**Food and Nutrition Sciences, 2016, 7, 895-905**
Published Online August 2016 in SciRes. http://www.scirp.org/journal/fns
http://dx.doi.org/10.4236/fns.2016.710089

# Shrinkage and Density Change of De-Boned Chicken Breast during Deep-Fat Frying

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Received 28 June 2016; accepted 27 August 2016; published 30 August 2016



## Abstract

**The effects of frying oil temperature (FOT) and time on densities and shrinkage in chicken breast meat during deep-fat frying were investigated. De-boned Chicken breast samples were diced and fried at different FOT (170˚C, 180˚C, and 190˚C) in an industrial fryer for periods varying from 5 to 900 s. Bulk and apparent densities were determined with a fluid displacement pycnometer, and fat analysis was conducted using soxhlet extraction with petroleum ether solvent. The physical structure of chicken meat changed significantly with the frying time and FOT ($P < 0.001$). Bulk density was 1.15 g/cm$^3$ in the raw product and decreased to 0.98, 0.95, and 0.93 g/cm$^3$ after 900 s of deep-frying at 170˚C, 180˚C and 190˚C, respectively. Similarly, apparent density changed from 1.13 to 1.25, 1.24 and 1.22 g/cm$^3$ and moisture loss was linearly correlated with both densities. Volumetric shrinkage was significantly ($P < 0.05$) affected by the process variables and hence a linear correlation also existed with moisture loss. The rates of shrinkage were 0.013, 0.001, and 0.008/s and occurred rapidly during the first 90s of FOT (170˚C, 180˚C, and 190˚C), respectively and decreased as frying time increased.**

## Keywords

**Pore, Frying, Shrinkage, Density, Chicken Meat**

## 1. Introduction

During deep-fat frying, the transfer of heat to the product results in opposite mass transfers, hence resulting to the expulsion of water and intrusion of oil, as mediated by the food product's physical characteristics [1] [2].

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**How to cite this paper:** Kassama, L.S. and Ngadi, M. (2016) Shrinkage and Density Change of De-Boned Chicken Breast during Deep-Fat Frying. *Food and Nutrition Sciences*, **7**, 895-905. http://dx.doi.org/10.4236/fns.2016.710089

This distinguishes frying from drying, baking and other thermal processes. When heat is applied to food components, morphological changes occurs as a result of moisture loss which is manifested by the change in density, development of pores and eventually the occurrence of shrinkage [2]-[4]. Therefore, the influence of physical properties of fried product is critical to food quality [1] [3].

In meat, the change in the connective muscle tissues during cooking may be attributed to shrinkage phenomenon due to the dehydration of the molecular bonding of the protein structure and changes in other intrinsic properties [2]. Volumetric variation as a result of protein degradation is a factor that modulates density, hence influenced by several factors such as geometry [5] [6]), drying methods [7]) and experimental conditions [8]. Parez and Calvelo [9] reported an apparent densities for beef to be 0.920 and 1.053 g/cm$^3$ at moisture contents of 4.7% and 74% wet basis (wb), and. 1.180 and 1.053 g/cm$^3$ at moisture content of 0.5% and 74% wb, respectively, *i.e*. meat density increases with increase in moisture content.

Porosity changes as result of shrinkage during thermal processing and is dependent on initial moisture content, composition and size of food materials, type of drying (freeze-dried or air dried) and drying conditions such as temperature and relative humidity [10] [11]. Rahman *et al*. [12] reported that the apparent density of calamari meat ranged from 1.063 to 1.356 g/cm$^3$. The authors observed that the apparent density's deviation from the bulk density was the result pore formation due to significant moisture loss. A linear relationship of bulk shrinkage over a full range of moisture levels was proposed by Kilpatrick *et al*. [13] while Lozano *et al*. [14] incorporated a correction factor at the lower moisture levels for food products.

A linear relation between shrinkage and moisture loss was observed up to 20% in fresh garlic during drying, similar relationships were found for other food products such as: soybeans [15]; fruits and vegetables [13] while a nonlinear-behavior was found at the lower moisture range for fish muscles [16]; Lozano *et al*. [14] for fruits. Moreira and Sereno [17] reported volumetric shrinkages to be a function of changes in moisture content, which is hence independently of drying rate.

Shrinkage and density are physical properties widely used in the modeling of transport phenomena. In developing mathematical models, density, shrinkage, and porosity are crucial to the adequacy of the model to predict and/or optimize real-time effects of transport process. Balaban and Pigott [18] studied shrinkages of ocean perch while Kilpatrick *et al*. [13], and Taiwo and Baik [19] studied shrinkage in sweet potatoes during frying. Lozano *et al*. [14] formulated an empirical model for the apparent densities of fruits and vegetables as a function of moisture content. Rahman and Potluri [16] fitted the mathematical model developed by Lozano *et al*. [14] to apparent density of squid meat during air-drying. Balaban and Pigott [18] reported a linear relationship between apparent density and moisture content of pigeon peas while Shepherd and Bhardwaj [20] reported a similar finding for grain and rewetted high moisture grain by Brusewitz [21].

Density can be measured by the pycnometric method. Several researchers have used fluid displacement methods [22]-[24]. Ngadi *et al*. [25]) and Kassama [22]) used a pycnometer to measure the skeletal density of meat patties extended with soy protein. Hence, the objective of this investigation was to study the relationships between moisture loss and the physical properties such as density and shrinkage in de-boned chicken meat during deep-fat frying.

## 2. Materials and Methods

### 2.1. Materials

Fresh de-boned chicken breast was used throughout this study. Samples were purchased from a local supplier. The stock was stored in a freezer at −20˚C until used. It was then thawed in a refrigerator at 4˚C for 24 to 36 h before commencement of the experiment.

### 2.2. Sample Preparation

The thawed chicken breast meat was cut into approximately 10 × 20 × 15 mm slabs. The sample slabs were individually deep-fat fried in a liquid shortening (Can Amera Food, Oakville, ON) in a commercial programmable computerized pressure deep-fat fryer (Henny Penny Computron 7000 Pressure Fryer, Model 500C, Henny Penny Corporation, Eaton, OH). The fryer was preheated at 170˚C for 2 h prior to the commencement of frying. Samples were placed in a wire basket to ensure good contact between the sample and the oil. Fried samples were cooled at room temperature, weighed, and placed in plastic Zip-Lock sample bags until the density measurements were to be executed.

### 2.3. Drying and Moisture Content Determinations

The moisture content was determined at the end of each frying period. Moisture content was determined based on AOAC Method 934.01 [26]. Two grams of fresh samples were placed in an oven at 100˚C for 18 h and the final moisture content was computed based on weight differences. In preparation of fat analysis the samples were freeze fried using a freeze-dryer ModulyOD-115 (Thermo Savant, Holbrook, NY) for 30 h. Prior to freeze drying, all samples were frozen overnight in a freezer at −20˚C. The freeze-dryer's refrigerating system and vacuum chamber were operated at −50˚C and 750 μm Hg, respectively. This approach was adopted to minimize major post changes in the sample's microstructure [25].

### 2.4. Fat Analysis

The fried, freeze-dried samples were ground using a blender (Proctor-Silex, model E160B, Picton, ON), and fat was extracted with a solvent extractor (SER148, Velp Scientifica, Usmate, Italy) using petroleum ether based on AOAC Methods 945.16 (AOAC, 2007). Ground samples were weighed and placed in thimbles (procedure followed as recommended by (SER148, Operation manual) for details). The oil content (OC) dry basis was computed for each sample based on the following relationship (Equation (1)).

$$\mathrm{OC}(\%) = \frac{\text{mass of oil extracted}}{\text{mass of dried sample}} \times 100 \tag{1}$$

### 2.5. Density Measurements

**Bulk density:** Bulk or total density of the samples was measured using the liquid displacement technique with water. The method requires coating sample with wax (to ensure no liquid penetration of the samples during the test) and immerse in a volumetric displacement (Archimedes) pycnometer. The apparatus was filled with water and the samples were immersed in the sample compartment, which was then hermetically sealed with the lid. The volume displacement was measured by turning the apparatus upside down twice, the first time without the samples and the second time with the samples immersed in the liquid. The volume displacement was computed based on the follow relationship (Equation (2)).

$$V_s = V_f - V_i \tag{2}$$

where $V_s$ is the volume of the samples, $V_f$ is the final volume of the samples immersed in the liquid, and $V_i$ is the initial volume without the samples, the volume of the wax was subtracted from the final volume. The shrinkage volume was measured using the same method.

**Apparent density:** The apparent or skeletal density was measured using a helium pycnometer (Model 1305 Multivolume, Micromeritics Instrument Corporation, Norcross, GA). The fried samples were weighed prior to analysis. The solid volume of the samples excludes pores within the sample material. Using the pycnometry method, the sample was placed in the 35 cm$^3$ sample chamber and was subjected to cyclic action (purging) by a pressurizing and depressurizing with helium gas prior to analysis in order to expel all the air and vapors trapped in the pores and crevices. The analysis was conducted at a room temperature with pressure of 134 ± 1.4 kPa (19.5 ± 0.2 psi). Initially, all valves were closed while the system equilibrated to the atmospheric pressure. The inlet valve was opened to fill the sample chamber with helium at an elevated pressure and closed for 15 s of pressure equilibrium, after which time the pressure was recorded as $P_1$. Then intermediate valve was opened, allowing the trapped helium to flow into the expansion chamber, and pressure $P_2$ was measured. The exhaust valve was then opened to release the spent helium gas from the system. The following general equation (Equation (3)) was used to compute the volume of the samples. For detailed methodology and procedure, refer to the standard protocol [27].

$$V_{Samp} = V_{Cell} - \frac{V_{Exp}}{\left[(P_1 - P_2) - 1\right]}, \tag{3}$$

where: $V_{Samp}$ = the volume of the samples of interest; $V_{Cell}$ = volume of the sample cell with the empty sample cup in place; $V_{Exp}$ = the volume of the expansion chamber; $P_1$ = sample chamber initial pressure with the expansion chamber closed; and $P_2$ = final chamber pressure with the expansion chamber open.

### 2.6. Definitions of Terms

Density is a physical property of all matter; it is simply the unit quantity of matter per volume of the same quantity (kg·m$^{-3}$). The densities used in this study are defined as follows:

*Bulk density*: the measure of bulk density includes all pores, interparticle spaces, moisture, and air in the material.

*Apparent density*: this measure includes blind and non-interconnected pores of the material and excludes open, interconnected and interparticle pore spaces.

### 2.7. Experimental Design

A full (3 × 20) factorial design with 3 replications was used in this study. The factors were frying oil temperatures (FOT) with three levels (170˚C, 180˚C, and 190˚C), and frying time with 20 levels, and samples were fried randomly at each 20 frying times (5, 10, 15, 20, 30, 45, 60, 90, 120, 150, 180, 210, 240, 300, 360, 420, 480, 540, 600, and 900 s)within each FOT. The analysis of variance (ANOVA) and non-linear regression were conducted using SAS software (SAS 2012). All mean comparisons were performed by using Duncan's multiple range test (DMRT), at the 5% level of significance.

## 3. Results and Discussions

### 3.1. Densities

Bulk and particle densities of deep-fat fried de-boned chicken meat samples are shown in **Figure 1** and **Figure 2**, respectively. The bulk density decreased with frying time, whereas the apparent density increased with frying time, Wang and Brennan [28]) reported similar trends in air-drying of potato. The analyses of variance (ANOVA) of the two densities show that the temporal changes ($P < 0.01$) were influenced by frying oil temperature (FOT). Synergy between FOT and frying time significantly ($P < 0.05$) impacted the changes in density.

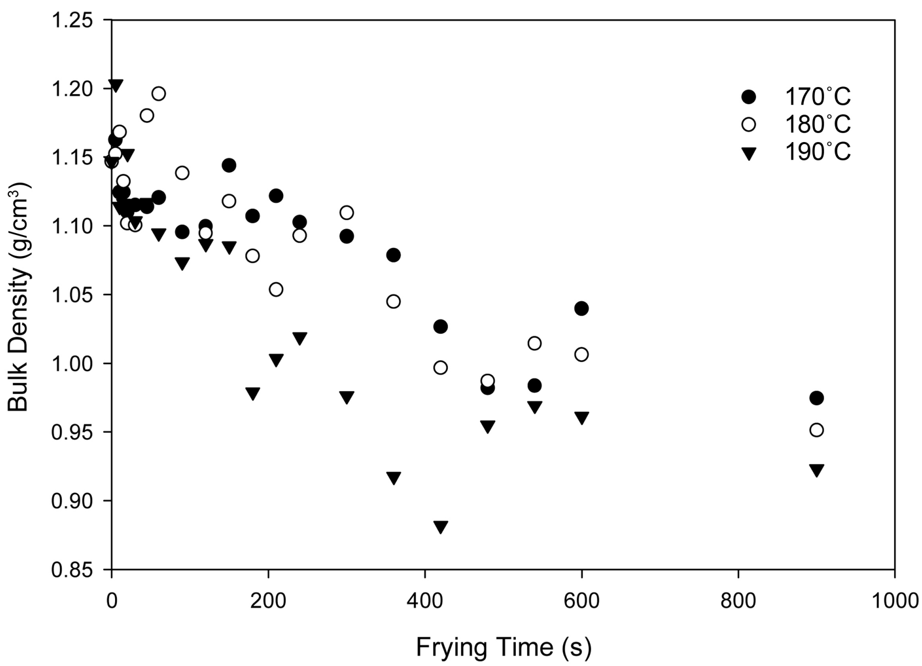


**Figure 1.** Bulk density as a function of time for de-boned chicken meat deep-fat fried at 170˚C, 180˚C, and 190˚C.

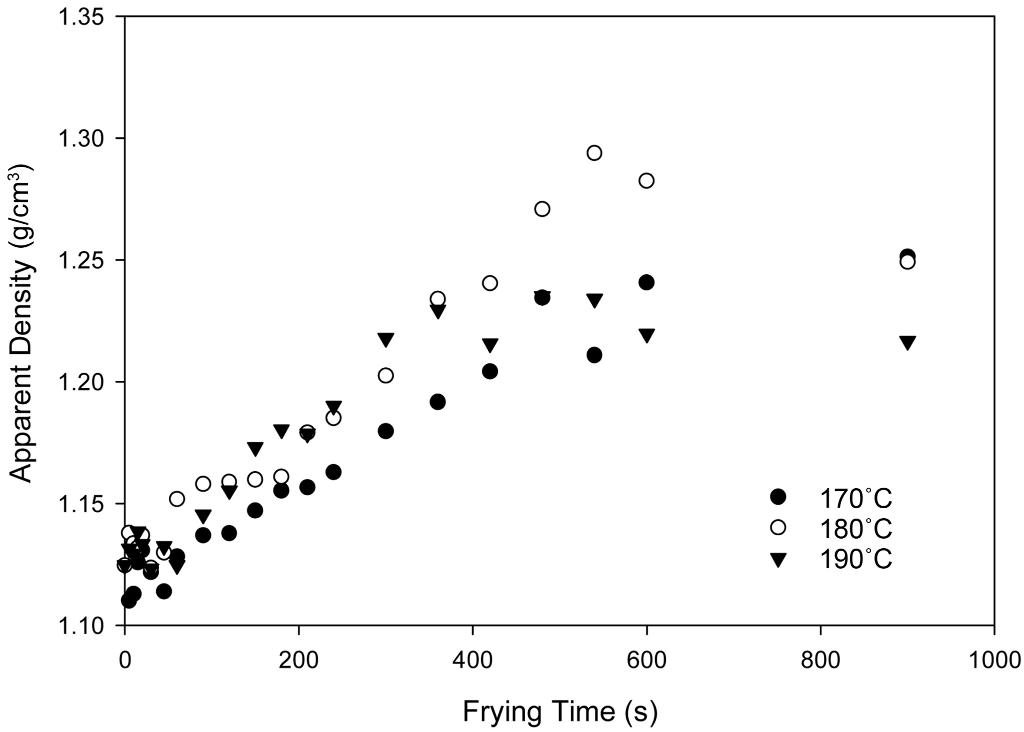


**Figure 2.** Apparent density as a function of time for de-boned chicken meat deep-fat fried at 170˚C, 180˚C, and 190˚C.

The mean apparent density was not significant different at FOT 180˚C and 190˚C. The bulk density values decrease from 1.15 g/cm$^3$ (control, for which there was no moisture loss) to 0.98, 0.95, and 0.92 g/cm$^3$ after 900 s of frying at the following FOTs 170˚C, 180˚C and 190˚C and final moisture contents of 33%, 25%, and 16% wb, respectively. Frying at a higher temperature resulted in a lower bulk density. This is due to the effect of aggravated water loss resulting in pore formation and subsequent pore structure collapse resulting to shrinkage, was also observed by Rahman *et al*. [12] in drying fish muscles. In contrast, the apparent density increased from 1.13 g/cm$^3$ (for the control) to 1.25, 1.24 and 1.22 g/cm$^3$. The apparent density increased consistently when fried for 540 s, and the mean values were 1.21, 1.29 and 1.23 g/cm$^3$ at 170˚C, 180˚C and 190˚C, respectively, after which it tended to equilibrate. This behavior was analogous to the oil absorption curves during deep-fat frying reported by Kassama and Ngadi [23]. The morphological change that modulates densities variation could also be attributed to physicochemical reaction induced by the deterioration of solid content and collageneous connective tissues. Denaturation of protein is also a significant factor that contributes to alteration of the physical properties, thus change in densities. Additionally, the change in state could also be attributed to oil absorbed into the empty voids, hence the volumetric gain due to oil uptake in place of voids evacuated by moisture may explain the decreasing trend of the apparent density Kassama and Ngadi [3], Krokida *et al*. [29] made similar observations for deep-fat fried potato strips.

**Figures 3(a)-(c)** show bulk and apparent densities as functions of moisture loss during deep-fat frying. Bulk density decreases while apparent density increases, as moisture loss increases. These results agree with the observations of various researchers [19] [22] [30]. The relationships between distinct parameters such as the moisture content, bulk and apparent density and the process variables are shown in the Pearson correlation coefficients matrix (**Table 1**). A weak linear correlation ($r = 0.66$; $P < 0.01$) exists between moisture content and bulk density.

The apparent density peaked at the low moisture region, while the bulk density peaked at the high moisture region. There was a linear relationship ($r = 0.83$; $P < 0.01$) between moisture loss and apparent density. The FOT was poorly correlated to both the bulk and apparent density, while frying time was high positively correlated. A weak correlation ($r = -0.66$; $P < 0.01$) was achieved between the bulk and apparent density of de-boned chicken meat during deep-fat frying. Therefore, the bulk and apparent density may be adequately predicted by a

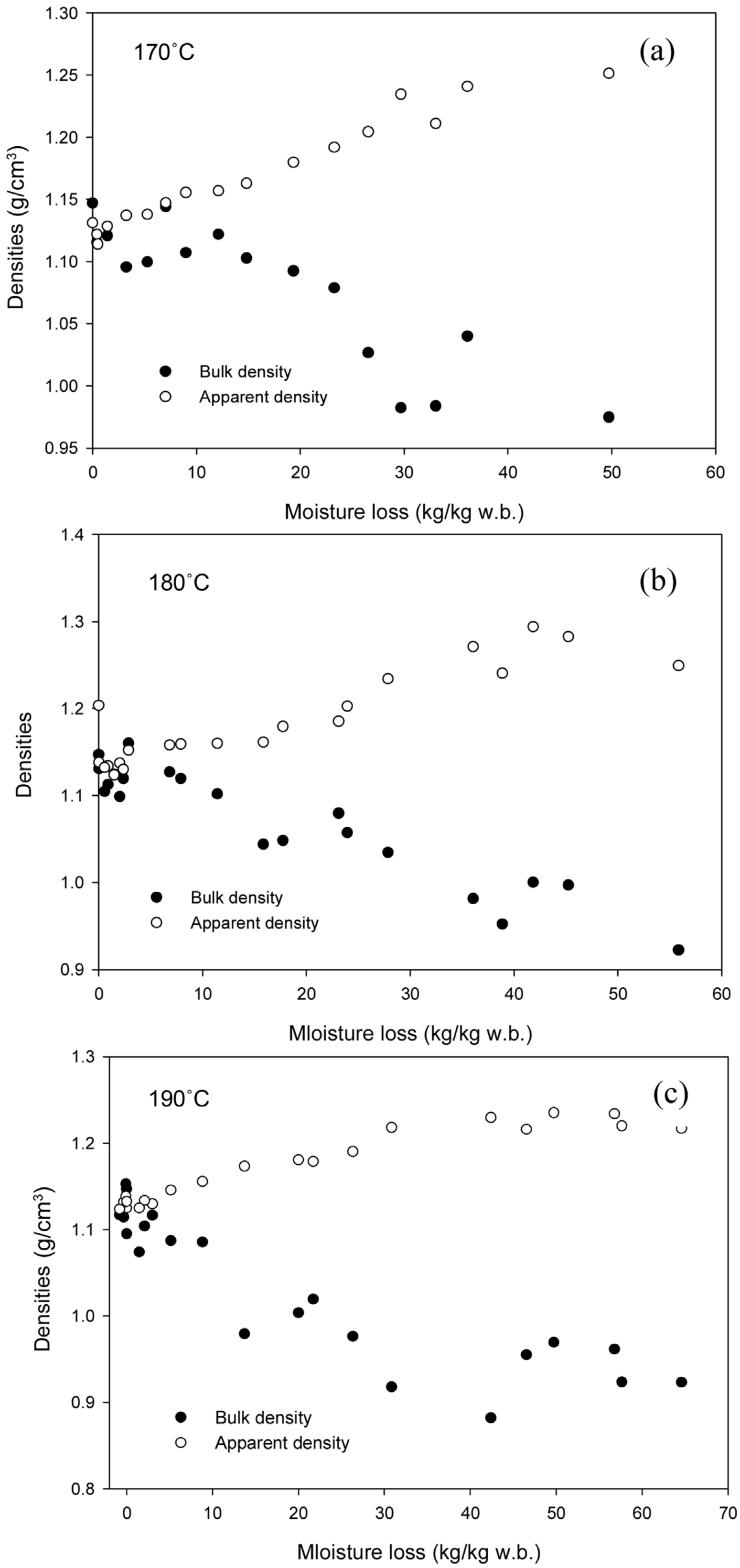


**Figure 3.** Bulk and apparent densities as a function of moisture loss during deep-fat frying of de-boned chicken meat.

**Table 1.** Pearson correlation coefficients matrix for bulk and apparent densities as a function of various process parameters.

| | Temperature | Time | Bulk density | Apparent density | Moisture content |
|---|---|---|---|---|---|
| Temperature | 1.00 | 0.00 | −0.27 | 0.10 | 0.13 |
| Time | 0.0 | 1.00 | −0.70 | 0.83 | −0.94 |
| Bulk density | −0.27 | −0.70 | 1.00 | −0.66 | 0.66 |
| Apparent density | 0.01 | 0.83 | −0.66 | 1.00 | 0.83 |
| Moisture content | 0.13 | −0.94 | 0.66 | −0.83 | 1.00 |

$P < 0.01$.

linear equation with a higher degree of accuracy as a function of moisture loss in de-boned chicken meat during the deep-fat frying process. Balaban and Pigott [18] reported a best fit with the $R^2$-value of >0.86 for density for fish muscle during drying by assuming linearity in their application of the drying model equation which will be appropriate to our study.

The experimental data were fitted to the following empirical equations (Equation (4) and Equation (5)) to predict the bulk and apparent density of chicken meat during deep-fat frying.

$$\rho_B = \rho_{oB} + a \times X \tag{4}$$

$$\rho_A = \rho_{oA} + a \times X \ , \tag{5}$$

where $\rho_B$ is the bulk density, $\rho_{oB}$ is the initial bulk density, $\rho_A$ is the apparent density, $\rho_{oA}$ is the initial density, $a$ is a constants and $X$ is the moisture loss.

**Table 2** shows the corresponding values of the constants and the coefficient of determination ($R^2$) obtained from a linear regression analysis. The estimation of density parameters by Equation (4) and Equation (5) shows a good fit, and thus the coefficients of the determinations are relatively high for all ranges of the FOT as seen in **Figure 4** the experimental and predicted curves as a function of moisture loss.

### 3.2. Shrinkage

Shrinkage is a change in volume induced by moisture loss and probably formation and collapse of the pore structures. Shrinkage in meat is anisotropic [3] [31]. Rahman and Perera [32] reported that the rate of shrinkage is dependent in the muscle fiber orientation. In biological materials, the rate of shrinkage is dependent on orientation of the fiber stretch either in the longitudinal or transversal plane during frying [22] [33]. Shrinkage is temperature-dependent and excessive shrinkage causes distortion of shapes, hence affects the final texture and quality attributes of a food product. The ANOVA for volumetric shrinkage data shows significant changes ($P < 0.05$) in time. The trend in time was not affected by temperature as indicated by the non-significant interaction.

Shrinkage increases logarithmically with time as seen by the shape of the curve in **Figure 5**. The rates of shrinkage were 0.013, 0.001, and 0.008/s and occurred rapidly during the first 90 s of FOT 170˚C, 180˚C, and 190˚C, respectively and decreased as frying time increased. Thus, there was a linear relationship between shrinkage and moisture loss as shown in **Figure 6**. However, the rate of volumetric shrinkage slows down after 300 s of frying probably due to the oil uptake at low moisture regions. A linear relationship was observed at all levels of FOT, similar correlations were reported by others researchers on drying of foods [17] [19] [23] [30]. The regression equations for each temperature are given in **Table 3** and the correlation coefficients indicate a close fit to the experimental data.

## 4. Conclusion

Process variables such as FOT significantly ($P < 0.01$) influenced the physical properties of de-boned chicken breast during the deep-fat frying process. Bulk density decreases with an increase in frying time, while apparent density increases. A strong linear correlation exists between the bulk and the apparent density, and the moisture

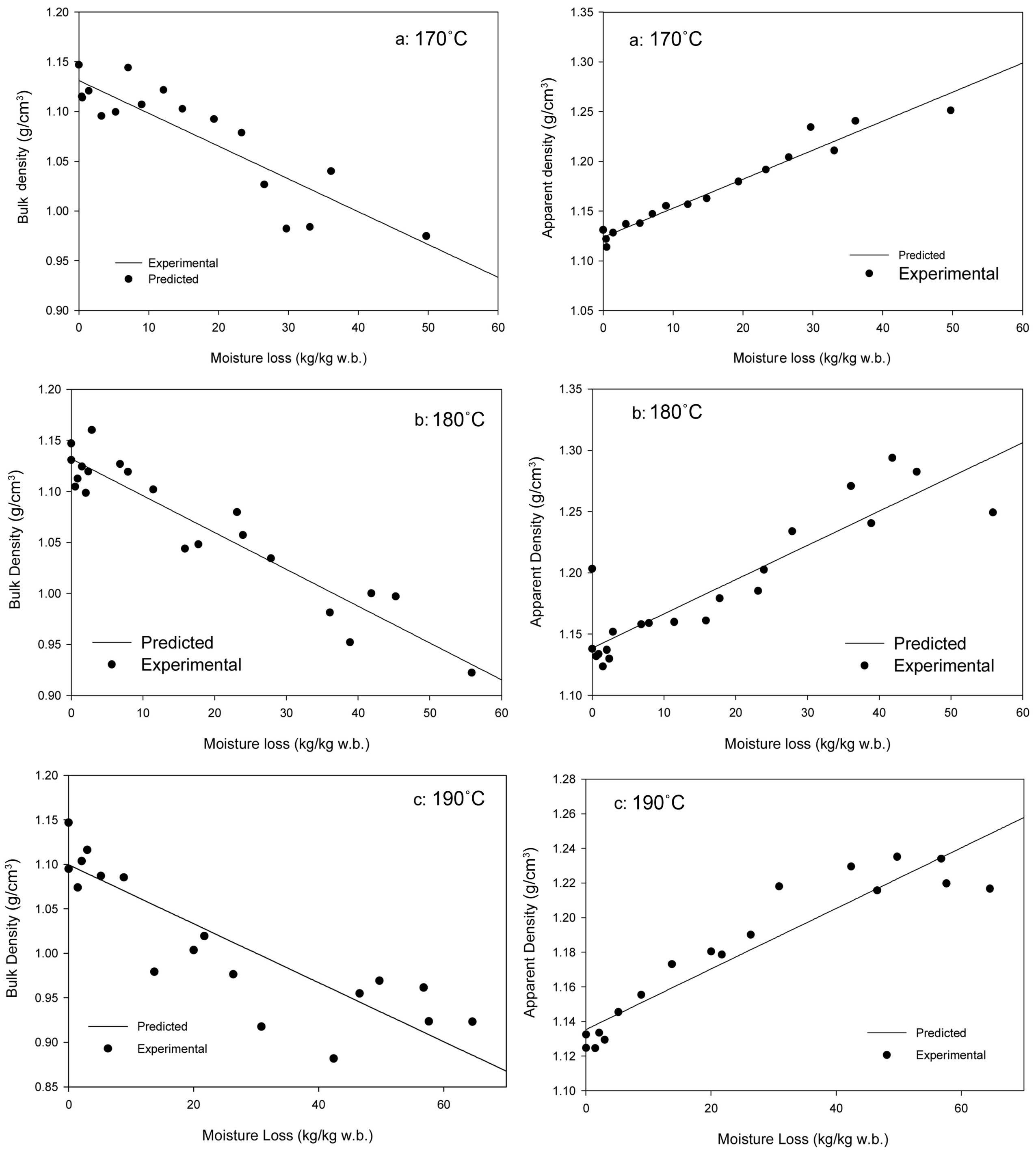


**Figure 4.** Experimental and predicted densities (bulk and apparent) of de-boned chicken meat as a function of water loss fraction during deep-fat frying.

loss, hence a linear model provides good prediction of densities. A linear relation was also found between volumetric shrinkage and moisture loss. The rates of shrinkage were 0.013, 0.001, and 0.008/s and occurred rapidly during the first 90 s of FOT (170˚C, 180˚C, and 190˚C), respectively and decreased as frying time increased. The results of volumetric shrinkage may be utilized to adequately predict apparent moisture diffusivity during frying.

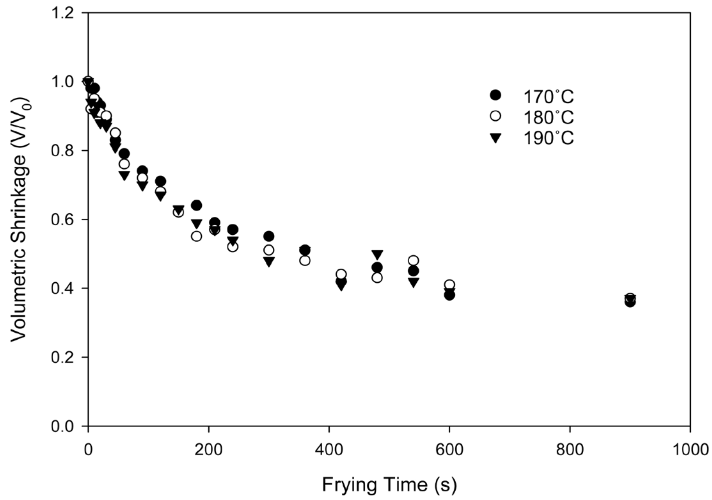


**Figure 5.** Volumetric shrinkage as a function frying time.

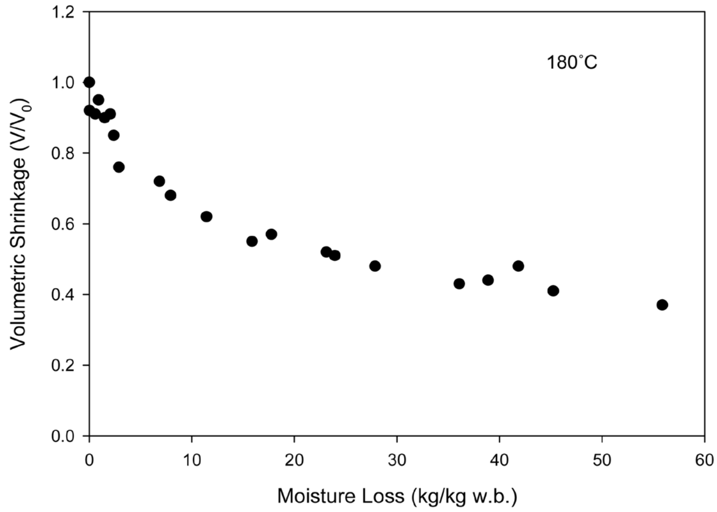


**Figure 6.** A typical apparent volumetric shrinkage of as a function of moisture loss for FOT 180˚C.

**Table 2.** Estimated constant values from Equations (4) and (5) for the determination of bulk and apparent density parameters of de-boned chicken meat during deep-fat frying.

| Temp (˚C) | Model Parameters (Bulk Densities) | | | | $R^2$ |
|---|---|---|---|---|---|
| | $\rho_{oB}$ | | $a$ | | |
| | Estimate | SE | Estimate | SE | |
| 170 | 1.1312 | 0.0074 | −0.0033 | 0.0001 | 080 |
| 180 | 1.1319 | 0.0070 | −0.0036 | 0.0003 | 0.89 |
| 190 | 1.0996 | 0.0126 | −0.0033 | 0.0004 | 0.78 |
| Temp (˚C) | Apparent Densities | | | | $R^2$ |
| | $\rho_{oA}$ | | $a$ | | |
| | Estimate | SE | Estimate | SE | |
| 170 | 1.1238 | 0.0028 | 0.0029 | 0.0001 | 0.96 |
| 180 | 1.1386 | 0.0075 | 0.0028 | 0.0003 | 0.82 |
| 190 | 1.1354 | 0.0042 | 0.0017 | 0.0001 | 0.89 |

**Table 3.** Regression equations describing volumetric shrinkage as a function of moisture fraction for de-boned chicken meat during deep-fat frying.

| Temperature | Regression Equation | $R^2$ |
|---|---|---|
| 170˚C | $S_v = 0.85 - 0.0131x$ | 0.82 |
| 180˚C | $S_v = 0.83 - 0.0011x$ | 0.83 |
| 190˚C | $S_v = 0.84 - 00082x$ | 0.83 |

$S_v$ = volumetric shrinkage; $R^2$ = coefficient of determination; $x$ = moisture loss; ($P < 0.01$).

## Acknowledgements

The authors acknowledged the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Alabama Agricultural and Mechanical University (AAMU) Experimental Station were appreciative for providing funds for this research project.

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