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Effect of Frying Time and Falafel Ball Size on Fat Uptake During Deep Fat Frying

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Abstract: One of the most important fried foods in the Middle East is falafel balls. Oil content in fried falafel balls is of primary importance to consumers and processors. The aim of this study was to investigate the effects of frying time and falafel ball size on quality of deep fat fried falafel. Falafel balls were prepared and fried at a temperature of 170°C. The effect of different frying times (0.5, 1, 1.5, 2, 2.5 and 3 min) and falafel ball sizes (small, medium and large) on moisture loss, oil uptake and expansion of fried falafel balls were investigated. Results indicated that oil content in fried falafel balls could be reduced by decreasing frying time and increasing falafel ball size.

Key words: falafel balls · Oil uptake · Moisture loss · Frying · Expansion

INTRODUCTION

Frying is one of the oldest cooking methods used to prepare local food in Jordan. The high temperature used in frying causes several chemical and physical changes, including starch gelatinization, protein denaturation, water vaporization and crust formation [1]. Together with heat transfer, mass transfer takes place during the frying process. Mass transfer is characterized by movement of oil into the product as well as movement of water from the product into the oil [2].

Deep fat frying is widely used in the industrial and institutional preparation of foods because consumers prefer the taste, appearance and texture of fried food products. However, these products contain a substantial amount of fat, as much as 45%, because food, particularly those that are naturally low in fat, absorb large amounts of fat during deep fat frying [1]. Because of public health concerns, there is a high demand to reduce the oil content of fried foods [2]. Bouchon and Pyle [3] stated that low fat snack products are a primary concern and will probably be the driving force of the snack industry during the next few years.

One of the largest applications of deep fat frying in the Arab East is fried falafel balls. Falafel, also known as "ta`amiyya" in Egypt and Sudan, is a fried ball made from spiced fava beans and/or chickpeas. Most of the work that has been done to decrease oil absorption in fried products has been confined to potato chips. Different means of reducing oil uptake in fried potatoes have been reported, for instance, use of post-frying treatments such as hot air drying and superheated steam drying [3], lowering the moisture content of the food before frying, use of hydrocolloids such as cellulose derivatives [1, 2], soaking potato strips in NaCl solution [2], use of vacuum frying [4], use of different sources and types of oils [1], use of oils with different qualities [1] and studying frying process conditions such as temperature and time [1,5, 6].

However, the food industry was unsuccessful in developing a low-fat products with just enough fat to impart the desired quality attributes of deep fat fried food, such as flavor, texture, appearance and mouthfeel[3]. Very little work has been done to decrease oil absorption in fried falafel balls. Pinthus *et al.* [7] investigated the effect of added powdered cellulose and methyl cellulose on oil uptake during deep fat frying of donuts and falafel balls. From this study, it has been concluded that methyl cellulose gives the best result. The aim of this study was to investigate the effects of deep fat frying time and falafel ball size on fat uptake, moisture loss and expansion.

MATERIALS AND METHODS

Preparation of Falafel Mix: The falafel mix was prepared by soaking 500g of dried chickpeas (No. 7, Turkey) overnight. Rehydrated chickpeas were ground (MG510 grinder, Kenwood, China) using fine grinding screen. The following ingredients were subsequently added to

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ground chickpeas: onion (100 g), parsley (40 g), shallot (40 g), coriander (10 g), falafel spices (10 g), dried ground coriander (4 g), dried ground cumin (4 g), salt (10 g), water (10 g) and sodium bicarbonate (0.5% of the total mix). The mixture was blended (KM336 blender equipped with dough hook, Kenwood, China) for 2 min.

Frying of Falafel Balls: A commercial deep fat fryer was used to fry falafel balls. The fryer was equipped with a temperature controller of ±1°C. The fryer was filled with 2 L of sunflower oil and set to 170°C. The oil was preheated for approximately 1 h prior to frying to ensure steady-state conditions. Six falafel balls were fried in each batch and one ball was removed from the oil according to predetermined frying times (0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 min) to monitor fat uptake and moisture loss as a function of frying time. Fried samples were removed and allowed to cool; excess fat was drained for 5 min. After each frying trial, the amount of oil was checked and the oil was replenished. Oil was changed after 1 h of frying time. The whole experiment was repeated three times. The effect of falafel ball size was analyzed according to the above described procedure using three sizes of falafel balls made with falafel ball molds available commercially with the following dimensions (width × height, in mm): small size mold (27.86 ×10.6 mm), medium size mold (32.76 × 11.5 mm) and large size mold (35.9 × 12 mm).

Moisture Content Determination: Moisture content in raw and fried samples was measured according to AOAC method [8]. Water lost (as a percentage of dry matter) was calculated according to the following equation:

[(Initial moisture content - moisture content at specified frying time)/initial moisture content]× 100

Fat Content Determination: Oil content of fried samples was determined according to AOCS [9] using the Soxhlet extraction method. Oil uptake (as a percent of dry matter) was calculated according to the following equation:

[(Initial oil content - oil content at specified frying time)/initial oil content] × 100

Dependence of Oil Uptake by Falafel Balls on Moisture Loss During Frying: Two methods were used to investigate the dependence of oil uptake on moisture loss. The first method involved the calculation of the uptake ratio U_R criterion, which was developed by Pinthus *et al.* [7] to evaluate different treatments for oil uptake as a function of water loss. The U_R criterion is defined as the amount oil taken up (g) divided by the amount of water lost (g). The U_R criterion was calculated at different frying times. The second method involved plotting oil uptake (g) versus amount of water lost (g) and performing a correlation analysis on these data.

Dimensional Change: The height of falafel ball samples was monitored before and during frying using calipers. Results were expressed by plotting the height (mm) of falafel balls as a function of frying time for different falafel ball sizes or by plotting the percent increase in the height of falafel balls as a function of frying time for different falafel ball sizes.

Statistical Analysis: The data obtained were analyzed statistically by analysis of variance using factorial design. Means separation were performed using LS-means with significance at $p \leq 0.05$. Selected correlations were performed with different variables. Statistical analysis was performed using SAS system (SAS software, SAS institute Inc., NC, USA version nine).

RESULTS

Moisture Loss: Figure 1 shows the results of moisture content in falafel balls (g/g dry matter) as a function of frying time for different falafel ball sizes. The three curves followed a classical drying profile. Moisture content decreased significantly with increasing frying time. The regression equations for moisture content as a function of frying time for each falafel ball size are shown in Table 1. Falafel ball size significantly affected moisture content. The moisture content in falafel balls increased with increasing size at a given frying time. This difference between different sizes was low during the initial period of frying and increased as frying proceeded. After 3 min of frying, the moisture contents were 0.83, 0.72 and 0.66 g/g dry matter basis (db) for large, medium and small falafel balls, respectively. From these results, the moisture contents in small and medium falafel balls were lower than that in large falafel balls by 20.48% and 12.25%, respectively. At the end of frying time, percentages of water lost were 58.23%, 54.43% and 47.70% for small, medium and large falafel balls, respectively.

Fat Uptake: Figure 2 shows the oil content profile of the three falafel ball sizes during frying. The regression equations are listed in Table 2. Fat content increased with increasing frying time to 1.5 min; after that fat content

Table 1: Moisture loss regression equations

Size of falafel ball	Regression equations	R^2
Small	$Y= -0.0994X^3 + 0.5716X^2 - 1.1264X + 1.5565$	0.98
Medium	$Y= -0.0866X^3 + 0.5091X^2 - 1.0328X + 1.5567$	0.97
Large	$Y= -0.0871X^3 + 0.5147X^2 - 1.0082X + 1.562$	0.98

Table 2: Fat uptake regression equations

Size of falafel ball	Regression equations	R^2
Small	$Y= -0.0428X^4 + 0.3114X^3- 0.7871X^2 + 0.8087X + 0.0031$	0.99
Medium	$Y= -0.375X^4 + 0.2755X^3- 0.7056X^2 + 0.405X + 0.0027$	0.99
Large	$Y= -0.0332X^4 + 0.244X^3- 0.6283X^2 + 0.6702X + 0.0026$	0.99

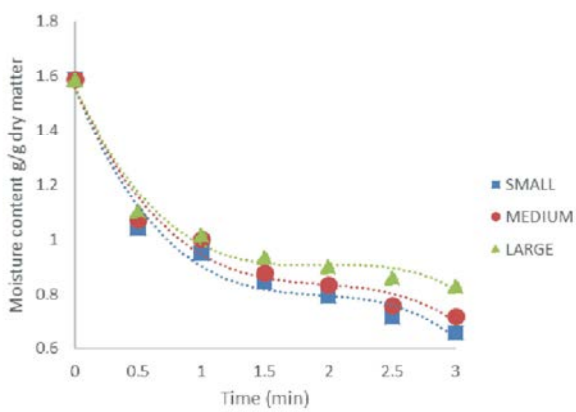

Fig. 1: Effect of frying time and falafel ball sizes on moisture content of falafel balls during frying

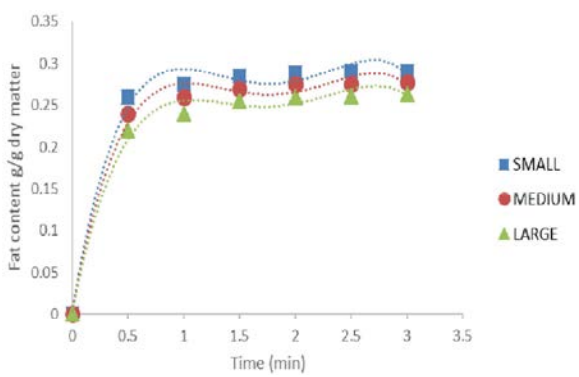

Fig. 2: Effect of frying time and falafel ball sizes on fat content of falafel balls during frying

remained constant. Fat content of falafel balls decreased with increasing size when frying time was kept constant. After 3 min of frying, the fat contents were 0.26, 0.27 and 0.29 g/g (db) for large, medium and small falafel balls, respectively. From these results, it was calculated that fat contents of large and medium falafel balls were lower than that of small falafel balls by 9.31% and 4.48%, respectively.

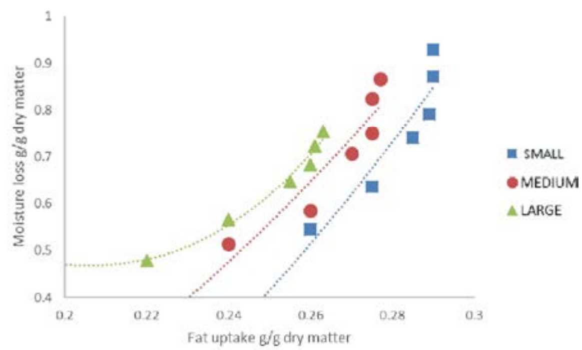

Fig. 3: Correlation between fat uptake and moisture loss for different sizes of falafel balls during frying

Table 3: Oil uptake criterion for falafel balls

	Size of falafel ball		
Frying time (min)	Small	Medium	Large
0	0	0	0
0.5	0.48	0.47	0.46
1.0	0.43	0.44	0.42
1.5	0.38	0.38	0.39
2.0	0.37	0.37	0.38
2.5	0.33	0.33	0.36
3.0	0.31	0.32	0.35

Dependence of Oil Uptake on Moisture Loss: The U_R criterion values for different falafel ball sizes during frying are shown in Table 3. U_R values decreased with increasing frying times. Maximal decreases in U_R values occurred during the initial frying time period (up to 1.5 min); after that the U_R values decreased slightly with increasing frying time. U_R values increased with the size of falafel balls when frying time was kept constant. After 3 min of frying, U_R values were 0.35, 0.32 and 0.31 g/g (db) for large, medium and small falafel balls, respectively.

Figure 3 demonstrates a strong correlation between moisture loss and fat uptake for all falafel ball sizes. However, significant differences between fat uptake

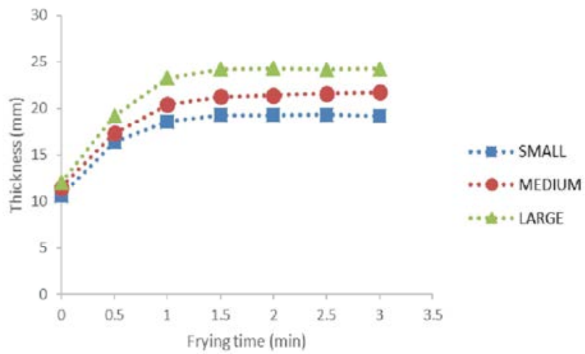

Fig. 4: Effect of frying time and falafel balls sizes on the expansion of falafel balls during frying

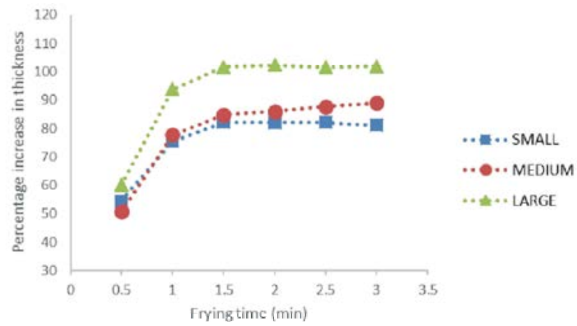

Fig. 5: Effect of frying time and falafel balls sizes on percentage of expansion of falafel balls during frying

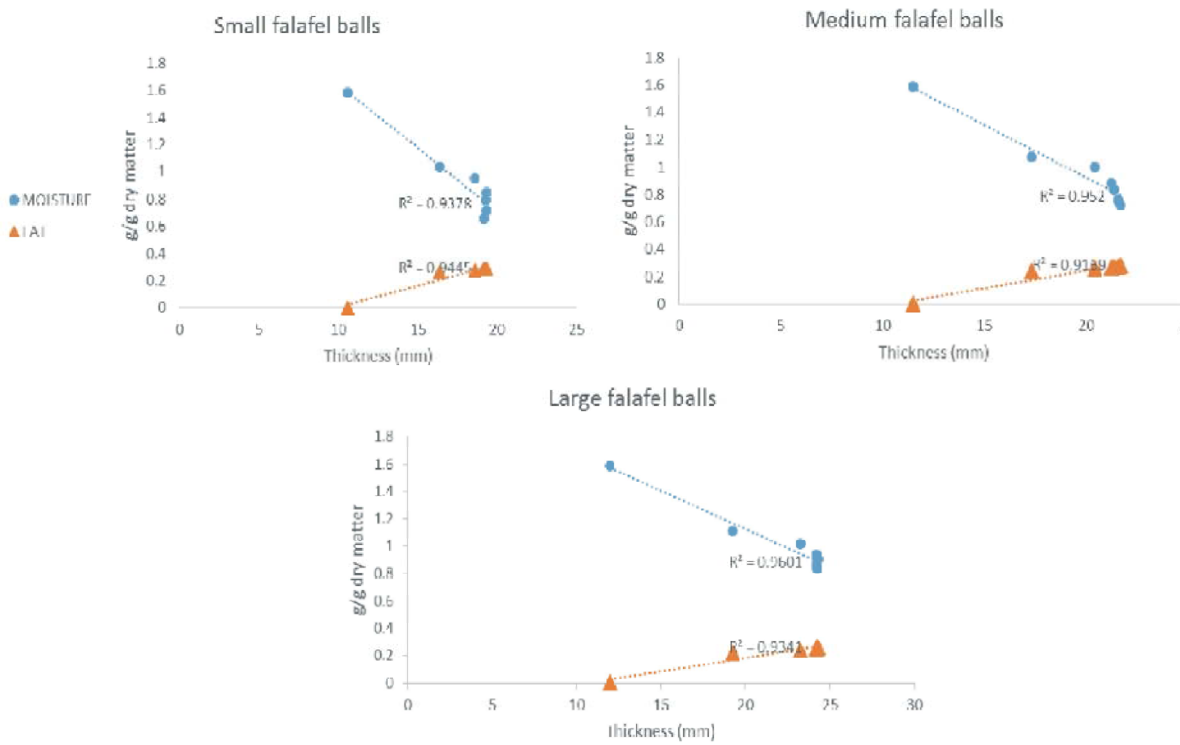

Fig. 6: Correlation between moisture loss or fat uptake and thickness of falafel balls during frying for all falafel ball sizes

amounts at given levels of water loss were observed for different sizes. Small falafel balls absorbed higher amounts of fat in comparison with medium sized falafel balls, which in turn absorb higher amounts of fat than large falafel balls, considering the same amount of water loss in all sizes.

Dimensional Change: The thickness profile of falafel balls and the percent increase in thickness during frying are shown in Figures 4 and 5, respectively. Frying time up to 1.5 min significantly affects the thickness and percent increase in thickness; as frying time increases, both parameters significantly increase. However, after 1.5 min, no significant increase in either parameter was observed for all falafel ball sizes. After 3 min of frying, the thicknesses (and percent increase in thickness) were 19.2 (81.13%), 21.73 (88.96%) and 24.23 (101.5%) mm for small, medium and large falafel balls, respectively. Figure 6 shows strong correlation between the change in height of falafel balls and moisture loss and fat uptake during frying for all falafel ball sizes.

Table 4: Fat content of falafel balls cited in different literatures

Fat content (g) per 100 g dry matter	Source
27.23	[28]
33.84	[29]
44.3–58	[30]
23.1	[31]

DISCUSSION

One of the most important quality attributes of a deep fat fried product is oil content. High oil content is costly to the processor and results in an oily and tasteless product [10]. In addition, with the increasing health consciousness of the consumer, the demand for lower oil content fried foods has increased. Hence, the consumer trend is toward less greasy, healthier products.

According to cited literature, the percentage of fat in fried falafel balls vary widely (Table 4). This variation is a strong indication that processing conditions affect the percentage of fat uptake by falafel balls and by optimizing these conditions, the percentage of fat uptake could be controlled to the lowest possible values. In this study, falafel ball sizes, frying time and expansion significantly affected the percentage of fat uptake.

Falafel ball size was found to be inversely correlated with fat uptake and water loss (Figs. 1 and 2). These results were in agreement with the results of Guillaumin [11], who reported that oil absorption increased significantly when product thickness was reduced and product surface was increased. Paul and Mittal [12] found that French fries absorbed less oil than chips because of a smaller surface/volume ratio. A linear relationship between surface area and oil content has been established [13]. Mellema [14] reported that potato samples can be prepared in larger chunks or surface roughness can be reduced via quality control of the slicing blades to reduce fat uptake. The effect of product thickness on fat uptake could be explained by the fact that oil uptake is a surface phenomenon; therefore, the specific dimensions of a food will determine the amount of oil that can be taken up [15]. It has been shown that oil does not enter the product at a great extent during frying, but it is drawn from the oil film on the product when it is removed from the oil bath [16-20].

Crust is one of the most palatable characteristics of fried food [21]. In addition to effect of surface area, crust is another factor that could contribute to the difference in frying characteristics of different falafel ball sizes. It is expected that as the size of falafel balls decreases, the surface area of the balls increases, which enhances the rate of heat transfer leading to earlier crust formation and the formation of a thicker crust in comparison with that of the larger sized balls. This could explain the increasing oil uptake in falafel balls as the size of the balls decreases. The physical properties of the crust (thickness, gel strength and porosity) significantly affect oil uptake by deep fried food [22]. Singh [23] reported that crusts have different physical properties (moisture content and boiling point) as compared with the core. Several studies have shown a strong association between crust formation and oil uptake [21, 22, 24, 25].

Because of the dependence of fat uptake on moisture loss, the correlation between these two variables was investigated. The results demonstrated a strong correlation between moisture loss and oil uptake for different falafel ball sizes. Gamble *et al.* [24] found that moisture loss and oil uptake were interrelated and that both were linear functions of the square root of frying time. They hypothesized that oil entering the slice would lie in the voids left by the escaping water. Hence, in addition to quantitative aspects, water loss can become an explanatory variable for transformation and especially oil uptake [26]. In this study, the following two methods were used to investigate the dependence of fat uptake on moisture loss: plotting the correlation between moisture loss (Fig. 3) and fat uptake and the oil uptake criterion (U_R) (Table 3).The contradictory result between the two methods is related to the fact that the U_R criterion is affected by many factors. Pinthus*et al.* [7] reported that high values of U_R could be due to small amounts of moisture loss and not necessarily due to large amounts of oil uptake.

In this study, the expansion of falafel balls affecting oil uptake was the last factor that we investigated (Figs. 4 and 5). The results provided evidence for its effect on moisture loss and oil uptake for all falafel ball sizes. Despite the fact that percent expansion was higher for large size falafel balls, small size falafel balls absorbed a higher amount of oil, which indicated that porosity did not affect oil uptake. The porous medium created during frying is a solid permeated by an interconnected network of pores (voids) that can be filled with oil and air. There are three possible types of pores: interconnected pores (accessible from many directions), isolated pores (inaccessible) and non-connected pores (accessible from one direction) [27]. Kassama and Ngadi [27] experimentally demonstrated that interconnected pores, rather than non-connected pores, contributed to the transport of fluid across the porous medium, whereas the effect of isolated pores on transport phenomena was limited. Therefore, it is expected that the pores in falafel balls belong to the non-connected type. The strong correlation shown in this study between oil uptake and moisture loss and the percent expansion (Fig. 6) could be related to the increased surface area of falafel balls and not to the porosity that developed during frying. The high expansion of falafel balls as the size increased may be related to the earlier formation of crust in small sizes (as a result of increased surface area, which in turn enhances heat transfer) that prevents falafel balls from expanding.

CONCLUSION

Frying time and falafel ball size significantly affected the frying profile of falafel balls. Frying time was proportional to moisture loss, expansion and oil uptake, whereas falafel ball size was proportional to expansion and inversely correlated with moisture loss and fat uptake. Increased surface area and crust thickness are factors that may contribute to increased oil uptake by small, fried falafel balls. Early crust formation may be responsible for the lower expansion values of small falafel balls compared with those of large falafel balls.

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