Original Research Article

Sorption isotherm and effect of packaging materials on organoleptic properties, proximate composition and lipid oxidation of chicken nuggets stored at different temperatures.

ABSTRACT

The study Investigated sorption isotherm features and the effects that packaging made from both high-density and low-density polyethylene exerts on sensory properties and lipid oxidation of chicken nuggets in storage. Analyses were carried out according to standard procedures. The investigation showed that sensory qualities, proximate composition and lipid oxidation of chicken nuggets were markedly affected by the variance in temperature settings, with distinct disparities seen among different materials for packaging. Chicken nuggets stored at higher temperature caused a significant loss in organoleptic properties and some nutritional composition such as protein and fat. Increase in temperature also caused increase in malondialdehyde value as compared to chicken nugget stored at lower temperature. The water activity and monolayer moisture results of sorption analysis revealed that good packaging materials of very low water vapour transmission rate should be used for storage of chicken nuggets as high-density polyethylene offered a promising alternative than low density polyethylene.

Keywords: Flavour, Malondialdehyde, Polyethylene, Proximate, Water activity

1.0 INTRODUCTION

Chicken nuggets, a famous fast-food item (1), present both nutritional benefits and loss concerns. Chicken nuggets are enjoyed by people of all ages, with various flavors and coatings available to suit different preferences. Despite their widespread availability and popularity, the sorption characteristics of the product need to be studied. Sorption isotherm is a critical concept in the field of food science and engineering (2), specifically in the study of moisture absorption by food products such as chicken nuggets. The understanding of this relationship between the equilibrium moisture content of a food product and the water activity of its surrounding environment is essential for predicting the shelf-life of

food products, determining their stability, and optimizing their processing conditions (3,4). By analyzing the sorption isotherm of chicken nuggets, valuable insights into the moisture sorption behavior of this popular food item, which can ultimately inform strategies for improving its quality and extending its shelf-life can be evaluated.

Stability determinants in processed foods play a crucial role in maintaining product quality and safety over an extended period (5). Factors such as water activity, pH, packaging materials, storage conditions, and microbial contamination can significantly impact the stability of processed foods (6). It is essential to understand the interactions between these determinants in order to establish effective shelf-life prediction models for specific food products. Additionally, studying the impact of packaging materials on moisture migration and oxygen barrier properties can help optimize packaging design to extend the shelf-life of chicken nuggets. Packaging plays a critical role in influencing the shelf-life of food products by protecting them from external factors such as moisture, oxygen, light, and microbial contamination (7,8). In the case of chicken nuggets, the type of packaging used can affect the equilibrium sorption isotherm and ultimately the shelf-life stability of the product. For example, packaging materials with high moisture barrier properties can prevent moisture loss or gain, which is crucial for preserving the texture and flavor of the chicken nuggets (9). Therefore, investigating the influence of packaging on the shelf-life of chicken nuggets is essential for ensuring the quality and safety of the product for consumers. Overall, a comprehensive understanding of stability determinants in processed foods is essential for ensuring product quality, safety, and consumer satisfaction.

Chemical changes in food products can significantly impact their shelf-life stability, sensory attributes, and overall quality. In the case of chicken nuggets, various chemical reactions may occur during storage, leading to changes in flavor, texture, and nutritional content (10). For example, lipid oxidation, protein denaturation, and Maillard browning are common chemical processes that can occur in chicken nuggets over time, affecting their color, taste, and nutritional value (11). Understanding the chemical changes taking place in chicken nuggets is crucial for designing appropriate packaging materials and storage conditions to extend their shelf-life and maintain product quality. Physical changes in chicken nuggets can occur during storage due to various factors such as moisture migration, lipid oxidation, and protein

denaturation. Moisture migration can lead to changes in texture, resulting in a loss of crispness and a decrease in overall quality (12).

Research has shown that sensory changes can greatly impact the quality and shelf-life stability of food products such as chicken nuggets (13). These sensory changes can occur due to various factors including oxidation, microbial growth, and storage conditions. As chicken nuggets age, they may experience color changes, off-flavors, texture modifications, and a decrease in overall palatability. Understanding and monitoring these sensory changes is crucial for determining the shelf-life of chicken nuggets and ensuring consumer satisfaction. By studying the equilibrium sorption isotherm and sensory changes of chicken nuggets, researchers can gain valuable insights into the factors affecting their quality over time.

Previous studies on meat products have primarily focused on their nutritional content, sensory attributes, and production methods with limited information on its sorption characteristics and nutritional changes in storage. For example, a study by Alugwu*et al.* (14) investigated the effect of different frying techniques on the nutritional quality of chicken breast meat. They found that air frying Chicken breast meat resulted in higher cooking yield and lower fat content than when deep fat frying method.

The research objectives of this study are twofold. Firstly, the study aims to determine the equilibrium sorption isotherm of chicken nuggets to understand the moisture absorption behavior of the product. This is crucial for predicting the shelf-life stability of chicken nuggets under different storage conditions. Secondly, the study seeks to investigate the effect of packaging materials on the shelf-life of chicken nuggets by analyzing the changes to nutritional composition sensory characteristics and lipid oxidation in storage. By achieving these objectives, this research will contribute to the understanding of the factors influencing the shelf-life of chicken nuggets and provide valuable information for improving the product's packaging and storage practices

2.0 MATERIALS AND METHODS

2.1 Preparation of Chicken nuggets

1000g of boneless chicken breast was procured from Bolab Farm, Ado Ekiti, Nigeria. This was cut into sizeable weight of 50g each, dried ingredients for coating were measured into a separate mixing bowl; 100g of all-purpose flour, 1g of common salt, 2g of garlic powder, 1g of ginger powder, 2g of guava leaf powder, 2g of bitter leaf powder, 1g of oregano, 1g of baking powder and 2g of chili pepper. 2 large table size eggs were cracked, beaten and used as a binder. Each chicken cut was dipped into the beaten eggs, pressed into the flour containing all ingredients and allowed to be coated properly.Excess flour was shaken off. Coated chicken cuts were fried with canola oil in a large skillet in batches at temperature of 180^{o}C and cooked until 72^{o}C internal temperature was obtained using meat thermometer.

2.2 Procedure of Adsorption

The experimental setup for sorption isotherm analysis in this study involved using a gravimetric method to determine the water sorption behavior of chicken nuggets at various equilibrium relative humidity levels. Five (5g) grams of oven-dried chicken nugget samples were placed in a controlled humidity chamber, and the weight changes of the samples were monitored until equilibrium was reached. The sorption isotherm data obtained from this experimental setup were then fitted to GAB mathematical model to evaluate the sorption behavior of chicken nuggets. The determination of the equilibrium moisture content was carried out by oven dry method, the sample was dried at 105 °C for 24 h. All the experiments were carried out in triplicate. Ten saturated salt solutions prepared ranged between 0.030 to 0.970. The water activities and the salt solutions used were as reported (15) and this is as given in Table 1. For the chicken nugget to attain equilibrium moisture content, the experiment was set at 15 °C.

Table 1: Saturated salt solution used for sorption studies.

Salt	aw (15^{0}C)
Cesium Flouride	0.043
Lithium Chloride	0.113
Potassium Acetate	0.234
Magnesium Chloride	0.333

Potassium Carbonate	0.432
Sodium Bromide	0.607
Sodium Chloride	0.756
Potassium Chloride	0.859
Potassium Sulfate	0.979

2.2.1 Determination of water activity and monolayer moisture

Water activity and monolayer moisture value of the product were determined according to GAB equation (17) which was rearranged into second degree polynomial for the determination of water activity and monolayer

GAB Equation = $= \frac{M}{Mm} = \frac{ABaw}{(1-Baw)(1-Baw+ABaw)}$(16) …… Equation 1

Mo – Monolayer value = $1/\sqrt{b^2 - 4ac}$ …… Equation 2

$a_w = a_w/M$ = Equation of line=y …… Equation 3

2.2.2Determination of equilibrium moisture content

Determination of equilibrium moisture content was carried out as stated below:

$\mathrm{EMC} = \frac{We}{Wi}(\mathrm{Mi}+1) - 1$ (Tantala et al., 2019) (18) ……..Equation 4

where We is the equilibrium weight of the sample (g), Wi is the initial weight of the sample (g), and Mi is the initial moisture content of the sample (g)

2.3 Sensory evaluation of Chicken nuggets

The sensory assessment was evaluated using a 9- point hedonic scale ranked as follows; like extremely to very much (8–9 scores), like moderately to like slightly (5–7 scores), neither like nor dislike to dislike slightly or dislike moderately (2–4 scores) and dislike extremely to dislike very much (0–1 score) for,

tenderness, texture, aroma, flavor and over all- acceptability. A ten member of semi-trained taste panelist of both sexes were engaged in the assessment of sensory properties of this product. The assessors were placed in an individual unit cell and each person was given unsalted biscuits and fresh orange juice to cleanse palate after each taste of the sample. Samples were coded and independently evaluated (19).

2.4Proximate composition determination of Chicken nuggets

The proximate composition of the chicken nuggets samples was determined according to the methods of the Association of Official Analytical Chemists (AOAC). All analyses were conducted in triplicate to ensure reliability (20).

2.5 Lipid oxidation

Malondialdehyde (MDA) levels as a marker of lipid oxidation was measured with thiobarbituric acid reactive substances (TBARS) assay (21).

2.6 Stability assessment

Chicken nugget used for stability assessment was packaged in four different packaging materials. The packaging materials include high-density polyethylene (HDPE) of 10µm and 20µm thickness and low-density polyethylene (LDPE) of 10µm and 20µm thickness. These were stored in the refrigerator at 4 ℃ *and 25℃*4 ℃for 30 days.

2.7 Statistical analysis

Statistical analysis was carried out using IBM SPSS Statistics 20, One-way ANOVA Post Hoc Multiple Comparisons of Ryan-Einot-Gabriel-Welsch F' test at 0.05 significance level (22)

3. RESULTS AND DISCUSSION

The results interpretation of the equilibrium sorption isotherm and shelf-life stability of chicken nuggets study revealed that the product exhibited type IV isotherm behavior, which provides valuable insights into the adsorption behavior of water onto chicken nuggets. The obtained data show that the adsorption process follows a typical monolayer adsorption mechanism, where water molecules form a multilayer on the surface of the nuggets. This type of isotherm is often observed in porous materials with heterogeneous surfaces, where the formation of multiple layers of adsorbates takes place (23). The equilibrium moisture content of chicken nuggets ranged from 25.36% to 71.25%, covering a range of 0.043 to 0.979 water activity respectively, suggesting a relatively high-water content. The shelf-life stability assessment indicated that chicken nuggets stored at 4°C maintained an acceptable quality for up to 30 days, based on sensory evaluation and moisture content analysis. These findings suggest that equilibrium sorption isotherms and shelf-life stability are crucial factors to consider in the formulation and storage of chicken nuggets to ensure product quality and consumer satisfaction.

In this study, water adsorption by chicken nuggets seems to be more of multilayer condensation than chemisorption and physical adsorption. This is implied because the monolayer value of 59.77 (g H_2O / g Solid) for chicken nugget falls in the region C of sorption isotherm where water is loosely bond to chicken nugget with much water held in large capillaries. This water may be much available for chemical reaction, microbial spoilage especially if this product is stored 0.1 above its water activity. The calculated values of the maximum monolayer adsorption capacity (qm) indicate the maximum amount of water that can be adsorbed by the nuggets at equilibrium. The equilibrium sorption isotherm data obtained in this study, suggest that the adsorption of water either strongly or loosely bind onto the chicken nuggets is a multilayer process, as evidenced by the non-linear relationship between water activity and moisture content (24). Additionally, the shelf-life stability studies at 25^0 C demonstrate that the moisture content of the nuggets remains relatively constant over time with different packaging materials investigated, indicating that the product is comparably stable under ambient storage temperature.

The findings of the study of sorption isotherm have several implications for food industry. Understanding the sorption isotherms of chicken nuggets can aid manufacturers in designing appropriate packaging materials and storage conditions to maintain product quality and extend shelf-life. By determining the

equilibrium moisture content at different relative humidities, producers can optimize packaging materials to prevent moisture migration and reduce the risk of microbial growth or lipid oxidation. These insights can ultimately help the food industry ensure the safety and sensory attributes of chicken nuggets throughout their distribution and consumption.

Table 2: Sorption Isotherm of Chicken Nuggets

aw (15^0C)	EMC	aw/M
0.043	25.36	0.0017
0.113	26.34	0.0043
0.234	37.62	0.0062
0.333	40.32	0.0083
0.432	55.15	0.0078
0.607	69.36	0.0088
0.756	69.55	0.0108
0.859	70.13	0.0123
0.979	71.25	0.0137

EMC- Equilibrium moisture content, a_{w-} Water activity, $a_{w/}$M- Water activity of moisture

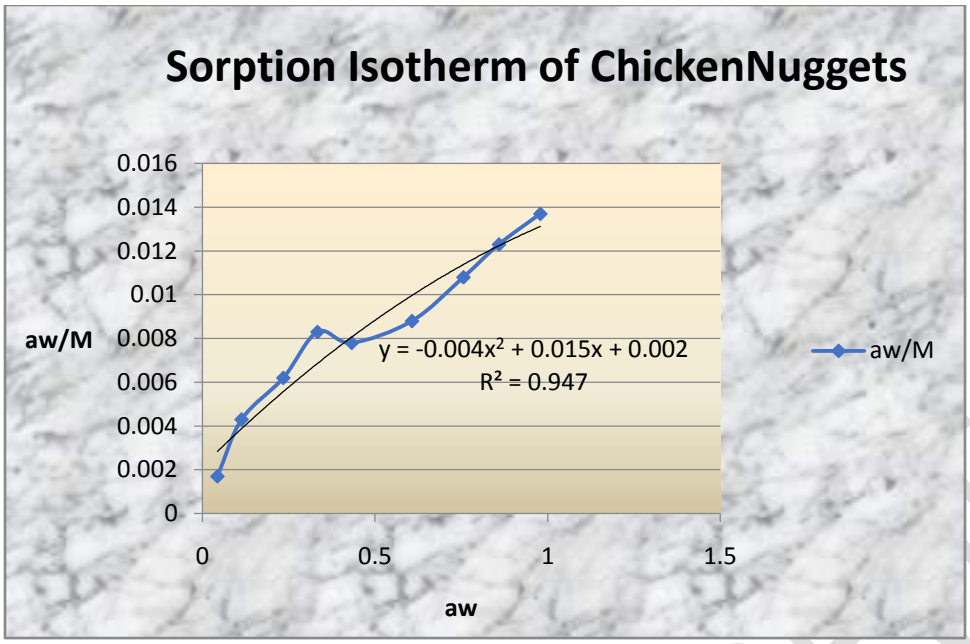

Figure 1: Adsorption Isotherm Curve of Chicken Nuggets

Table 3. Analysis of sorption data of Chicken Nuggets according to GAB Model

Product sample	Water activity (a_w)	Monolayer value (Mo) (g H_20/g Solid)	R^2(Fitness of curve)
Chicken Nuggets	0.5759	59.77	0.947

Figure 2. Sample of chicken nugget product

Table 4. Proximate composition of fresh fried chicken nuggets

Component	Composition (%)	SEM
Crude protein	48.67	0.333
Moisture content	38.07	0.000
Ash	3.83	0.333
Fat	6.17	0.000
Carbohydrate	3.43	0.333

Table 5. Oxidative stability of fresh fried chicken nugget

Parameter	Composition	SEM
TBARS (MDA/Kg meat)	0.167	0.000

TBARS- Thiobarbituric Acid-Reactive Substance, SEM- standard error of mean, MDA- Malondialdehyde.

Table 6. Sensory properties of fresh fried chicken nugget

Sensory properties	Mean value	SEM
Flavour	7.17	0.543
Aroma	7.33	0.422
Juiciness	6.33	0.365
Texture	6.17	0.477
Tenderness	6.17	0.477
Overall acceptability	7.5	0.563

SEM- standard error of mean

Table 7. Effects of packaging materials on sensory properties of chicken nugget stored at different temperatures for 30 days

Packaging materials	Sensory properties of chicken nugget stored at 4 ^{0}C Mean + SEM						Sensory properties of chicken nugget stored at 25 ^{0}C Mean + SEM					
	Ar	Fl	Tx	Tend	OA	Ju	Ar	Fl	Tx	Tend	OA	Ju
HDPE (20µm)	8.17 ±0.31^c	7.67 ±0.2^b	7.50 ±0.34^c	5.50± 0.22^a	6.83 ±0.31^b	6.28 ±0.003^d	6.17 ±0.31^c	5.67 ±0.21^b	5.50 ±0.34^c	3.50 ±0.22^a	4.83 ±0.31^b	5.18 ±0.003^d
HDPE (10µm)	6.83 ±0.31^b	5.50 ±0.22^a	6.00 ±0.37^b	5.16 ±0.31^a	6.50 ±0.22^b	6.03 ±0.033^c	4.83 ±0.31^b	3.50 ±0.22^a	4.00 ±0.37^b	3.17 ±0.31^a	4.50 ±0.22^b	5.04 ±0.043^c
LDPE (20µm)	5.67 ±0.33^a	5.00 ±0.26^a	5.33 ±0.21^{ab}	4.83 ±0.31^a	5.33 ±0.21^a	5.55 ±0.029^b	3.67 ±0.33^a	3.00 ±0.26^a	3.33 ±0.21^{ab}	2.83 ±0.31^a	3.33 ±0.21^a	4.46 ±0.019^b
LDPE (10µm)	5.33 ±0.21^a	4.67 ±0.33^a	4.50 ±0.34^a	4.66 ±0.33a	5.17 ±0.31^a	5.11 ±0.003^a	3.50 ±0.22^a	2.67 ±0.33^a	2.50 ±0.34^a	2.67 ±0.33^a	3.17 ±0.31^a	4.12 ±0.009^a

SEM- Standard error of mean, Ar- Aroma, Fl- Flavour, Tx- Texture, Tend- Tenderness, OA- Overall acceptability, Ju- Juiciness, HDPE- High density polyethylene, LDPE- Low density polyethylene

Table 8. Effects of packaging materials on proximate composition of chicken nugget stored at different temperatures for 30 days

Packaging materials	Proximate composition of chicken nugget stored at 4 ^{0}C					Proximate composition of chicken nugget stored at 25 ^{0}C				
	Protein	Fat	Ash	MC	CHO	Protein	Fat	Ash	MC	CHO
HDPE (20µm)	48.53 ±0.012^b	6.08 ±0.006^a	4.32 ±0.116^d	37..75 ±0.012^c	3.41 ±0.006^d	46.43 ±0.006^d	5.66 ±0.006^d	7.11 ±0.006^a	35.41 ±0.006^a	5.39 ±0.006^a
HDPE (10µm)	48.49 ±0.007^a	5.98 ±0.006^b	4.82 ±0.006^c	36.87 ±0.012^d	3.84 ±0.006^c	44.11 ±0.006^c	5.42 ±0.095^c	8.71 ±0.006^b	33.78 ±0.012^b	7.98 ±0.006^b
LDPE (20µm)	48.21 ±0.003^c	4.88 ±0.006^c	6.70 ±0.006^b	35.89 ±0.003^b	4.32 ±0.006^b	43.12 ±0.000^b	3.91 ±0.000^b	10.98 ±0.006^c	32.34 ±0.000^c	9.65 ±0.000^c
LDPE (10µm)	47.10 ±0.006^d	4.53 ±0.006^d	7.12 ±0.000^a	35.33 ±0.006^a	4.65 ±0.012^a	42.33 ±0.116^a	3.43 ±0.006^a	11.83 ±0.000^d	31.62 ±0.012^d	10.79 ±0.012^d

SEM- Standard error of mean, MC- Moisture content, CHO- Carbohydrate, HDPE- High density polyethylene, LDPE- Low density polyethylene

Table 9. Effects of packaging materials on lipid oxidation of chicken nugget stored at different temperatures for 30 days

Packaging materials	Lipid oxidation at 4 ^{0}C	Lipid oxidation at 25 ^{0}C
	TBARS (MDA/Kg meat)	TBARS (MDA/Kg meat)
HDPE (20µm)	0.1700±0.00289^b	0.5233±0.00333^a
HDPE (10µm)	0.2233±0.00882^b	0.5533±0.00333^b
LDPE (20µm)	0.2413±0.10403^{ab}	0.6367±0.00333^c
LDPE (10µm)	0.4270±0.00351^b	0.8133±0.00333^d

HDPE- High density polyethylene, LDPE- Low density polyethylene, TBARS- Thiobarbituric Acid-Reactive Substance, MDA- Malondialdehyde

The study of the effects of packaging materials on the proximate composition of chicken nuggets stored at different temperatures for 30 days provided valuable insights into the impact of packaging on food composition quality (25). The results indicate that the type of packaging material used can significantly

affect the composition of chicken nuggets, with clear differences observed in terms of moisture content, protein levels, and lipid oxidation. Also, the storage temperature plays a crucial role in determining the rate of deterioration of these properties, highlighting the need for careful consideration when selecting packaging materials for food products (26). This study underscores the importance of composition of food products, the packaging materials and storage conditions in ensuring the maintenance of optimal quality and safety standards for consumers.

Additionally, the findings of this study highlight the significant impact of packaging materials on the lipid oxidation of chicken nuggets during storage at various temperatures for an extended period. The results demonstrate that the type of packaging used can greatly influence the rate of lipid oxidation, with oxygen permeable packaging leading to increased oxidation compared to barrier packaging (27). This suggests that selecting the appropriate packaging material is crucial in preserving the quality and shelf life of the product. Furthermore, the effect of temperature on lipid oxidation was also established, with higher temperatures accelerating the oxidation process. As such, careful consideration should be given to both packaging materials and storage conditions to minimize lipid oxidation and maintain the sensory attributes of chicken nuggets. Future research could delve into more specific packaging materials and temperature combinations to optimize the preservation of lipid quality in poultry products.

The comparison of lipid oxidation levels in chicken nuggets stored under different packaging materials and temperatures yielded insightful results. Chicken nuggets stored in high-density polyethylene packaging materials at 4°C, has their lipid oxidation levels significantly lower compared to those stored in low-density polyethylene packaging materials at the same temperature (28). However, at 25°C, the differences in lipid oxidation levels between the packaging materials were pronounced. This suggests that the type of packaging material plays a crucial role in maintaining the lipid quality of the chicken nuggets. These findings highlight the importance of selecting appropriate packaging materials to extend the shelf life of food products and minimize lipid oxidation.

The results of the effects of packaging materials on the sensory properties of chicken nuggets stored at different temperatures for 30 days revealed important insights. The results indicate that the type of packaging material used significantly influences the sensory attributes of the chicken nuggets over time.

Sensory spoilage, such as changes in flavor and odor, can precede microbiological spoilage in foods (29). It was observed that certain packaging materials helped maintain the quality of the product, while others led to a deterioration in sensory properties such as taste, aroma, and texture. Therefore, selecting appropriate packaging materials tailored to specific storage conditions is essential in preserving the sensory quality of food products over time. Additionally, variations in storage temperatures further impacted the sensory profiles of the chicken nuggets (30,31). These findings underscore the importance of selecting appropriate packaging materials and storage conditions to ensure the preservation of sensory qualities in food products. At lower temperatures, where oxidation is reduced, the sensory properties were more preserved compared to storing at higher temperatures where degradation may accelerate (32). The comparison of sensory properties of chicken nuggets stored in various packaging materials at different temperatures is essential in understanding the impact of packaging on chicken nuggets. It can be suggested that storage at higher temperatures can lead to faster deterioration of sensory attributes such as crispiness and juiciness, while lower temperatures may help preserve these characteristics for an extended period. Also, the use of oxygen barrier packaging can help preserve the freshness and flavor of chicken nuggets by reducing lipid oxidation and maintaining the product's sensory characteristics (33)

4. CONCLUSION

The study highlights the importance of understanding the sorption behavior of food products and the need for appropriate storage conditions to maintain product quality over an extended period. The findings of this study suggest that the choice of packaging materials significantly influences the quality of chicken nuggets during storage. The results indicate that packaging materials can have varying effects on the sensory attributes, proximate composition and lipid oxidation of chicken nuggets over time. Specifically, high-density polyethylene showed the most favorable outcomes in terms of maintaining product quality. These results underscore the importance of selecting appropriate packaging materials to ensure the preservation of chicken nugget quality during storage. Overall, this study provides valuable insights for food manufacturers and retailers seeking to improve the quality and shelf stability of their chicken nugget products.

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