core, and overall moisture content reduced during post frying holding time under heat lamp with the rate depending on the hydrocolloid type and frying method. This finding is in agreement with other studies that stated that the inclusion of hydrocolloids in batter formulations yielded a higher moisture content due to hydrocolloids water binding capacity (Varela & Fiszman, 2011; Yazdanseta et al., 2015). The overall moisture content of fried chicken nuggets as a result of post-frying holding time, and batter formulation (with and without hydrocolloids) are seen in (Figure 3.3).

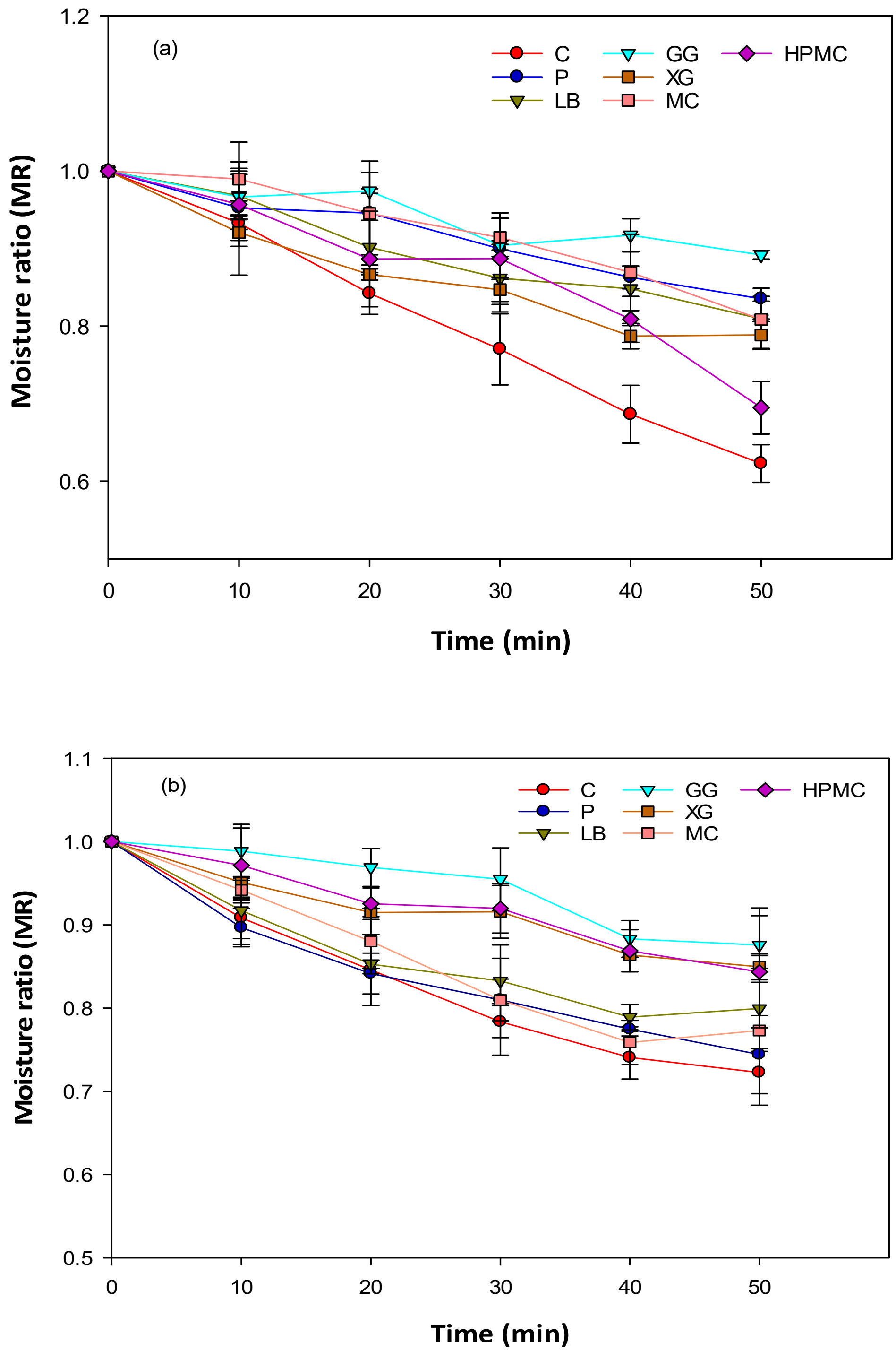
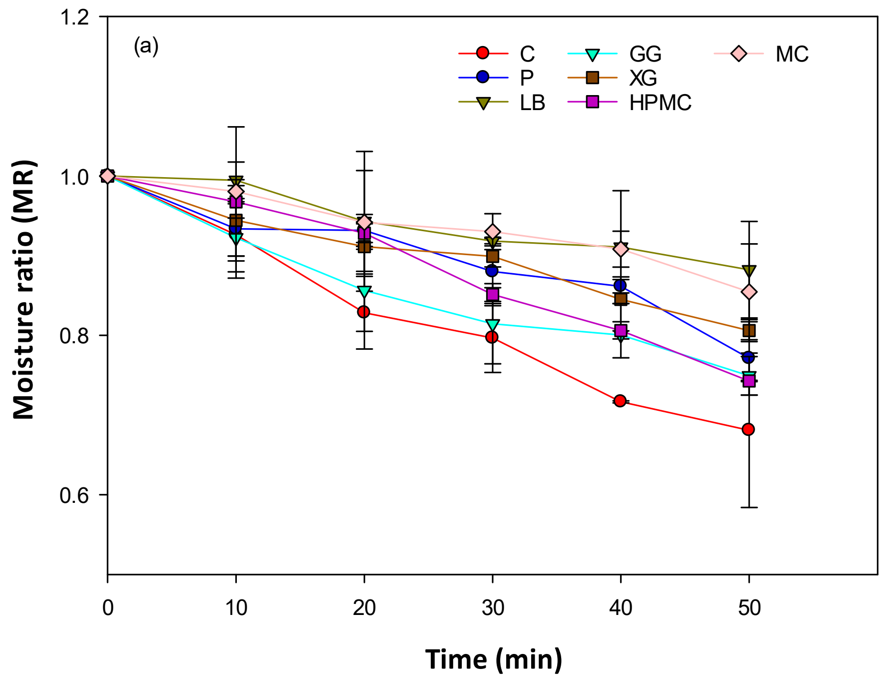


Fig. 3.3: Effect of post frying holding time under heat lamp on the overall moisture content (a) Air fried, (b) Deep fried; C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose

Frying method had a significant difference ($p < 0.05$) on moisture content and moisture loss under heat lamp. The highest moisture content was recorded for samples fried with deep frying compared to air frying. Since frying time has already been documented to have a major influence on the quality of fried foods (Ngadi et al., 2007), the lower moisture content recorded for air fried chicken nuggets could be as a result of longer frying time (18 min) used. In comparison, the rate of moisture loss in air-fried products was lower relative to deep-fried products. Regarding the hydrocolloid type, it was observed that deep-fried samples had the highest moisture content for samples containing HPMC and MC, which may be attributed to their higher water binding potential as stated by (Dogan et al., 2005a). The control (C) sample had the lowest moisture contents for both frying methods (ranged from 0.69 - 0.43 g/g db for air fried, and 1.09 - 0.78 g/g, db for deep fried samples), this could be due to the lower viscosity and batter pickup recorded for the sample. The moisture content of all the samples significantly decreased with post frying holding times. A similar trend of moisture content reduction in French fries stored under heat lamp was reported by (Rahimi *et al.*, 2017). In the crust of potato strips, the inclusion of hydrocolloids in the coating builds a strong film, which regulates moisture transfer during holding time. Different formulations of batter coating result in different properties of film making that specifically impact various behaviors of moisture migration in fried foods (Rahimi *et al.*, 2017).

The moisture ratio (MR) during post-frying holding revealed a comparable reduction in moisture loss in all hydrocolloid-containing samples and frying methods across all holding times, with hydrocolloid-containing samples having a higher value than the control. This might be due to the film-forming properties of hydrocolloids, which inhibit oil absorption while retaining moisture in the fried food. Other researchers have shown that hydrocolloid-containing fried foods retain a lot of moisture (Dogan et al., 2005a; Varela & Fiszman, 2011).

The moisture content of the crust portion of chicken nugget coated with the different hydrocolloids type ranged from 0.25 to 0.80 (g/g, db) depending on the frying method and the batter formulations (Figure 3.4). For the air fried sample, the chicken nugget coated with xanthan gum had significantly ($p<0.05$) the highest moisture content in the crust region. This could be due to the high batter pickup and the adherence of batter to the substrate which reduced the rate of moisture absorption and evaporation from the crust. Akdeniz *et al.* (2006) also reported that guar gum and a combination of guar gum and xanthan gum presented a sample with the highest moisture retention when compared with the control in carrot slice and this was attributed to the water binding capacities of the gums. Likewise, in the current study, it was observed that xanthan gum and guar gum showed very high viscosity and coating pickup which prevents the loss of moisture through their ability to provide total coverage to the coated products. For both air frying and deep frying, the moisture content in the crust portion reduced as post frying holding time increased. Rovedo *et al* (1999) reported a reduction in the moisture content of potato starch patty during the first 30 min after frying and an increase in the crust moisture content.



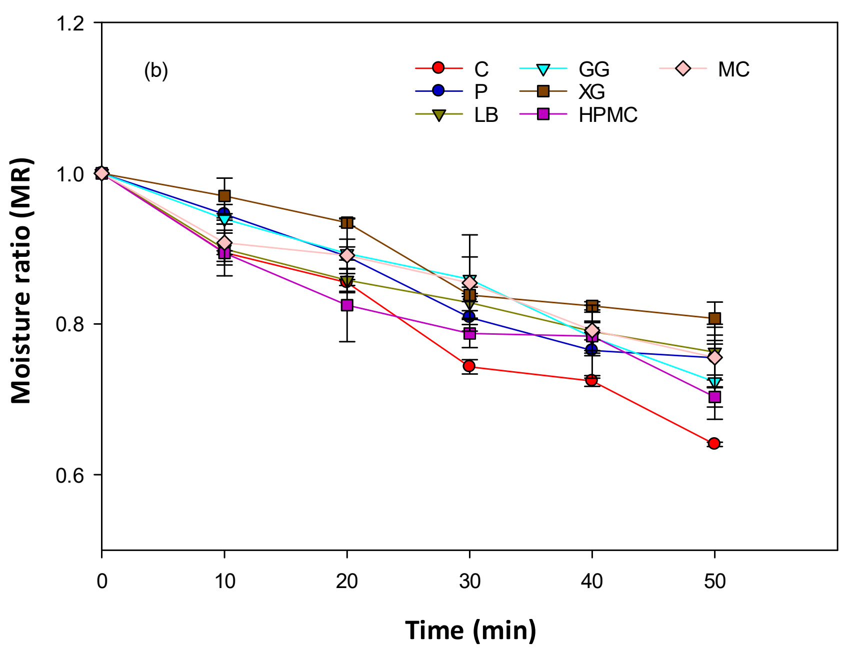


Fig. 3.4: Effect of frying method and hydrocolloid on the crust moisture content of chicken nuggets. (a) Air fried crust, (b) Deep fried crust; C - Control; P - pectin; GG - guar gum; LB - Locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

Post frying holding time, hydrocolloid type, and frying method had significant impact in controlling the moisture content of the core portion of the chicken nuggets. Specifically, the Core moisture content decreased significantly as post frying holding time increased for both air frying and deep frying (Figure. 3.5). Specifically, deep frying presented the chicken nuggets with higher core moisture content (ranged from 2.35 to 0.80 (g/g, db)) compared to the air frying (ranged from 2.08 to 0.77 (g/g, db)). In conclusion, this study revealed that storing fried food under heat lamp after frying could lead to an increase in the rate of moisture migration from the core to the crust and subsequent evaporation of the moisture from the crust thereby leading to higher hardness value. Therefore, frying time and temperature should be monitored during frying in other to obtain the desired quality attributes during heat lamp exposure.

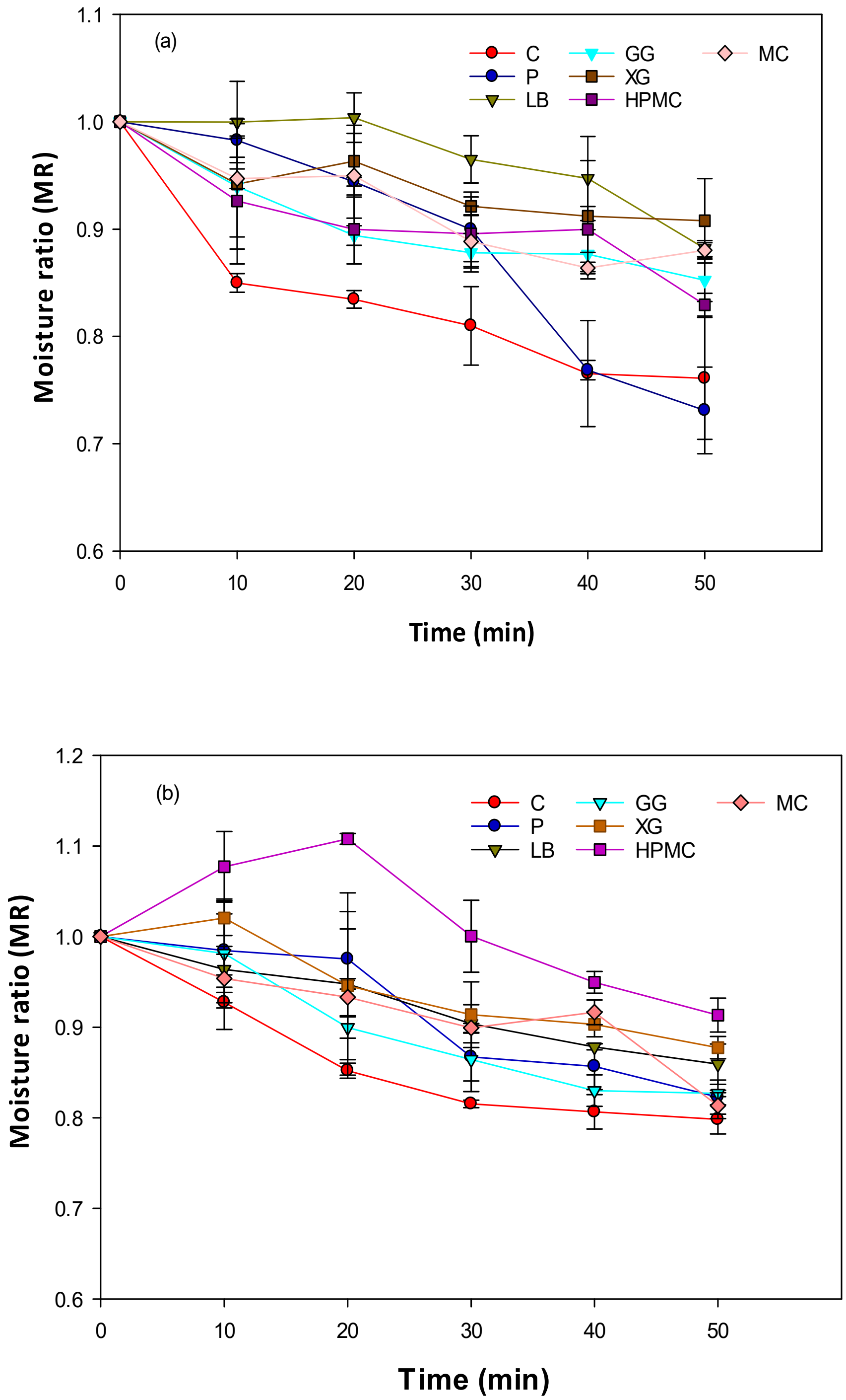


Fig. 3.5: Effect of frying methods on the moisture content of fried chicken nugget core. (a) Air fried core, (b) Deep fried core. C - Control; P - pectin; GG - guar gum; LB - Locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

3.4.6. Effect of batter formulations on fat redistribution of chicken nuggets during heat lamp holding times.

The effect of hydrocolloid type on the overall fat uptake of deep fried and air fried chicken nuggets is shown in Figure 3.6. Reduction in oil content of fried products as a result of the application of hydrocolloids has been widely reported in the literature (Lua *et al.*, 2020; Sahin *et al.*, 2005). Similarly, the addition of the different hydrocolloids significantly ($p < 0.05$) reduced the overall fat uptake of the fried chicken nuggets for both frying methods (deep-fat frying and air frying). This is in agreement with the report of Albert and Mittal, (2002) that hydrocolloids serve as a barrier to oil penetration in fried foods. XG was found to have the lowest fat content for the deep-fried sample. Furthermore, MC, HPMC, and GG also presented products with lower fat content. Similarly, Sahin *et al.* (2005) recorded the lowest fat content for batter containing HPMC and XG for chicken nuggets coated with different gums. Likewise, Garcıa *et al.* (2002) reported a lower fat content in MC compared to HPMC treated samples of potato strips. The higher oil content recorded for C, LB, and P could be due to their non-thermal gelling property or a lower coating pickup which prevents total coverage of the substrate. Coating pickup also influenced the amount of oil that is absorbed by fried foods (Amboon *et al.*, 2012; Izadi *et al.*, 2015). Furthermore, par-frying and subsequent frying with air frying had a significant effect in reducing the fat content of all the treatments. Compared to deep fat fried control, air frying caused a reduction in the oil absorption by 59.92, 52.28, 45.93, 49.80, 28.04, 27.09, and 37.57% for XG, MC, HPMC, GG, LB, P, and C, respectively. No significant difference of the effect of post-frying holding time was found on the overall fat content of both deep fried and air fried samples. However, there were significant differences ($p < 0.05$) in the oil content due to differences in the hydrocolloids used during frying.

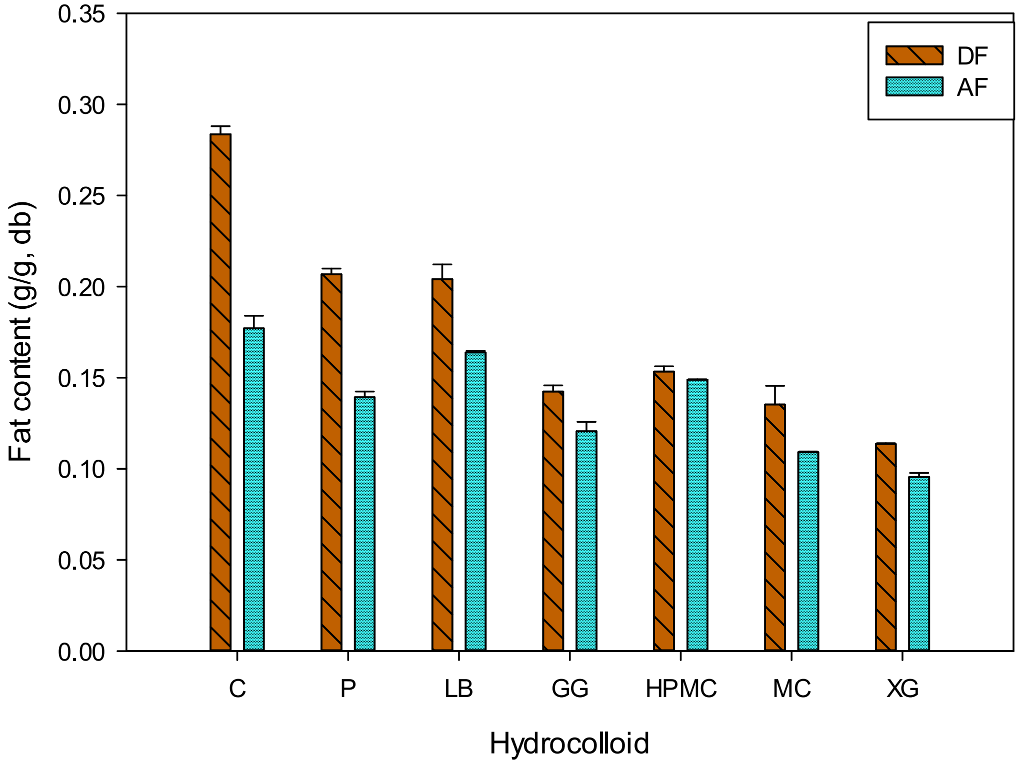


Fig. 3.6: Mean overall fat content of chicken nuggets at 10 min holding time. DF - Deep fried; AF - air fried; C - Control; P - pectin; GG - guar gum; LB - Locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

Post frying holding time under heat lamp caused a significant ($p < 0.05$) reduction in the crust fat content (Figure 3.7). The fat content was higher at the early exposure time below 20 min. However, a significant reduction in the fat content was observed as holding time increased. Specifically, the crust fat content ranged from 0.25 to 0.22 g/g for control air fried and 0.33 to 0.29 g/g for control deep fried. The crust fat content of potato strips stored under heat lamps was recorded by Rahimi et al. (2017) with similar results.

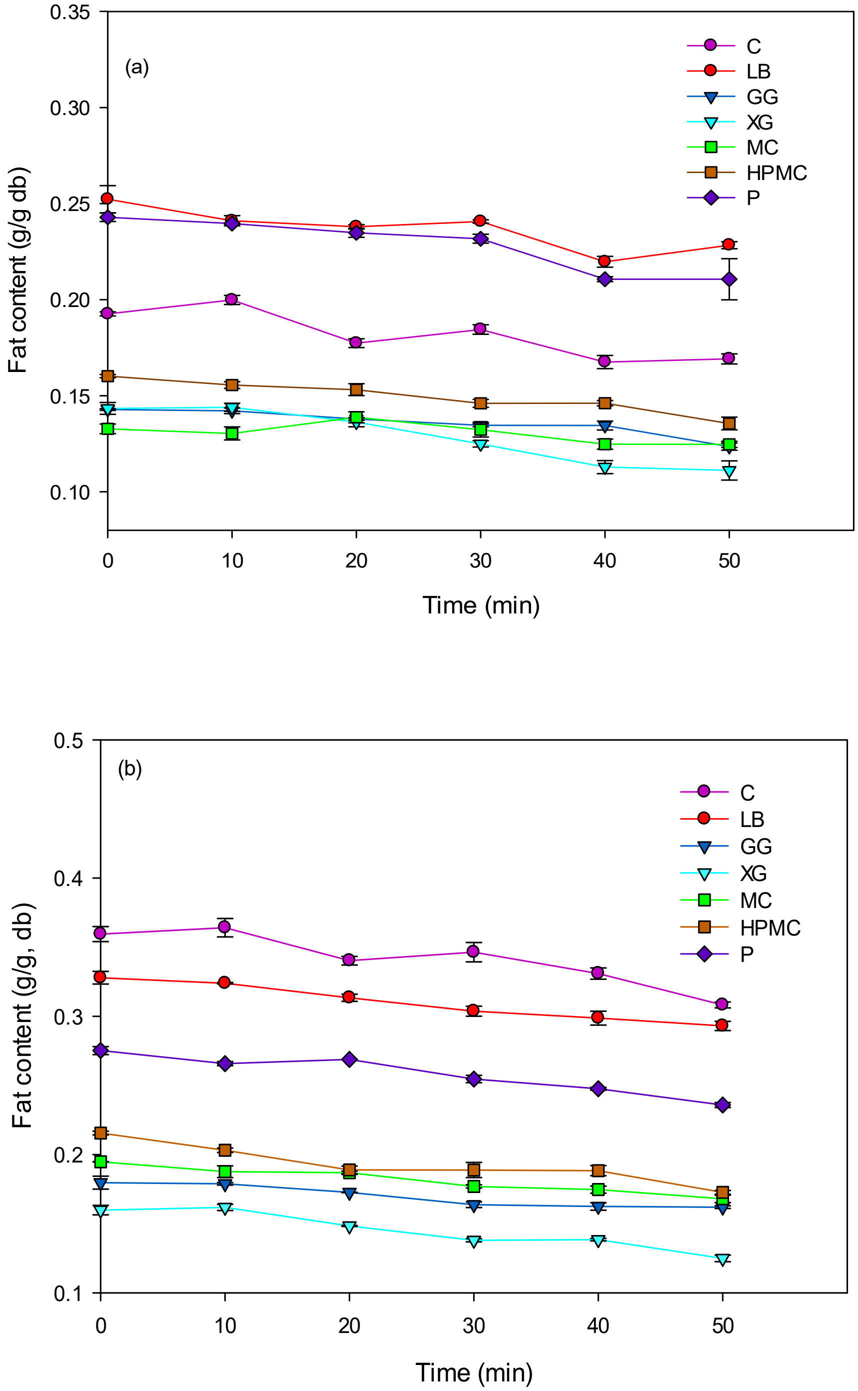


Fig. 3.7 : Mean fat content of the crust portion of a) Air fried ; b) Deep fried chicken nuggets during post-frying holding time under heat lamp. C - Control; P - pectin; GG - guar gum; LB - Locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

The average fat content of the core portion of deep-fried chicken nugget increased under heat lamp holding times (Figure 3.8). For deep fried chicken nuggets, the sample containing locust bean gum presented the lowest fat content in the core potion at all post frying holding times, with the core fat content ranging from 0.06 to 0.08 g/g db. Specifically, the fat content of the core portion of the fried chicken nuggets ranged from 0.06 to 0.04 g/g at 0 min and 0.07 to 0.09 g/g at 50 min holding time for deep fried and 0.03 to 0.08 g/g at 0 min and 0.06 to 0.11 g/g at 50 min heat lamp holding time for air fried. There were no statistical differences ($p < 0.05$) between the core fat content at 0 and 10 min holding time for nearly all the treatments.

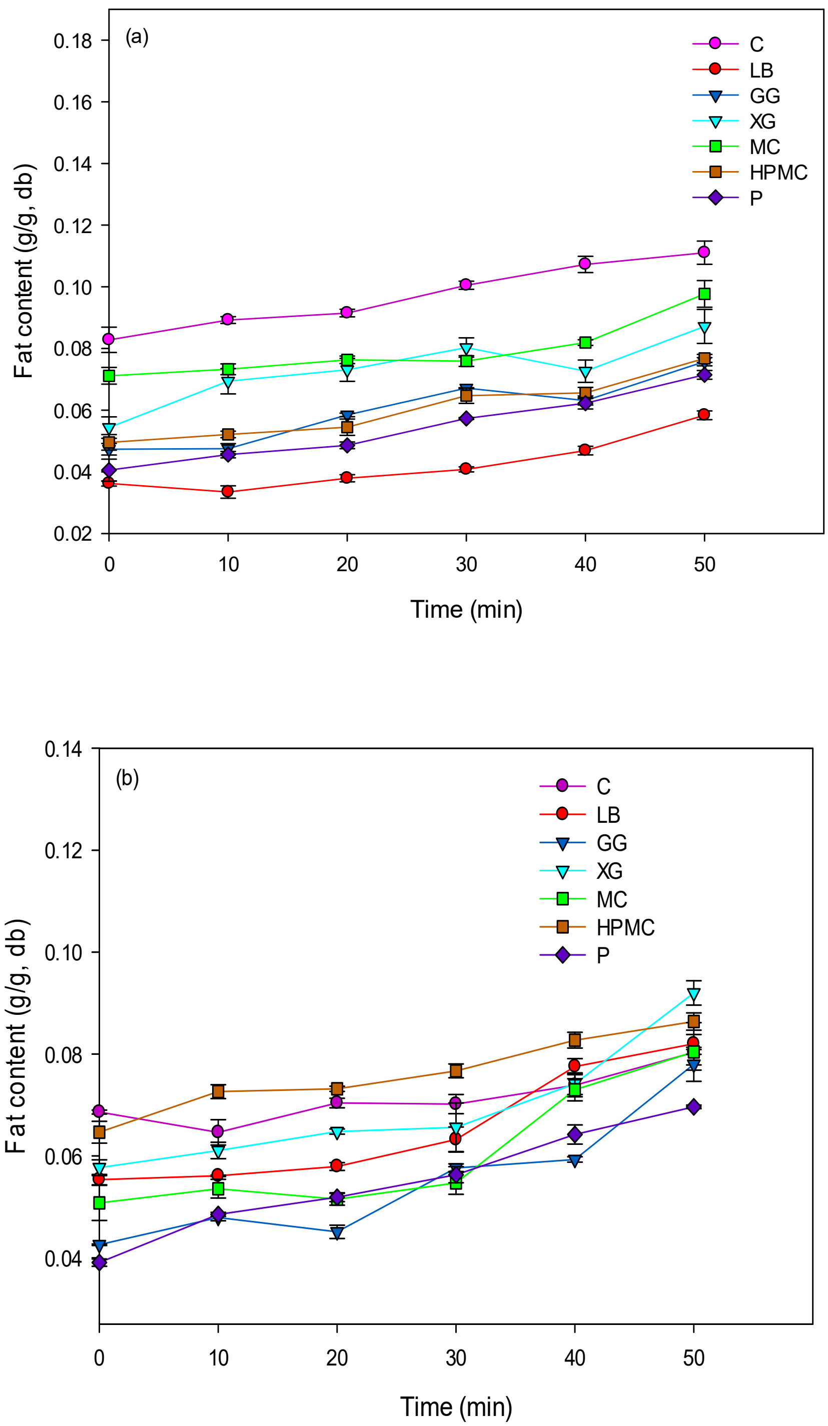
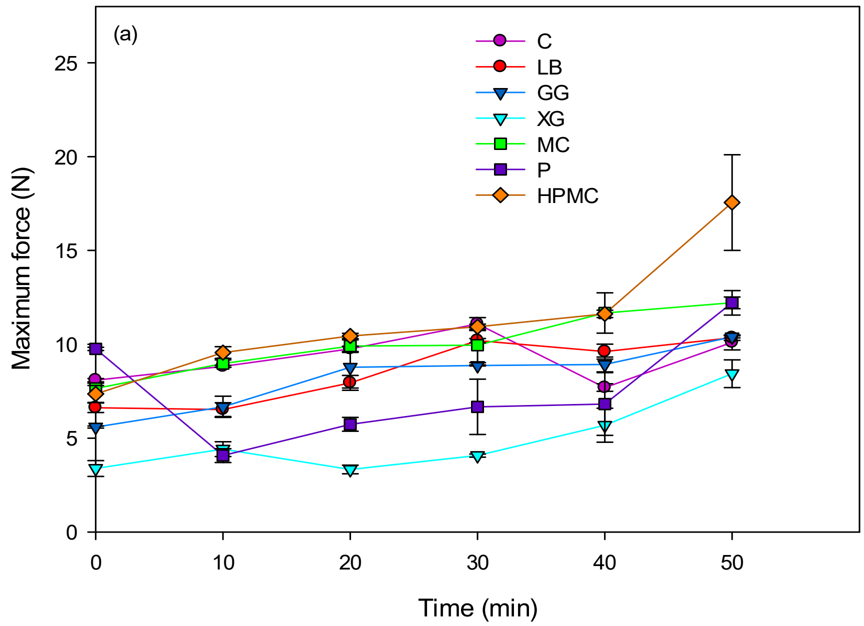


Fig. 3.8: Mean fat content of the core portion of (a) air fried; (b) deep fried; chicken nuggets during post-frying holding time under heat lamp. C - Control; P - pectin; GG - guar gum; LB - Locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

3.4.7. Effect of frying method and post frying holding time on the crispiness of chicken nuggets.

Figure 3.9 represents the effect of hydrocolloid types and post frying holding time under heat lamp on the textural property of the batter coated chicken nuggets. The inclusion of the different hydrocolloids had a significant effect ($p < 0.05$) on the crispiness of the products kept under heat lamp. Product formulated with Xanthan gum had the lowest crispiness which is depicted by the lower hardness value (cutting force) in (N) since crispiness is positively correlated with hardness in products with multi-domain moisture content such as chicken nuggets. The lower hardness value of the treatment with xanthan gum could be due to the viscosity and batter pickup of the sample, which retained high moisture in the crust during post frying holding. In their study of the impact of pre-dying and hydrocolloids on the textural quality of yam chips, Alimi et al. (2013) found that non-pre-dried yam chips treated with Xanthan gum had the lowest crispiness (lower hardness value). Some of the samples were found to have higher hardness values immediately after frying (LB, P, HPMC, and MC) for the deep-fried products. However, the hardness suddenly decreased during the 10 min storage time and started increasing thereafter, this could be due to the adhering surface oil blocking the pore spaces in the crust immediately after frying, and this could also indicate the impact of oil penetration into the core and moisture migration from the core and crust that resulted in changes in the textural properties of the fried products. The air fried samples were crispier compared to the deep-fried samples, this could be associated with the frying time and the low moisture content that was recorded in the crust portion of the air fried samples compared to the deep fat fried samples. Cao *et al.* (2020) comparison of air-fried and deep-fried chicken nuggets showed similar cutting force for samples air fried for 12 min and sample deep fried for 6 min, this could justify the reason for the higher hardness value recorded for the air fried products since it was air fried for 18 min. Garmakhany *et al.* (2014) reported that the higher cutting force recorded for guar gum and the control of French fries in their research when compared with xanthan gum could be linked to the higher moisture loss which resulted in surface shrinkage. Holownia *et al.* (2000) also reported a higher cutting force value for banana chips coated with guar gum compared to xanthan gum. Notably, guar gum presented a sample with a higher cutting force when compared to the xanthan gum treated samples, and the rate of textural changes was low in guar gum under heat lamp exposure compared to XG for all frying methods.



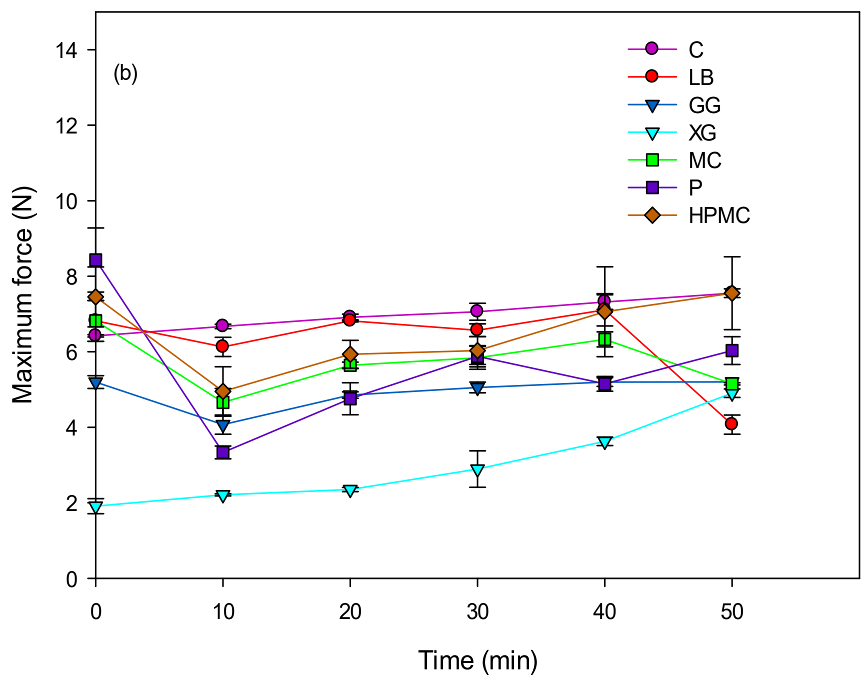


Fig. 3.9: Variation in the breaking force of chicken nuggets during post-frying holding under heat lamp (a) air fried and (b) deep fried chicken C - Control; P - pectin; GG - guar gum; LB - Locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

3.5 Conclusion

The effect of heat lamp holding time, frying method, and hydrocolloids on the changes in properties of fried chicken nuggets under heat lamp was determined in this study. There was a significant ($p < 0.05$) increase in the batter pickup, viscosity, and thermal properties of batter containing the different hydrocolloids. The frying method, hydrocolloid type, and post frying holding time significantly affected the moisture content, fat content, and their redistribution between different portions of the chicken nugget during heat lamp exposure. Regardless of the frying method and hydrocolloid type, the moisture content of the different portions of chicken nugget significantly decreased ($p < 0.05$) as heat lamp holding increased. Likewise, the fat content of the crust and core portion decreased and increased, respectively as holding time increases. Hydrocolloid type caused a significant reduction in the overall fat content of fried chicken nuggets. This study indicated that chicken nuggets coated with XG, HPMC, MC, and GG containing batter provided a water barrier that prevented the movement of water from the core to the crust during heat lamp exposure. However, Pectin and locust bean gum were not quite effective in limiting moisture migration and led to higher cutting force compared to HPMC, MC, GG, and XG. Furthermore, it was discovered that XG with 1% concentration provided a sample with the highest viscosity, batter pickup, and moisture retention, while the control sample showed the highest cutting force for fried chicken nuggets during post frying holding times under heat lamp.

CONNECTING TEXT TO CHAPTER FOUR

In chapter three, the impact of hydrocolloids and two frying methods (deep-fat frying and air frying) on improving the batter pickup, rheological properties, thermal properties, color attributes, moisture loss, fat uptake, and crispiness of fried chicken nuggets during post frying holding were evaluated. In the succeeding chapter, we investigated the combined impact of hydrocolloids and ultrasound treatments on similar parameters of deep-fried chicken nuggets during post frying holding under heat lamp.

CHAPTER FOUR

4. COMBINED EFFECT OF ULTRASOUND AND HYDROCOLLOID FORMULATED BATTER ON QUALITIES OF FRIED CHICKEN NUGGETS

4.1 Abstract

Impact of ultrasonication on the quality characteristics of batters formulated with different hydrocolloids were investigated in this study. Quality parameters investigated included batter pickup, flow behaviors and thermal properties. The effect of ultrasonication on quality (e.g. moisture loss, fat content, color and texture) of fried chicken nuggets coated with batters were studied during post frying by exposing them to heat lamp. The results showed that ultrasonication significantly reduced batter pickup. There were also significant differences between the consistency coefficients of the different batter formulations, ranging between 7.56 to 91.69 Pa.sn for untreated and 4.87 to 73.02 Pa.sn for ultrasound treated batter samples. The flow behavior was reported to range between 0.30 to 0.59 and 0.35 to 0.72 for non-ultrasonicated and ultrasonicated treatment, respectively. Moisture content of the samples decreased under heat lamp exposure, with the rate dependent on the type of hydrocolloid used in the batter formulation. Compared to the control (Chicken nugget coated with batter with no hydrocolloid and ultrasonication), fat content of the ultrasound treated batters decreased by 11.5, 39.0, 60.9, 64.1, 65.7, 65.0 and 62.87% for control, pectin, locust bean gum, guar gum, hydroxypropyl methylcellulose, methylcellulose, and xanthan gum, respectively. Finally, chicken nuggets coated with ultrasound treated batters showed a higher cutting force value which increased with longer heat lamp holding time. Thus, the application of ultrasound can be exploited by the frying food industry as an alternative approach to producing low fat chicken nuggets with good organoleptic qualities.

4.2 Introduction

Fried foods have high consumer acceptability due to their desirable organoleptic qualities such as crispiness, appearance, palatability and flavor (Aberoumand, 2014; Nourian *et al.*, 2003; Odenigbo *et al.*, 2012). Despite their desirable organoleptic properties, consumption of fried foods has been associated with development of chronic diseases such as arteriosclerosis, obesity, hypercholesterolemia, diabetes and cardiovascular diseases due to their high fat content (Moumtaz *et al.*, 2019; Varela & Fiszman, 2011). In order for the fried food industry to maintain its market share in the increasingly competitive food world, there is a need to develop alternative processes that will limit fat absorption during the processing of fried foods. However, it should also be highlighted that, while meeting this need, desirable organoleptic qualities such as crispiness which contribute to consumer acceptability of fried foods must not be sacrificed.

Crispiness, a textural attribute of fried foods, is one of the most important factors responsible for consumer acceptability and purchasing power of fried food (Antonova *et al.*, 2004). It is affected by microstructure, moisture, and fat concentrations as well as their redistribution during frying and post frying periods (Tunick *et al.*, 2013). To date, the inability to maintain the crispy nature of fried foods during post frying remains a big challenge to the fried food industry. According to Rahimi et al. (2017) and Luyten *et al.* (2004), fried foods lose their crispiness and become soggy during post frying, as a result of moisture gradient between the core and the crust. Therefore, there is a need to develop alternative materials with duo properties, that is, limiting fat and water absorption during frying and post frying holding, respectively. In light of this, the potential of hydrocolloids has been exploited and reported in the literature. Previous authors such as Kim et al. (2011) and Sothornvit (2011) pointed out that, application of hydrocolloids in foods has multifunctional benefits including texture modification, stability maintenance, moisture control, and fat reduction. Furthermore, Amboon *et al.* (2012) mentioned that the water binding capability of hydrocolloids could help in reducing the loss of crispiness in chicken nuggets during post frying holdings, by reducing the permeability of water from the core to the crust. Supporting the conclusions of these researchers is the study of Sanz *et al.* (2004 who observed a 54.8% reduction in fat content and an increase in moisture retention upon coating fried seafood with methylcellulose. This observation can be attributed to the film forming ability and thermal gelation properties of methylcellulose and other hydrocolloids from cellulose derivatives (Sothornvit 2011).

In order to reduce the high fat content absorbed by fried foods, new novel technologies and pretreatment operations such as battering, hydrocolloids, pre-drying, pre-dusting, vacuum treatment, ultrasound pretreatment, and a combination of these processes have been documented (Moumtaz *et al.*, 2019; Oladejo *et al.* 2017). Ultrasonication is a novel technology that has been proven to positively impact various food qualities, such as color, fat, and moisture loss (Chemat *et al.*, 2017; Ho et al., 2016). Additionally, Yao (2016) reported that ultrasound treatment is efficient in reducing the food pre-treatment time and physical properties of foods such as density, moisture, porosity, shrinkage, and color parameters. Ultrasound treatment minimises internal and external resistance to mass transfer in a liquid or osmotic solution by causing cavitation and producing microscopic channels that accelerate mass transfer through convection. (Mohammadalinejhad et al., 2018; Oladejo *et al.* 2017). Lua *et al.* (2020) investigated the fat absorption capacity of ultrasound treated methylcellulose formulated batter and reported a 31% reduced fat content in developed French fries. Oladejo *et al.* (2017) also reported a reduction fat content of ultrasonicated potato slices after immersion in distilled water containing the ultrasound probe by up to 65-75% compared to their non-ultrasonicated counterpart. However, there is a dearth of information with respect to how ultrasonication influences crispiness of fried foods coated with hydrocolloid formulated batter. Thus, taking advantage of the green technology of ultrasonication and GRAS (Generally accepted as safe) status of food hydrocolloids, it will be worth studying their combinative effects on fat absorption and final crispiness of fried foods such as chicken nuggets.

Therefore, the main objective of this work was to study the combinative effect of ultrasound and hydrocolloid types (i.e., pectin, guar gum, locust bean gum, methylcellulose, xanthan gum and hydroxypropyl methylcellulose) on texture, moisture and fat content of fried chicken nuggets during post frying holding time under heat lamp.

4.3 Materials and Methods

4.3.1 Material

Wheat flour (Five roses white all-purpose flour), corn starch (Fleischmann's corn starch), canola oil (Selection TM/MC, Quebec, Canada), chicken breast, and leavening agent ($Na_2H_2P_2O_7/NaHCO_3$) were purchased from a local grocery store in Montreal, Canada. Hydrocolloids (pectin, guar gum, locust bean gum, xanthan gum, and hydroxypropyl methylcellulose) were procured from Spectrum Chem. Mfg. Corp. New Brunswick, USA, whereas methylcellulose (Viscosity (2% in Water); 3000-5600 CP) was purchased from Fisher scientific, Canada.

4.3.2 Batter formulations

Batter formulations contained wet and dry ingredients. The dry ingredient is made up of 92% of wheat flour- corn starch blends (80%wheat flour and 20% corn starch) (Table 4.1). The dry ingredient to water ratio was 1:1.3. In order to allow complete hydration of the hydrocolloids, about 1% of the different hydrocolloids were weighed into the water and held in a water bath at 10 °C for about 30 min. The dry ingredients, as seen in Table 4.1, were subsequently added accordingly.

Table 4. 1: Batter formulation

Batter formulation	Wheat flour (%)	Corn starch (%)	Salt (%)	Leavening agent (%)	GG (%)	P (%)	LB (%)	CMC (%)	HPMC (%)	XG (%)
Control	78	19.5	2	0.5						
1	77.2	19.3	2	0.5	1					
2	77.2	19.3	2	0.5		1				
3	77.2	19.3	2	0.5			1			
4	77.2	19.3	2	0.5				1		
5	77.2	19.3	2	0.5					1	
6	77.2	19.3	2	0.5						1

C: Control; P: pectin; GG: guar gum; LB: locust bean gum; MC: methylcellulose XG: xanthan gum; HPMC: hydroxypropyl methylcellulose

4.3.3 Ultrasound treatment

The formulated batter with different hydrocolloids at 1% concentration were subjected to ultrasonication. Briefly, two-third of a 200 ml beaker was filled with batter and stirred consistently for about 5 min. The resulting batter containing different hydrocolloid formulations were subjected to high intensity ultrasonication for 20 min at 40% amplitude and 20°C ultrasound temperature using an ultrasound probe (Model VCX 500, Sonics and Materials. Inc, CT, USA). Ultrasonication was carried out in an ice-cold water bath to avoid possible heating of batter during the process.

4.3.4 Rheological properties measurement

Rheological properties were measured using a controlled stress rheometer (Advanced Rheometer 2000, TA Instruments, Delaware, USA). A 40 mm circular plate geometry with a gap of 1000 µm was used to determine the rheological properties of the ultrasound treated batters. Prior to measurement, the batter slurries were kept at room temperature (25°C) for 10 min. The samples were subjected to a steady shear viscosity test, and the steady shear was estimated in the range of 0.1 - 100 /s at 15 °C. The sample temperature was kept constant for 2 min prior to the start of the measurement. The power law model was used to describe the flow behavior of the ultrasound (US) and non-ultrasound (NUS) treated samples.

$$\tau = K\ (\gamma)^n \tag{4.1}$$

Where τ is shear stress (N/m^2), γ is shear rate (s^{-1}), K is consistency coefficient ($Pa.s^n$), and n is flow behavior index (dimensionless)

4.3.5 Batter pickup

The chicken nugget was coated in a batter slurry with and without ultrasounds pretreatment. Before the final weighing of the battered chicken nuggets, the excess batter was drained off for about 20 seconds. The batter pickup was measured as the percentage of battered chicken nugget weight compared to the original weight of non-battered chicken nuggets.

4.3.6 Differential scanning calorimeter

Thermal properties of the different batter formulations with and without ultrasound treatments were measured. Specifically, the gelatinization profile of the sample was measured using a differential scanning calorimeter (DSC250, TA Instruments, New Castle, Delware, USA). The peak temperature (Tpeak) and change in enthalpy (ΔHm) of the instrument were calibrated to be 156.59 °C and 28.425 J/g, respectively by using indium. About 15±2 mg of batter was measured into a DSC 40 µl aluminium pan and sealed hermetically. The gelatinization profile (onset, peak, and conclusion temperature of gelatinization) was evaluated from the DSC thermogram according to the method of Chandrapala *et al.* (2011). An empty pan of equal weight was used as the reference. Precisely, the pans were heated from 25 °C to 110 °C at a heating rate of 2 °C/min. The gelatinization enthalpy (ΔH) was recorded from the area of the endothermic peak and the average of three replicate of each treatment were used.

4.3.7 Preparation of chicken meat

Chicken breast meat was cleaned and placed on a mesh to drain the water. The chicken breast was later cut into 20 ± 2 g, and the chicken breast was pre-dusted with a batter containing a combination of dry ingredients.

4.3.8 Frying and post-frying holding

The frying experiment was carried out using a programmable deep fat fryer (De'Longhi, America Inc., Saddle Brooke, NJ 076663, China). Before frying, the fryer was filled with about 1.5 liters of canola oil and preheated to 180 °C for 1 hour. Samples were deep fried for 6 min at 180 ° C, the fried chicken nugget was drained by a paper towel from surface oil. The heat lamp (Model Sw-2430, Merco Inc., Lakewood, N.J., U.S.A.) was preheated for 30 min for post-frying exposure and the fried samples were subsequently put under the heat lamp for 0, 10, 20, 30, 40, and 50 mins.

4.3.9 Moisture loss and distribution

Moisture contents of the fried chicken nuggets samples were determined following the AOAC (2005) standard method. The core and the crust of fried chicken nuggets were separated by using a sharp knife. Samples were oven dried in a dryer at 105±2 °C for 24 hrs transferred immediately to a desiccator to allow equilibration for 20 min. Moisture content was calculated on a dry basis from the weight of the fried chicken before and after oven drying for 24 hrs.

4.3.10 Fat content determination

Fat contents of the different samples were determined using a Soxhlet extractor (SER 148, Velp Scientifica, Usmate, Italy). The solvent used was petroleum ether. Percentage fat content was determined by measuring the weight of the extracted fat and the overall sample weight prior to extraction.

4.3.11 Color

Crust color of the deep fat fried chicken nuggets samples was measured using the Konica Minolta spectrophotometer (CM-3500d, Konica Minolta Sensing Americas, Inc., NJ, USA). L*(blackness/whiteness), a* (greenness/redness), b* (blueness/yellowness), and ΔE (color difference) color parameters were obtained. For every formulated batch, six measurements were carried out at the surface of four coated nuggets, one measurement at different sides of each chicken nugget. The net color difference (ΔE) was determined using Eqn. 4.2.

$$\Delta E = \sqrt{((L_0 - L_t)^2 + (a_0 - a_t)^2 + (b_0 - b_t)^2)} \qquad (4.2)$$

L_0, a_0, b_0 are the L, a, and b values for Chicken nugget coated the control batter (without hydrocolloid)

L_t, a_t, b_t are the L, a, and b values for the chicken nugget coated with the formulated batter at the same frying time

4.3.12 Texture

The textural properties were determined using a texture analyzer (TA-HD plus, Stable micro systems, Godalming, UK) operating at 500 volt-ampere. The hardness of the chicken nugget samples was determined by a compression test (TA-42 knife blade with 45 °C chisel end) after storing the samples under heat lamp for different post-frying durations (0, 10, 20, 30, 40, and 50 min). The method of Mah and Brannan (2009) was used with a slight modification. The pre-test, test, and post-test speeds were set at 10, 1 and 10 mm/s, respectively.

4.3.13 Statistical analysis

Analysis of variance (ANOVA) was performed using the Generalized Linear Model (PROC GLM) procedure of SAS system software (Version 9.2, SAS Institute, Inc., Cary, USA) to assess the effect of ultrasound and non-ultrasound treatment on the quality attributes of battered chicken nuggets during post frying holding time. Tukey multiple comparisons were performed on the mean separation and treatment significant was measured at $p < 0.05$. All treatments were performed in triplicate and all data were presented as mean ± sd.

4.4 Results and Discussion

4.4.1 Effect of ultrasound treatment on batter pickup

Batter pickup of chicken nuggets coated with the formulated batters are shown in Figure 4.1. Batter pickup for the control sample (C) with or without ultrasound treatment was low compared to the other batter coatings. Xanthan gum (XG) samples showed the highest batter pickup for both NUS and US. There was a significant difference ($p < 0.05$) between batter pickup for ultrasound treated samples (US) and non-ultrasound treated samples (NUS). Ultrasound treatment tended to decrease batter pickup. However, the extent of decrease in batter pickup depended on the type of hydrocolloid. When compared with the NUS samples, the batter pickup of the US decreased by 22.7, 7.2, 45.9,27.4, 39.1, 36.0, and 8.2 % for C, P, LB, GG, HPMC, MC, and XG samples, respectively. This result could be attributed to the lower viscosity of ultrasound treated batter as documented by Amiri *et al.* (2018) and Tan *et al.* (2011).

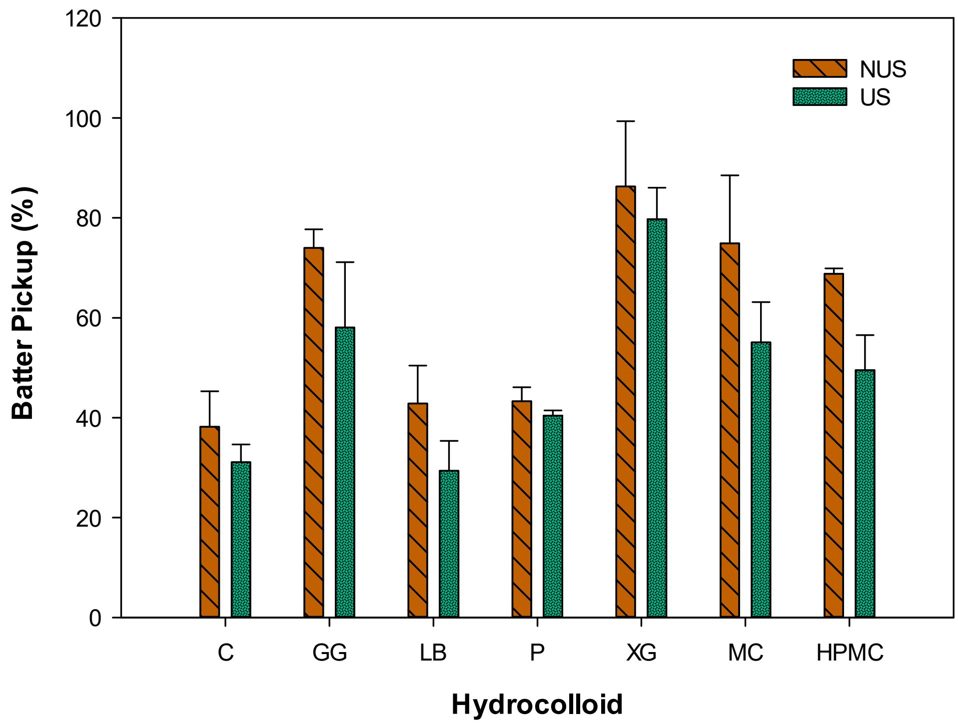


Fig. 4.1: Effect of ultrasonication on the coating pickup of batter containing different hydrocolloid types. NUS - non-ultrasonicated samples; US - ultrasonicated samples; C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC – methylcellulose; XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

4.4.2 Impact of ultrasound formulated batter on rheological properties.

All the batters used in this study exhibited the pseudoplastic (shear thinning) flow behavior. Table 4.2 shows the combined effect of ultrasonication and hydrocolloids on the consistency coefficient (k) and flow index (n) for the different batters. Consistency index (k) values for all US treated batter samples were lower than those for NUS samples. Among the hydrocolloid batter formulations exposed to ultrasonication, XG and GG presented the highest k values both for US (73.025 and 35.045 Pa.sn, respectively) and NUS treated batter samples (91.69 and 74.69 Pa.sn, respectively). The control (C) batter showed the lowest k values of 4.871 and 7.561 Pa.sn for US and NUS, respectively. Further, the flow index (n) for US treated C, P, LB, GG, HPMC, MC, and

XG batters increased by 18.3, 18.4, 23.5, 27.2, 23.7,12.9, and 14.8%, respectively, compared to their NUS counterpart. The variation in the power law parameters (k and n) of batter with different hydrocolloids could be due to the modification of the various chemical structures of the different hydrocolloids during ultrasound treatment.

Table 4.2: effect of ultrasonication on the rheological properties of wheat flour – corn starch-based batter

NUS				US		
Sample	k	n	R^2	k	n	R^2
CON	7.561 ± 0.24^{b}	0.573 ± 0.01^{a}	0.99	4.871 ± 0.21^{b}	0.701 ± 0.01^{b}	0.99
GG	74.695 ± 7.71^{c}	0.391 ± 0.03^{b}	0.99	35.045 ± 1.67^{c}	0.537 ± 0.01^{c}	0.99
LB	17.44 ± 1.35^{d}	0.543±0a	0.99	4.857 ± 0.18^{b}	$0.710 \pm 0b^{a}$	0.99
P	13.77 ± 0.51^{bd}	0.588 ± 0.02^{a}	0.99	6.228 ± 0.14^{b}	0.721 ± 0.01^{ab}	0.99
XG	91.69 ± 0.09^{a}	0.298 ± 0.01^{c}	0.99	$73.025 \pm 0.^{2a}$	0.350 ± 0^{e}	0.99
MC	43.625 ± 3.12^{e}	0.579 ± 3.12^{a}	0.99	21.485 ± 0.3^{e}	0.665 ± 0^{d}	0.99
HPMC	33.835 ± 2.6^{f}	0.55 ± 2.6^{a}	0.99	13.45 ± 0.6^{d}	0.721 ± 0.01^{a}	0.99

Results are means of triplicate ± standard deviation. Different letters within the same column depict a significant difference ($p<0.05$)

Ultrasonic energy is known to drive several chemical reactions leading to changes in the functional properties of proteins and carbohydrates in liquid foods (Amiri *et al.* 2018), The reactions are generated by acoustic cavitation via the formation and subsequent collapse of ultrasound-induced bubbles leading to the observed changes in flow properties. Figure 4.2 shows the apparent viscosities of the different ultrasonically treated batters as a function of shear rate. Lower viscosities were recorded for samples containing 1% concentration of hydrocolloids compared to ultrasonicated samples. From the results, ultrasonication significantly ($p<0.05$) reduced the apparent viscosity of all treated batter samples. This could be attributed to the structure modification of hydrocolloids upon ultrasonication. According to Chan *et al.* (2018) and Muñoz-Almagro *et al.* (2017), decreased viscosities among polysaccharides exposed to ultrasonication can be attributed to the breaking down of their complex molecular structure into simpler forms as a result of cavitation. Furthermore, ultrasound has been shown to degrade polysaccharides such as pectin into small molecular components (Li et al., 2017). Consequently, ultrasound may cause a reduction in the viscosity of hydrocolloids in solution.

In summary, ultrasonication caused a significant reduction in the apparent viscosity and k value and an increase in the n value when compared with the non-ultrasonicated samples. Other researchers have reported similar trends for the rheological behavior of ultrasonicated samples (Chung *et al.*, 2002; Izidoro *et al.*, 2011)

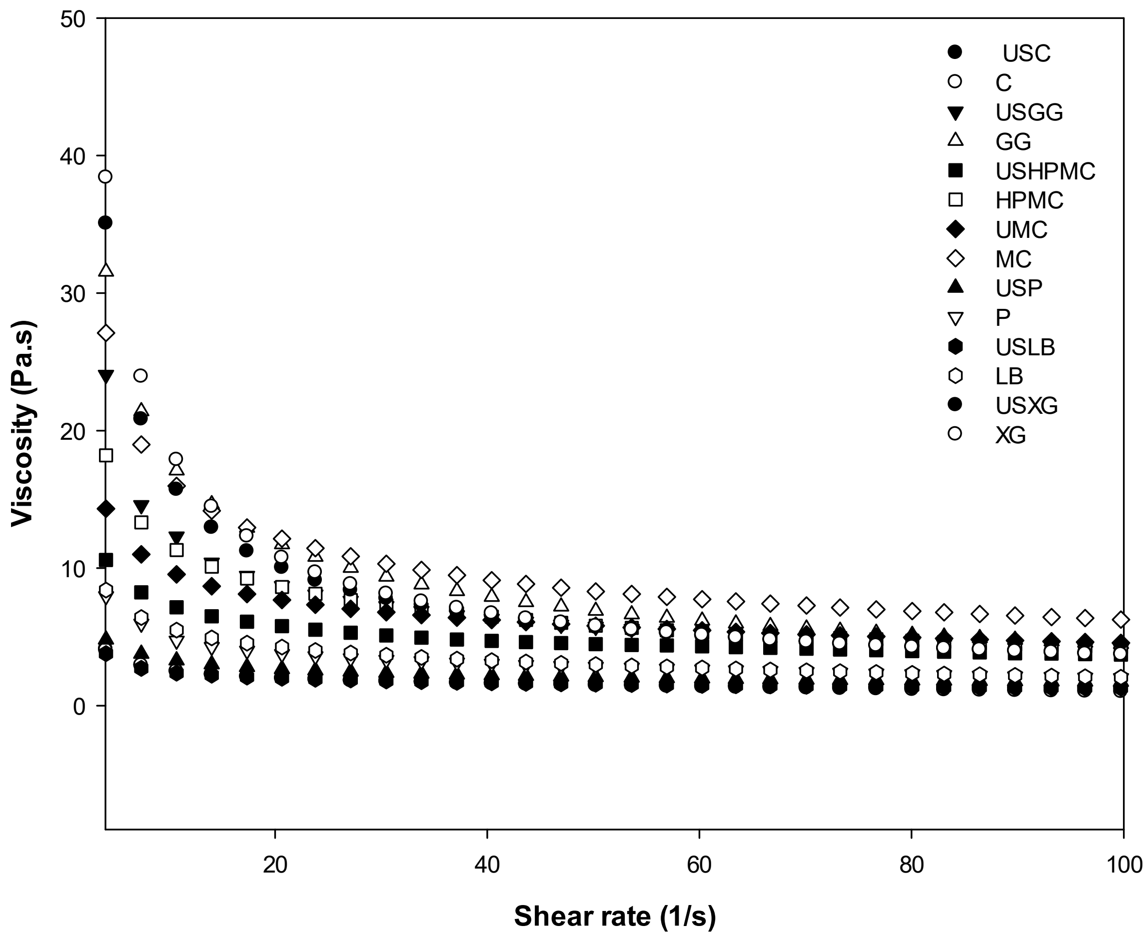


Fig. 4.2: Effect of ultrasonication on the apparent viscosity of batter containing different hydrocolloids types. US - ultrasonicated; C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methylcellulose.

4.4.3 Thermal properties of different batter formulations as affected by ultrasonication

The effect of ultrasonication (US) on thermal properties of the formulated batter is presented in Table. 4.3. DSC measurement was performed on the different batter formulations with and without ultrasonication. The onset temperature slightly increased for C, LB, P, XG and HPMC but decreased for MC and GG. Likewise, peak temperature for US showed a decreasing and increasing trend for GG, LB, XG and P, MC, HPMC, respectively. Statistical differences ($p < 0.05$) were also recorded for peak temperature of NUS. However, the peak temperature of gelatinization was the same for both US and NUS samples for the C (sample without any hydrocolloid). Furthermore, the conclusion temperature of gelatinization significantly changed (increased for GG, P and decreased for C, LB, MC, HPMC, XG). Ultrasound treatment (US) was found to decrease the gelatinization enthalpy (ΔH) for all investigated batter samples. This observation is in synchrony with the result of Zhu & Li (2019), who reported a decrease in the gelatinization enthalpy of quinoa flour upon ultrasound treatment. Accordingly, hydrocolloid-based batter samples treated with ultrasound showed the lowest gelatinization enthalpy value compared to their non-ultrasound treated counterparts (NUS). According to Xue and Ngadi (2007), various factors could contribute to the changes in the gelatinization enthalpy which includes the distribution of water between starch and gluten, hydration rate, starch granule size, and other interactions between their several components. The lower gelatinization enthalpy of ultrasonically treated batter might be attributed to the internal structure of the batter being broken down during ultrasound treatment, resulting in lower energy required for gelatinization. All investigated treatments (US and NUS) showed a single gelatinization peak, with peak temperatures between 66 °C and 67 °C, with no significant difference ($P < 0.05$) among US.

Table 4.3: Effect of hydrocolloids type and ultrasonication on thermal properties of wheat flour and corn starch batter blends

	NUS				**US**			
	T_o	T_p	T_c	ΔH	T_o	T_p	T_c	ΔH
C	60.23±0.14^{b}	66.53±0.21^{b}	73.42±0.66^{b}	3.15±0.72^{a}	61.25 ±0.35^{b}	66.53 ±0.2^{b}	70.06 ±0.16^{a}	1.46 ±0.17^{b}
GG	61.84±0.02^{c}	66.51±0.06^{b}	69.93±0.56^{c}	1.61±0.06^{b}	61.40 ±1^{b}	66.43 ±0.^{28b}	71.46±1.91^{a}	0.93±0.01^{b}
LB	61.43±0.21^{dcb}	66.99±0.^{02c}	74.57±0.24^{b}	2.18±0.21^{ab}	62.13 ±0.41^{b}	66.34 ±0.12b	71.12±0.6^{a}	1.01±0.06^{d}
P	62.40±0.04^{ac}	67.23±0.13^{ac}	71.85±0.16^{ba}	1.731±0.11^{dbac}	63.31 ±0.15^{ab}	67.36 ±0.23^{ab}	72.46±0.14^{ab}	0.78±0.07^{fe}
XG	62.05±0.56^{fcdea}	66.94±0.03^{bca}	71.45±0.68^{dcba}	1.82±0.97^{ebacd}	62.50 ±0.29^{b}	66.62±0.05^{b}	71.29 ±1.25^{a}	0.78 ±0.17^{g}
MC	61.61±0.33^{ecd}	66.04±0.02^{db}	75.75±0.38^{ab}	1.27±0.33^{cba}	60.99 ±0.21^{b}	66.44±0.08^{b}	69.54 ±0.28^{a}	1.05±0.06^{ebcd}
HPMC	60.75±0.14^{b}	66.31±0.35^{b}	72.07±0.96^{b}	2.61±0.33^{ab}	62.18±0.38^{b}	66.66 ±0.06^{b}	71.13 ±0.33^{a}	0.73±0.13^{c}

NUS - non-ultrasonicated ; US - ultrasonicated; C: control; P: Pectin; GG: guar gum; LB: locust bean gum; MC: methylcellulose XG: xanthan gum; HPMC: hydroxypropyl methylcellulose). Note: Results are means of triplicate ± standard deviation. Different letters within the same column depict a significant difference ($p<0.5$

4.4.4 Impact of ultrasound on color attributes of chicken nuggets.

Due to the relevance of the color of chicken nuggets in influencing consumer acceptability, color parameters (L*, a*, b*) were determined in this study. Xanthan gum formulations presented the highest lightness (L*) value for both NUS (63.02) and US (55.27) treated nuggets, compared to control (C) with 55.23 and 52.75 for NUS and US, respectively as shown in Table 3.4. However, lightness among NUS treated nuggets decreased for all the treatment when ultrasound treatment was applied. This observation agrees with the report of Zhu & Li (2019) who also reported a decrease in the lightness of ultrasonically treated quinoa flour with the lightness value decreasing with increase in ultrasonication time. This was attributed to ultrasound treatment that stimulated a Maillard reaction, which, along with changes in polyphenol causes a reduction in the color of ultrasound treated quinoa flour. Compared to the NUS samples, a* values (greenness/redness) of the US treated samples decreased for LB and GG but increased for C, XG, MC, HPMC, and XG. There was no statistical difference ($p < 0.05$) between a* values of NUS samples. However, significant differences ($p < 0.05$) were recorded among US treated samples. US treated Pectin formulations had the highest a* value of 6.56 compared to the US treated C with 4.30.

For NUS treated samples, the yellowness b* of the control C was higher than every other treatment. There was no significant difference ($P < 0.05$) between samples containing different hydrocolloids and treated with both NUS and US. b* value reduced from 21.20 to 18.32 for NUS and 19.47 to 14.91 for US treated samples. For NUS samples, ΔE ranged from 7.82 to 0.74 with xanthan gum and pectin having the highest and lowest ΔE, respectively. In addition, the total color difference (ΔE) value significantly increased for all US treated samples except xanthan gum.

Table 4.4: Effect of ultrasound on color attributes and ΔE of fried chicken nuggets

	NUS				US			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
C	55.23±2.02^{a}	4.16±0.6^{a}	21.20±1.23^{a}	3.86±2.15^{a}	52.75±1.11^{b}	4.30±0.86^{b}	17.37±1.85^{a}	4.00±2.01^{a}
LB	52.29±2.15^{b}	3.61±1.56^{a}	18.62±3.6^{a}	3.65±2.83^{a}	53.06±0.44^{b}	3.33±0.^{61b}	15.29±1.57^{a}	6.73±1.52^{a}
GG	54.10±0.17^{ab}	3.97±0.36^{a}	19.34±0.12^{a}	1.70±0.13^{a}	51.62±0.39^{b}	2.48±0.36^{cb}	14.19±0.22^{a}	4.43±0.06^{a}
XG	63.02±2.56^{a}	2.15±0.18^{a}	20.26±1.82^{a}	7.82±2.43^{a}	55.27±0.1^{a}	2.79±0.09^{dbc}	17.15±0.26^{a}	3.45±0.19^{a}
MC	57.00±0.52^{ab}	2.72±0.22^{a}	18.32±0.1^{a}	2.91±0.46^{a}	53.37±1.07^{ba}	3.18±0.14^{bcd}	16.91±1.51^{a}	4.11±1.81a
P	55.70±1.82^{ab}	3.71±1.17^{a}	19.80±0.47^{a}	0.74±1.04^{a}	51.47±0.18^{b}	6.56±0.51^{a}	19.47±0.49^{a}	4.71±0.32a
HPMC	57.13±2.78^{ab}	3.04±0.19^{a}	18.88±1.45^{a}	2.47±1.04^{a}	51.54±1.02^{b}	3.90±0.4^{bd}	17.62±1.13^{a}	4.77±1.49a

NUS - non-ultrasonicated; US - ultrasonicated; C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose. Results are means of triplicate ± standard deviation. Different letters within the same column depict a significant difference ($p<0.05$)

4.4.5 Impact of ultrasonication on moisture redistribution during post-frying holding.

Post-frying holding time under heat lamp caused a significant decrease in the moisture content of the overall, core, and crust portions of fried chicken nuggets coated with ultrasound (US) and non-ultrasound (NUS) formulated batters. Figure 4.3 shows the effect of heat lamp exposure on the overall moisture content of fried chicken nuggets. Generally, the rate of moisture reduction was very pronounced in NUS samples relative to US treated nuggets. This could be due to the lower moisture content reported for US treated samples (ranged between 1.15 and 0.69 g/g, db). Furthermore, Mohammadalinejhad and Dehghannya (2018) observed a low moisture content for potato strip pretreated with ultrasound. The authors attributed their observation to the capacity of ultrasound to create a micro-channel at the early stages of frying that were transformed into larger pores that connected neighboring cells together as frying continued. Heat lamp holding time significantly ($P < 0.05$) affected the moisture content of the fried chicken nuggets with moisture content reducing with post frying holding time under heat lamp. Control samples had the lowest moisture content 1.09 to 0.78 and 0.79 to 0.69 for NUS and US, respectively.

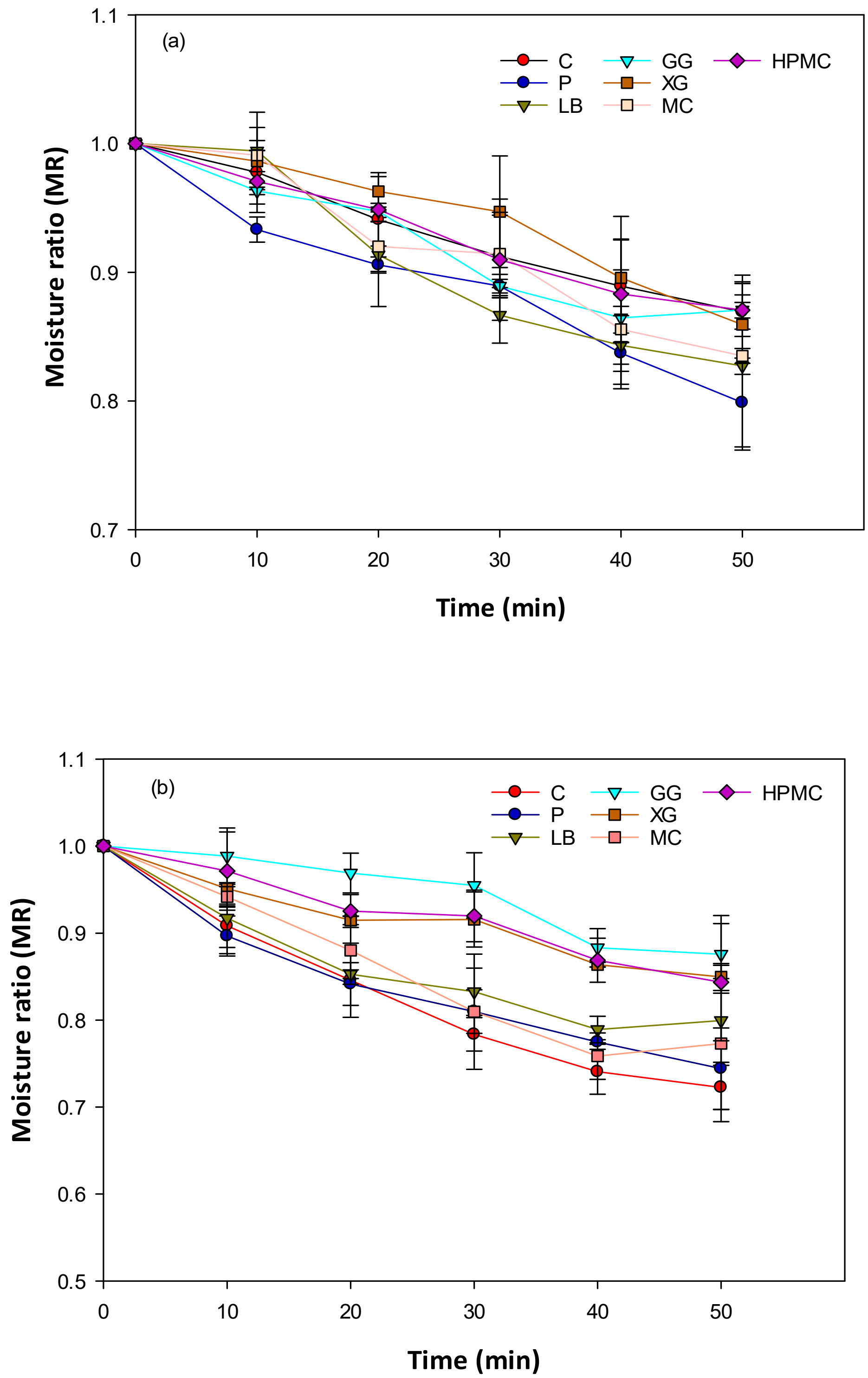


Fig. 4.3: Effect of post-frying holding time on the overall moisture content of chicken nuggets under heat lamp: (a) non-ultrasonicated; (b) ultrasonicated; C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose

For the crust portion, the moisture content of deep-fried chicken nuggets coated with NUS and US treated batters decreased under heat lamp exposure from 0.80 to 0.43 (g/g, db) and 0.80 to 0.36 (g/g, db), respectively (Figure 4.4). Overall, crust moisture content of chicken nuggets without ultrasound treatment produced the sample with the highest moisture content at all post frying holding times, compared to the US treated samples. Specifically, samples formulated with xanthan gum without ultrasound treatment recorded the highest level among all treatments and the control at all post frying holding times. This trend could be attributed to the high batter pickup and viscosity associated with the xanthan gum coated chicken nuggets which decreased the rate of moisture migration to the crust and subsequent evaporation of moisture from the crust. Post frying holding times also had a significant difference in the moisture content of the crust portion, with the moisture content decreasing for both NUS and US treated samples during post frying holding times. This is in accordance with the claims made by Xue and Ngadi (2007) that the migration of moisture in fried food depends on the composition of the batter and microstructure of the crust. A similar decreasing pattern was observed by (Antonova et al., 2003) for chicken nuggets kept under a heat lamp with the moisture content of the deep-fried chicken crust decreasing from 20.73 to 34.36% wb.

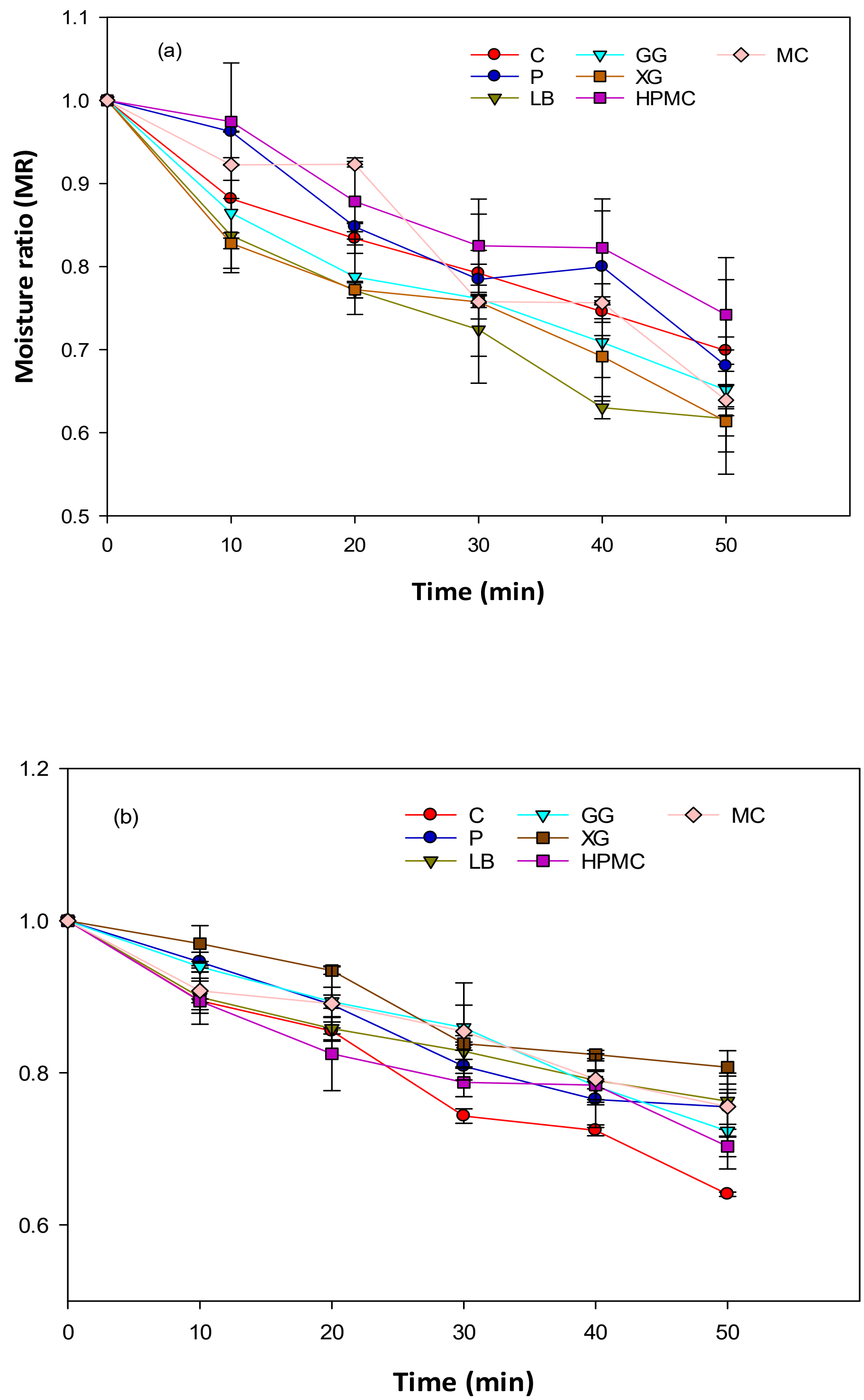
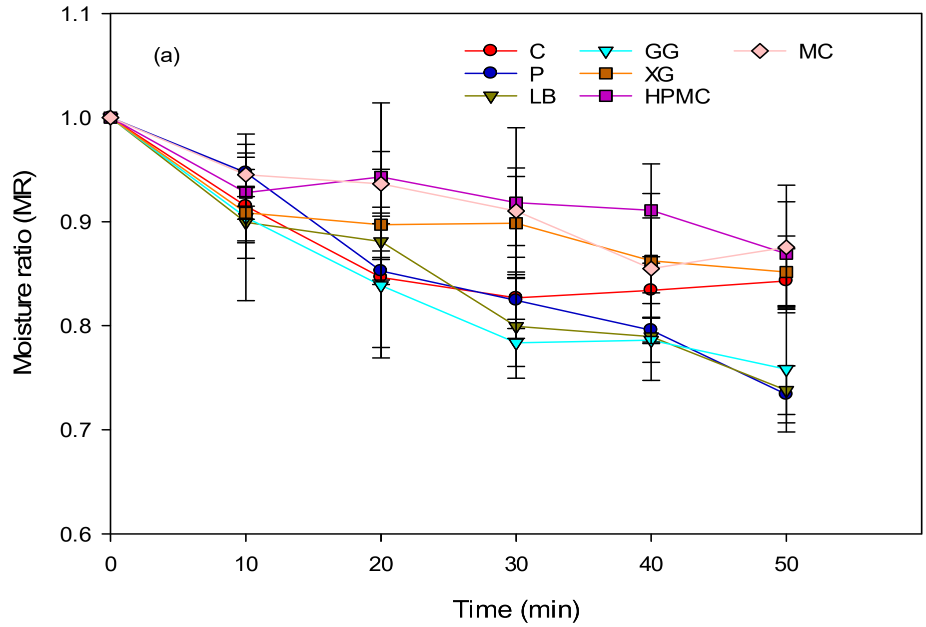


Fig. 4.4: Effect of hydrocolloid and ultrasonic treatment on the crust moisture content of chicken nuggets (a) US crust, (b) NUS crust, C - Control; P - pectin; GG - guar gum; LB - Locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

For the core portion, the moisture content decreased at a lesser rate than the moisture content of the crust during post-frying holding time under heat lamp exposure (Figure 4.5). This low moisture loss rate could be due to the hydrocolloid coating that provided a covering for the core portion. In comparison, the mean moisture content of the core portion of the deep-fried chicken nugget held under various heat lamp holding periods decreased from 2.38 to 1.47 (g/g, db) for the US and 2.35 to 1.82 (g/g, db) for the NUS. For both NUS and US treated samples, nearly all types of formulation with hydrocolloids significantly resulted in high moisture retention relative to control. Similarly, the decrease in the core moisture content for both NUS and the US under heat lamp followed a similar pattern. The findings gathered for moisture loss from the core portions of chicken nuggets are similar to the rates of moisture loss found for chicken nuggets and fried potato strips (Ballard & Mallikarjunan, 2006; Rahimi et al., 2017). The studies indicated a linear decrease in the moisture content of the fried samples held under heat lamp. specifically, Moisture loss from the chicken nuggets exposed to the heat lamp for 30 minutes ranged from 65.2 to 60.3 %, while moisture loss from the potato strip exposed to heat lamp for 15 minutes ranged from 5.44 to 3.81 g/g, db.



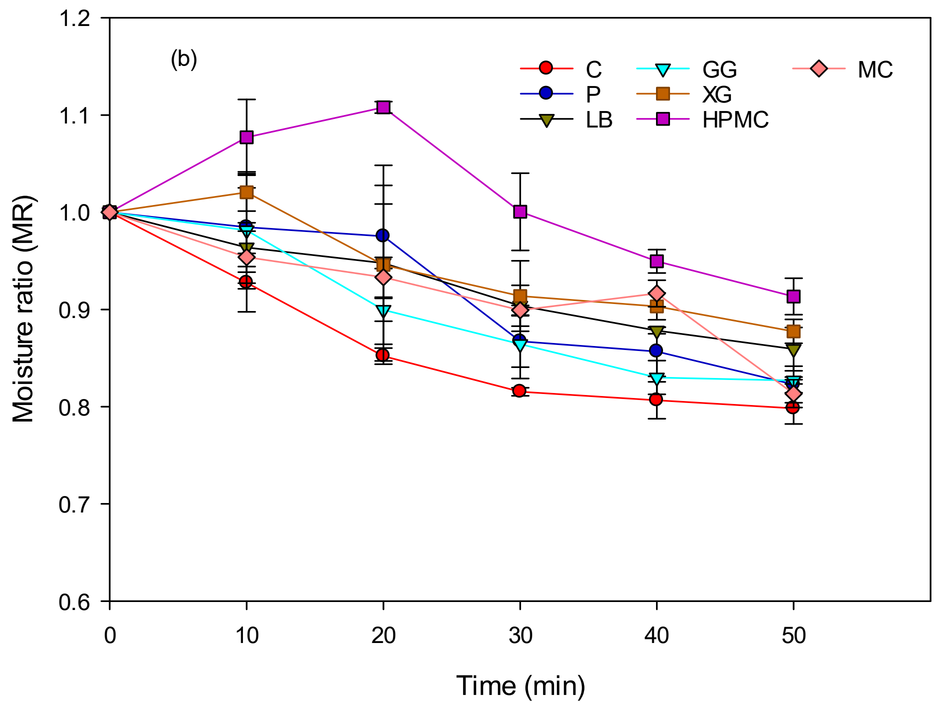


Fig. 4.5: Effect of hydrocolloid type and ultrasonic treatment on the core moisture content of chicken nuggets (a) US core; (b) NUS core; C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

Generally, the crust, core, and overall moisture content of both NUS and US treated samples decreased with post frying holding time under a heat lamp. Samples treated with GG provided the highest moisture content in the core of both NUS and US treated samples. In the same way, xanthan gum also showed the highest moisture content of the sample and the lowest moisture loss from the crust for NUS treated samples. Differences in the moisture content of the US and NUS crusts for each treatment could be due to the cleavage of the batter to the chicken nugget, resulting in less transfer of moisture from the core to the crust during the post frying period under a heat lamp.

4.4.6 Impact of ultrasonication on fat redistribution during post-frying holding.

Fat content is the amount of oil absorbed by a fried food during the frying process. Literature has reported that fried foods absorbed the majority of oil during post frying holding time, i.e the period immediately after frying (Rahimi *et al.*, 2017). Fig. 4.6 shows the effect of ultrasound treatment on the overall fat content of chicken nuggets coated with different hydrocolloid batters. From the results, it can be deduced that ultrasonication in combination with different hydrocolloids significantly reduced the fat content of chicken nuggets. For the overall fat content, the co-application of ultrasound and hydrocolloids reduced the fat content of the different samples by 11.5, 16.4, 45.6, 33.8, 44.3, 26.6, and 7.3% for C, P, LB, GG, HPMC, MC, and XG, respectively. Similarly, Lua *et al.* (2020) recorded a 31.03% reduction in the fat content of batter containing 1% of MC treated with ultrasound. In relation to the control (NUS) sample, the fat content of the NUS was reduced by 11.5, 39.0, 60.9, 64.1, 65.7, 65.0, and 62.87% for C, P, LB, GG, HPMC, MC, and XG, respectively upon ultrasound treatment. Similar result was reported by Oladejo et al. (2017)

where the authors observed between 65 – 75% reductions in the fat content of ultrasound treated sweet potato when compared to the non-ultrasound treated counterpart.

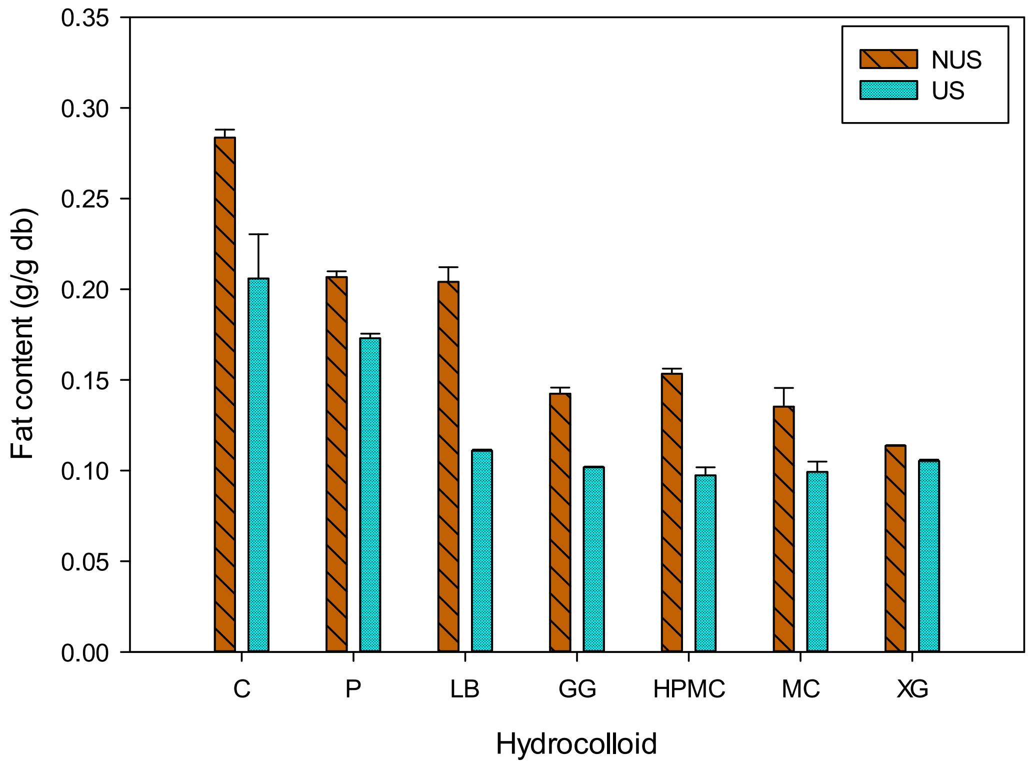


Fig. 4.6: Mean overall fat content of chicken nuggets at 10 min holding time. NUS - non-ultrasonicated; US - ultrasonicated; C - Control; P - pectin; GG - guar gum; LB - Locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methylcellulose.

The fat content of the crust portion of deep fried chicken nugget decreased under heat lamp holding times (Fig 4.7). The surface oil penetrated through the pores into the core portion with the rate depending on post frying holding time and hydrocolloid type. The rate of oil penetration was higher for the control samples probably due to the high porous structure generated by the sample. There were no statistical differences between the crust fat content at 0 and 10 min holding time for most of the treatments. However, a significant reduction was obtained after 10 min holding period, with the product stored for 50 min having the lowest fat content in the crust portion. The fat content of the crust portion of the fried chicken nuggets ranged from 0.36 to 0.16 g/g at 0 min and 0.30 to 0.13 g/g at 50 min storage time for NUS and 0.28 to 0.15 g/g at 0 min and 0.24 to 0.13 g/g at 50 min heat lamp holding time for US. As expected, the lowest crust fat content was recorded for US treated samples and statistical differences were recorded for both post frying holding times and hydrocolloid type.

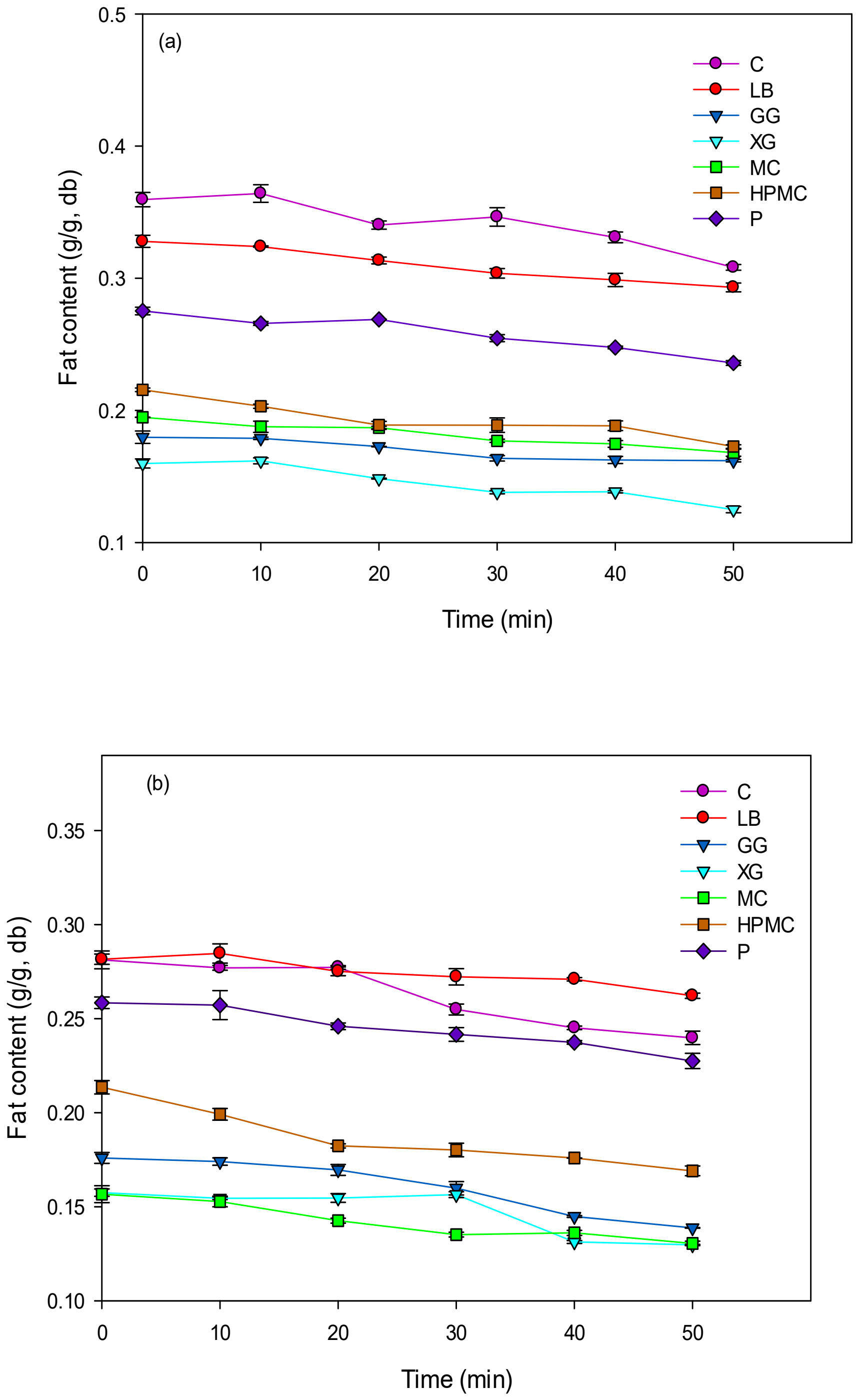


Fig. 4.7: Mean fat content of the crust portion of chicken nuggets a) NUS crust, b) US crust, during post-frying holding time under heat lamp. C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

The average fat content of the core portion of deep-fried chicken nuggets increased under heat lamp holding times (Fig 4.8). The combinative effect of hydrocolloid and ultrasound treatment resulted in a lower core fat content compared to non-ultrasound treated samples. Specifically, the fat content of the core portion of the fried chicken nuggets ranged from 0.06 to 0.04 g/g at 0 min and 0.07 to 0.09 g/g at 50 min storage time for NUS and 0.04 to 0.05 g/g at 0 min and 0.04 to 0.07 g/g at 50 min heat lamp holding time for US. There were no statistical differences between the core fat content at 0 and 10 min holding time for most of the treatments. However, a significant increase was obtained after 10 min holding period, with the product stored for 50 min having the highest fat content in the core portion.

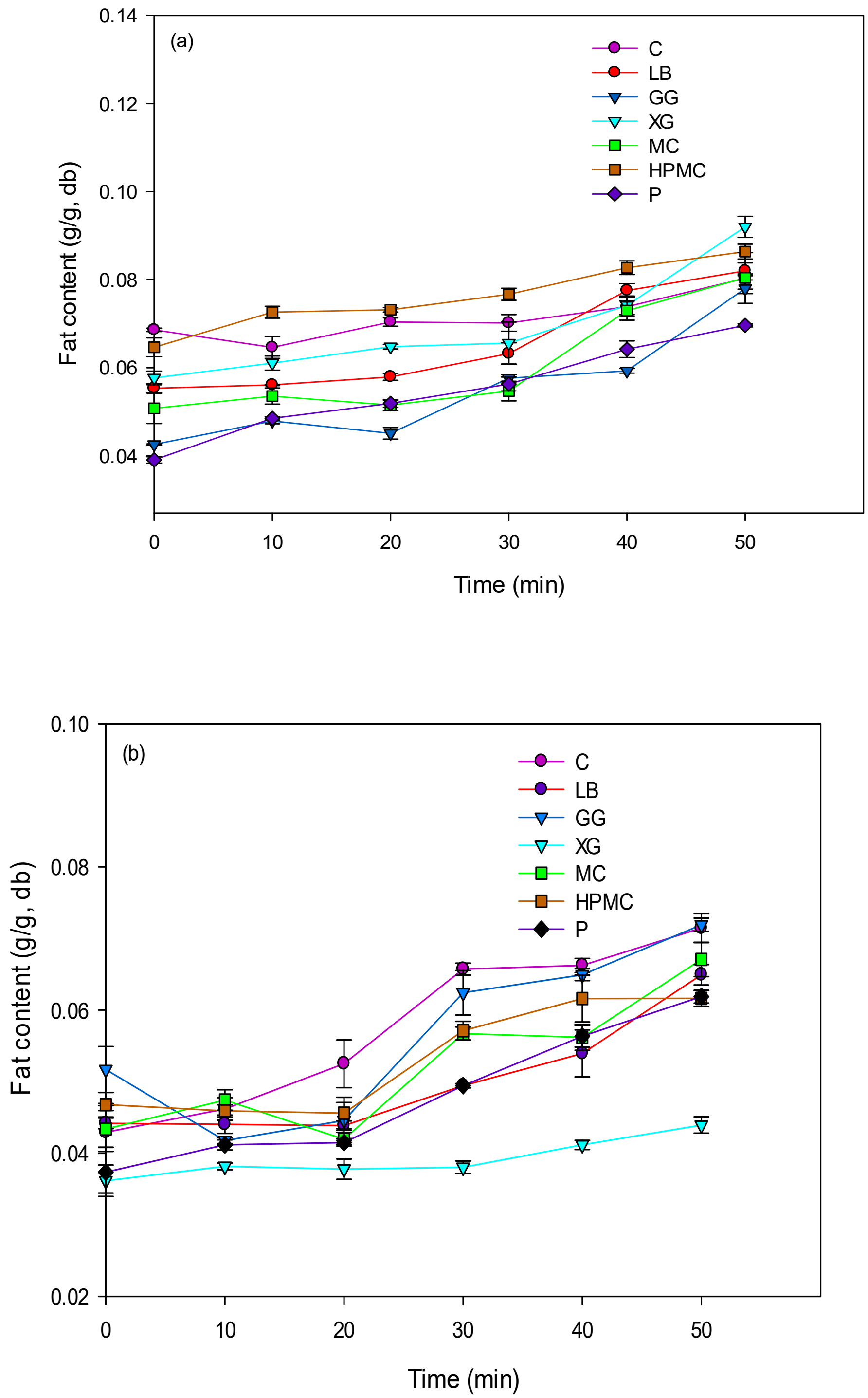


Fig. 4.8: Mean fat content of the core region of chicken nuggets a) NUS core; b) US core, during post-frying holding time under heat lamp. C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methylcellulose.

4.4.7 Effect of ultrasonication on the crispiness of chicken nuggets under heat lamp

Crispiness is one of the well-appreciated textural properties of fried products where consumers are craving a product with a crispy crust and juicy core. The post frying period represents the period between the moment fried products are removed from the fryer and the time they are consumed (Rahimi et al., 2017). During these periods, various textural changes occur due to heat and mass transfer (Troncoso et al., 2009). Figure 4.10 shows the textural attributes of the chicken nuggets coated with the different hydrocolloids and stored for different times under a heat lamp. Significant differences ($p < 0.05$) were obtained for the samples with different coatings. The control (C) had the highest cutting force for both US and NUS treated samples with the cutting force increasing as holding time increases. Xanthan gum presented a sample with the lowest cutting force (between 1.91N to 4.9N for US and 3.09N to 4.31N for NUS). However, for NUS samples, higher cutting force was recorded for some of the samples held for 0 min. Precisely, a higher cutting force was recorded for LB, P, HPMC, and MC at 0 min holding time, however, the cutting force decreased during the first 10 min of exposure to heat lamp and increased thereafter, this could be as a result of rapid moisture loss in the crust portion of the fried chicken nuggets immediately after frying. A similar trend was recorded for deep-fried chicken nuggets at 0 min holding time by (Antonova et al., 2003). Ultrasound treated samples were found to impact the cutting force by producing an exceptionally high cutting force relative to non-ultrasound samples. The increased cutting force for US treated samples could be attributed to the low moisture and reduced fat content of the crust of deep-fried chicken nugget. This is due to the process of cavitation which occurred in the water within or outside the batter cells as ultrasound wave passes through the product, resulting in cell/tissue destruction and the consequent development of cavities and micro channels. The existence of these micro-channels is assumed to be the key effect of ultrasound technologies on the enhancement of mass transfer phenomena in food processing (Miano et al., 2016). From this study, Guar gum was able to maintain the crispiness of fried chicken nuggets held under heat lamp with a cutting force ranging between 4.79 to 5.82N. However, Xanthan gum presented the lowest cutting force at each post frying holding time except for 0 min.

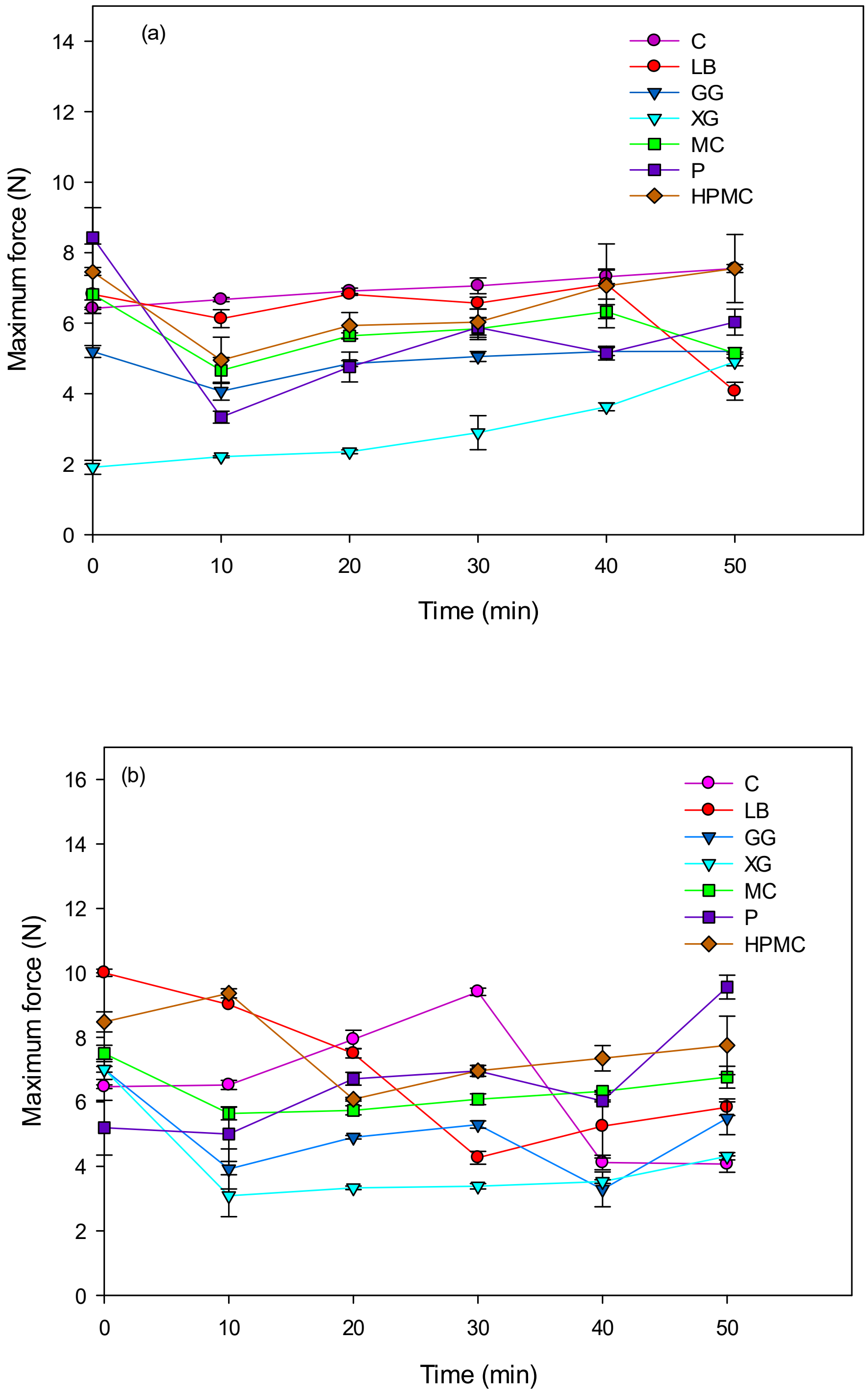


Fig. 4.9: Variation in the breaking force of chicken nuggets during post-frying holding under heat lamp (a) US - ultrasound treated; (b) NUS - non-ultrasound treated; C - control; P - pectin; GG - guar gum; LB - locust bean gum; MC - methylcellulose XG - xanthan gum; HPMC - hydroxypropyl methyl cellulose.

4.5 Conclusion

Hydrocolloid has the potential of influencing various properties of batter and quality of fried chicken nuggets. This research work examined different properties of batter made from wheat flour and corn starch blend fortified with 1% concentration of different hydrocolloids and ultrasonicated for 20 min (20KHz, 500W). From this work, ultrasound had a significant impact on batter pickup, gelatinization profile, and rheological properties of wheat flour-corn starch batter fortified with hydrocolloids. Furthermore, the co-application of ultrasound and hydrocolloids (specifically HPMC and MC) significantly reduced the overall fat content of deep-fried chicken nuggets by 65.68 and 64.99%, respectively when compared with the control sample without ultrasound treatment and hydrocolloid. Additionally, from this study, storage of chicken nuggets under heat lamp significantly ($p < 0.05$) reduced the moisture content, with ultrasonically treated control sample presenting the lowest moisture content of 0.69 g/g, db at 50 min exposure time under heat lamp. However, the ultrasound-treated batter did not improve the crispiness of chicken nuggets when compared with their non-ultrasound counterparts. Overall, the crispiness of the fried product decreased within the 10 minutes after frying and started increasing thereafter. At almost all the holding times, the control sample had the highest crispiness for both NUS and US. Guar gum, on the other hand, produced a sample with less changes in crispiness during post-frying holding. The crispiness of fried chicken nuggets was improved and maintained with ultrasound-treated batter.

CHAPTER FIVE

5. SUMMARY AND CONCLUSIONS

Chicken nugget is a good delicacy for many consumers, even though this product is well accepted by consumers due to the different qualities they possess (flavor, texture, and quick cooking time), the high fat content deposited in this product during frying and the loss of crispiness after frying has led to dissatisfaction among consumers due to their health concerns and perception of the quality of fried foods. In order to offer a new approach to these problems, the use of hydrocolloids is one of the key strategies used to minimize fat uptake. While cellulose-derived hydrocolloids have been shown to be effective in reducing the fat content of fried foods to some degree; numerous problems, such as toxicity, non-degradability and high purchasing costs, have restricted their use in the food industry. Furthermore, consumers are concerned about their wellness and are more interested in food prepared with natural ingredients. New alternative methods and hydrocolloids from natural sources have become a new area of exploration. The use of hydrocolloid in batter coatings has proved to be one of the effective ways of improving the crispiness of fried foods due to their thermal gelling properties and water binding capability, which prevent the absorption of oil and maintain high moisture, thereby producing a product with a crispy crust and juicy core. Similarly, emerging innovations such as ultrasound have also been used as a method to combat the high fat content in fried foods and have been found to be effective in reducing fat content. However, the effect of this treatment on the crispiness of fried products has not been established.

So far, several studies have focused on the use of hydrocolloids in reducing fat absorption in fried foods. In this study, the crispiness of fried chicken nuggets was investigated using six different hydrocolloids, subjecting them to ultrasound treatment, and comparing the effect of two frying methods (air frying and deep fat frying) and the following conclusions are drawn from the research carried out:

1. In the first experimental study, the effect of different hydrocolloids and two frying methods (deep fat frying and air frying) were studied. During post frying holding, chicken nuggets fried with deep fat frying was compared with chicken fried with air frying when stored under heat lamp for 0, 10, 20, 30, 40, and 50 minutes. It was discovered that post frying holding time under heat lamp significantly $p<0.05$ affected the crispiness of the fried chicken nuggets. The changes in crispiness depended on the type of hydrocolloid used and the frying method. Air frying presented the sample with the highest crispiness at almost every post frying holding time. Air fried samples also produced the sample with the lowest moisture content and fat content when compared with deep fried samples. In Particular, air frying was able to reduce the fat content of the samples by about 17% to 37.5% depending on the type of hydrocolloid used.
2. In the second experimental study, the co-impact of the different hydrocolloids and ultrasonication was studied on the properties of deep-fried chicken nuggets stored under heat lamp for 0 10, 20, 30, 40, and 50 minutes. The result showed that the combination of ultrasound treatment and hydrocolloid significantly reduced the fat content by 60.9, 64.1, 65.7, 65.0, and 62.87% for GG, HPMC, MC, and XG, respectively. Furthermore, the effect of ultrasonication on the crispiness of fried chicken nugget was increased, this is probably due to the lower moisture content that was obtained for ultrasound treated samples.

3. Hydrocolloid was effective in controlling various properties of the formulated batter such as batter pickup, viscosity, and gelatinization enthalpy. Specifically, the batter pickup and viscosity of samples containing hydrocolloid significantly increased. However, the gelatinization enthalpy was reduced. Furthermore, the combinative effect of hydrocolloid and ultrasonication significantly reduced the viscosity of the formulated batters and presented samples with lower batter pickup, viscosity, and gelatinization enthalpy compared to samples without ultrasound treatment.

5.1 Suggestions for Future Studies

1. This study used a single frying time and temperature; perhaps, frying at different times and temperature could help in reducing moisture and fat redistribution during post frying storage.
2. Secondly, since hydrocolloids are known for their thermo-gelling properties and water binding capability, further studies should be performed on the functionality of composite of different hydrocolloids to enhance the different properties of batter and fried chicken nuggets.
3. Thirdly, a study on the application of ultrasound pretreatment on the various batters formulated with hydrocolloids at different ultrasonication times and amplitudes could further improve the stability of fried chicken nuggets during post frying holding.
4. A study of the effects of ultrasonically treated hydrocolloids combined with par-frying (air frying) could be studied.

5. Also, other methods of quantification of moisture content and fat content and their redistribution during post-frying operations could be studied using instruments such as MRI and NMR.

CHAPTER SIX

6. BIBLIOBGRAPHY

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