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Araştırma Makalesi/*Research Article (Original Paper)*

The Effects of Microwave Frying on Myofibrillar and Sarcoplasmic Proteins of Chicken Breast Meat

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Abstract: The main objective of this study is to investigate the effects of microwave frying and different frying times on myofibrillar and sarcoplasmic proteins of chicken breast muscle. The color and texture of the fried samples were also determined. Frying was performed in microwave oven at 365W (70%) power level for 0.5 and 1.5 minutes after bringing the oil temperature to 180°C. Samples were also fried in a conventional fryer at 180°C for 2.0 and 5.0 minutes for comparison. The moisture content was dropped to 59.3% and 32.7% for 0.5 and 1.5 min microwave fried samples, respectively. Microwave frying provided lighter colored samples with lower hardness values when compared to the conventional frying for 5.0 min. Fried chicken breast muscle proteins were examined using sodium dodecyl sulphate-polyacrylamide gel electrophoresis (SDS-PAGE). In both frying methods, the intensity of the myosin heavy chain band was observed to decrease significantly. In general, it was observed that the frying method and frying time did not cause divergent interactions on myofibrillar and sarcoplasmic proteins of chicken breast muscle. Microstructural analysis of samples was also performed.

Keywords: Chicken meat, Color, Microwave frying, Myofibrillar protein, Sarcoplasmic protein, SEM

Mikrodalgada Kızartmanın Tavuk Göğüs Eti Miyofibriler ve Sarkoplazmik Proteinleri Üzerine Etkileri

Özet: Bu çalışmanın temel amacı mikrodalgada kızartma işleminin ve farklı kızartma sürelerinin tavuk göğüs eti miyofibriler ve sarkoplazmik proteinleri üzerine etkilerinin incelenmesidir. Kızartılmış ürünlerin renk ve tekstürü de belirlenmiştir. Kızartma işlemi mikrodalga fırında 365W (%70) güç seviyesinde 0,5 ve 1,5 dakika sürelerde, yağın sıcaklığı 180°C'ye getirildikten sonra gerçekleştirilmiştir. Örnekler ayrıca, karşılaştırma amaçlı olarak, fritöz içerisinde 180°C'de 2,0 ve 5,0 dakika süreler ile kızartılmıştır. Nem oranı, 0,5 ve 1,5 dakika süre ile mikrodalgada kızartılan örnekler için sırasıyla %59,3 ve %32,7'ye düşmüştür. Mikrodalga kızartma işlemi, 5,0 dakika süresince konvansiyonel yöntem ile kızartmayla karşılaştırıldığında, daha açık renk ile daha düşük sertlik değerlerine sahip örnekler sağlamıştır. Kızartılmış tavuk göğüs eti proteinleri, sodyum dodesil sülfat-poliakrilamid jel elektroforezi (SDS-PAGE) ile incelenmiştir. Her iki kızartma yönteminde de myosin ağır zincirine ait bandın yoğunluğunun önemli derecede azaldığı gözlenmiştir. Genel olarak bakıldığında, kızartma yönteminin ve kızartma süresinin tavuk göğüs eti miyofibriler ve sarkoplazmik proteinleri üzerinde farklı etkileşimlere yol açmadığı gözlemlenmiştir. Örneklerin mikroyapısal analizi de yapılmıştır.

Anahtar kelimeler: Tavuk eti, Renk, Mikrodalga kızartma, Miyofibriler protein, Sarkoplazmik, SEM

Introduction

Microwaves offer many advantages in certain food processing operations with regards to time, space and energy savings, as it ensures preservation of nutritional value, process control, and selective heating (Ekezie et al. 2017a, b;. Guo et al. 2017). Microwave heating mechanism differs from conventional methods. Volumetric heating is the most important feature of microwave heating. Absorption of microwave energy results in internal heat generation within product. However, in traditional heating methods, the heat is transmitted from the surface to the inside of the food. The popularity of microwave heating increases in heat treatment applications because of increasing preference for high quality products that can be prepared in a short period of time along with the development of technology (Cui et al. 2004; Sahin et al. 2007; Barutcu et al. 2009a; Wojdylo et al. 2014; Karacabey et al. 2016; Icier et al. 2017; Leone et al. 2017).

Deep frying is a very fast way of preparing foods with unique sensory properties of color, flavor, texture, and palatability. Hubbard and Farkas (2000) defined frying process as the immersion of a food product in edible oil heated above the boiling point of water. Frying may be considered as a dehydration process (Achir et al. 2009). In the process of frying, certain physical and chemical changes occur inside the product (Dobarganes et al. 2000; Mittal 2009; Zhang et al. 2012; Bordin et al. 2013). Chemical changes are caused by the effect of the temperature and dehydration. One of the most important of these chemical changes is protein denaturation. Denaturation causes the degradation of bonds in the tertiary and secondary structure of proteins. Since the denaturation temperature is below 100ºC, not only the surface, but also inner side of fried foods experience protein denaturation (Gao et al. 2009; Pokorny and Dostalova 2011; Yu et al. 2017).

Chicken products are one of the most popular foods preferred as fried. Chicken breast meat is composed of approximately 74% water, 23% protein and 1.2% fat (Öztan 1999). Muscle tissue proteins are classified into three main groups, including sarcoplasmic, myofibrillar and connective tissue proteins (Smith 2001; Öztan 1999). Chicken breast protein is composed of 62.63% myofibrillar and 35.71% sarcoplasmic proteins (Murphy et al. 1998). The most important myofibrillar proteins are myosin (43%), actin (22%), titin (8%), troponin (5%), tropomyosin (5%), nebulin (3%) and α –actinin (2%) (Schreurs 2000). There are several studies related to myofibrillar proteins in chicken meat in the literature (Hay et al. 1973; Foegeding, 1987; Murphy and Marks 2000; Kurozawa et al. 2008). The studies examining the effects of heating process on chicken meat proteins through SDS-PAGE method are also available in the literature (Murphy and Marks 2000; Murphy et al. 2001; Nishimura et al. 2004; Wattanachant et al. 2005; Llorca et al. 2007; Okitani et al. 2009; Gao et al. 2009). It is recorded that increasing cooking temperature causes degradation of high molecular weighted proteins (Murphy and Marks 2000). The reduction of the intensity of certain protein bands while some others becoming more apparent indicates denaturing effect of the heat as well as the emergence of new protein interactions by heat (Murphy and Marks 2000; Llorca et al. 2007). However, the effect of heat is examined by using water bath (Murphy and Marks 2000; Wattanachant et al. 2005) and convection oven (Murphy et al. 2001) in these studies. For the chicken products cooked in convection oven, it is observed that as the temperature increases, soluble proteins decrease (Murphy et al. 2001). In a study on batter-coated squid rings, it is reported that frying process degrades protein fraction, specifically myofibrillar proteins, of squid rings (Llorca et al. 2007).

Although frying is one of the oldest cooking methods used quite prevalently and popularly in food industry, high fat content and the formation of acrylamide which is a probable human carcinogen, directed researchers to conduct studies to diminish health hazard effects of frying process (Granda et al. 2004; Masson et al. 2007; Ziaiifar et al. 2008; Moreira 2014; Koklamaz et al.2014; Hosseini et al. 2016; Kurek et al. 2017). Considering various studies in literature, microwave frying method can be proposed as a new way of improving the quality of fried foods (Sahin et al. 2007; Oztop et al. 2007; Barutcu et al. 2009a, b). During microwave heating, the most significant material properties affecting the heating performance are the electromagnetic properties, especially the dielectric properties of the food. Dielectric properties of food products depend primarily on their moisture, salt and solid contents (Mudgett 1982, 1986; Venkatesh and Raghavan 2004). Dielectric properties of oil are known to be very low (Venkatesh and Raghavan 2004; Tang 2005). However it is known that other than dielectric properties, thermal properties also play important role in microwave heating of foods (Sumnu and Sahin 2012). It has been stated in literature that depending on the sample size, oil may be heated faster than the water in microwave oven due to its low specific heat (Ohlsson 1983; Schiffmann 1986). During microwave frying, heat generation creates a significant internal pressure within the food. This increases rate of moisture removal from the product and shortens the frying time (Datta 1990; Feng and Tang 1998; Sahin and Sumnu 2009). However, it is known that microwave interact in different ways with different food components. In the sense of understanding the effect of microwave on frying process, this interaction should be examined thoroughly.

In this study, possible effects of microwave frying on myofibrillar and sarcoplasmic protein structure of chicken breast meat were examined at different frying times. The quality parameters of hardness and color of samples were also evaluated. In order to understand the effect of microwave frying method on the structure of chicken meat protein, SDS-PAGE results acquired from microwave fried chicken samples were compared with conventionally fried ones. The examination of the effects of microwave frying process which is considered as an alternative way of conventional frying method, on the protein structure of chicken meat is important as it provides new information on the applicability of this method.

Material and Methods

Material

Chicken breast meat and sunflower seed oil used in the research was obtained from a local market. All chemicals used were of analytical grade and were used as received without any further purification. Chemicals were obtained from Merck (Darmstadt, Germany) and Sigma Chemicals Co. (St. Louis, MO) unless otherwise noted.

Sample Preparation
Chicken breast meats bought from a local market were stored at -18ºC until being used. Before the experiments, frozen breast meats were thawed in the refrigerator (+4ºC) and then cut into pieces (7.5 x 1.7 x 1.1 cm) with a weight of 12±1 g.

Frying
A domestic microwave oven (Arçelik, Turkey) was use for microwave frying. First, 750 mL of oil, placed in a glass container, was heated to the frying temperature (180±1ºC) by using 365W microwave power level. It took nearly 50 minutes to heat up the oil from room temperature to 180±1ºC. Then, frying of chicken breast slices were performed in hot oil at two different times (0.5 (MW0.5) and 1.5 (MW1.5) minutes) at 365W power level. Only one piece was immersed into frying oil each time. The oil temperature was monitored by a fiber optic temperature probe (FISO Technologies, Inc, Quebec, Canada). IMPI (International Microwave Power Institute) 2-L test was used to determine the power level of microwave oven (Buffler 1993). For comparison, conventional frying was conducted in commercial bench-top deep fryer containing same amount of oil (TEFAL, France) at 180±1°C. The frying times were chosen by undertaking preliminary experiments. Microwave frying for 1.5 min and conventional frying for 5.0 minutes were found to provide acceptable final product based on preliminary sensory trials. Therefore, the samples were fried in conventional fryer for 5.0 (CF5.0) minutes. To see the effect of conventional frying time on investigated parameters, the samples were also fried in conventional fryer for 2.0 minutes (CF2.0) which provided similar color development when compared to 0.5min microwave frying according to preliminary trials.

Moisture content analysis

Moisture content of the samples was determined by drying in an oven (FN 500, Nüve A.Ş, Turkey) at 105°C until constant weight (AOAC 1995) and results were expressed on a % wet basis (g water/100 g wet sample).

Color analysis

The color values of samples were measured with a Minolta Chromameter CR-400. CIE L*, a*, b* color parameters were measured at four different locations of each sample. For each sample, results represent the arithmetic mean of three replications.

Textural analysis

Texture Analyzer TA.XT.plus (Stable Micro System, England) equipped with a cylindrical probe in 2mm diameter and 50N load cell was used in hardness testing of the fried chicken samples. The probe proceeded to penetrate a predetermined percentage of the sample thickness (40%) at a rate of 3.0 mm/s pre-test speed and 1.0 mm/s test speed and then was pulled out from the sample at 10mm/s speed. The values of hardness were calculated by using instrument software (Texture Exponent v.6.1.1.0, Stable Microsystems). For each sample, results represent the arithmetic mean of eight replications.

Protein content analysis

Protein contents of raw and fried chicken samples were determined by using Kjeldahl method (AOAC 1995). Nitrogen conversion factor was 6.25.

SDS-PAGE analysis

Protein extraction
A modification of the method of Claeys et al. (1995) was used. Raw/fried chicken samples were chopped and about 2.5 g of chopped sample was homogenized (Ultra Turrax T18) in 25 mL buffer solution (0.25M sucrose, 0.05M Tris, 1mM EDTA, pH 7.6 at 4°C) for 2min (speed: 12 000 1/ min). Homogenized samples were

centrifuged at 1000 × g for 10 min (IEC Centra CL2 Centrifuge). The supernatant was retained and used as a source of sarcoplasmic proteins. It was kept at -80°C until being used. The pellet was resuspended in 25 mL of the same buffer solution for two times each followed by centrifugation at 1000 × g for 10 min and supernatant was discarded. The pellet was resuspended in 25 ml of 0.05M Tris and 1mM EDTA buffer solution (pH 7.6 at 4°C) and centrifuged again (1000 × g for 10 min). After decanting the supernatant the procedure was repeated with 25 ml of 0.15 M KCI solution (4°C). pH was adjusted by using HCl. After centrifugation the pellet was frozen with liquid nitrogen and stored at -80°C.

Preparation of samples for SDS-PAGE

Frozen pellet and supernatant samples were thawed in ice-water. 0.3gr of pellet was dissolved in 3ml of sample buffer pH 7.6 containing 0.03M Tris, 0.15M KCl (at 4°C). Solution was filtered to remove connective tissue (Whatman 41-20-25µm). Supernatant was first passed through Whatman 41 filter. After centrifugation of the filtrate at 2000 × g for 15 min (4°C) (Mikro 200R Hettich, Zentrifugen), the upper part was filtered again (Whatman 40-8 µm). Protein contents of the filtrates both from pellet and supernatant were determined by Bradford Micro Assay (Bradford, 1976). Bovine serum albumin was used as the protein standard (P0834, Sigma-Aldrich).

Electrophoresis

After mixing with loading buffer at a ratio of 1:5 (loading buffer: sample solution), 5µl of each protein solution and 5µl of marker were loaded on a polyacrylamide gel (5% stacking and 12.5% separating gel) (Mazi et al. 2016). The apparatus used was a Mini Protean II system (BIO-RAD Laboratories, Richmond, CA). Separation was achieved at constant voltage 10 V at separating gel at room temperature. The protein bands were visualized by staining with Coomassie Brillant Blue R (B7920 Sigma-Aldrich) and compared with molecular-weight markers (PageRuler^{TM} Plus Prestained Protein Ladder #SM1811 and Thermo Scientific Spectra Multicolor Broad Range Protein Ladder # 26623).

SEM analysis

Microstructure of the chicken breast muscle was analyzed by using a low vacuum (0.003kPa) scanning electron microscope (Hitachi SU1510, Tokyo, Japan) with a constant voltage of 15kV. All the images were taken at 100X magnification. Fried chicken breast samples (7.5 x 1.7 x 1.1 cm) were dissected by a disposable scalpel to approximately 1 cm × 1 cm × 0.25 cm pieces.

Statistical analysis

The data represent mean ± standard deviation (SD) of triplicate determinations unless otherwise specified. The results were assessed by analysis of variance (ANOVA). Differences among individual means were compared by using Tukey Comparison test ($p \leq 0.05$) (MINITAB for Windows, Version 14).

Results and Discussion

The moisture content of raw chicken breast was averagely 72.9% (wet basis) and it decreased to approximately 32.7% after 1.5 min microwave frying. Chicken samples reached similar moisture content when conventionally fried for 5.0 minutes (Table 1). In addition, to examine the effect of frying time, chicken samples were also fried in microwave oven for 0.5 min and conventional fryer for 2.0 min. As the frying time increased, moisture content of chicken samples decreased significantly for both frying methods. The moisture content of 1.5 min microwave fried and 5.0 min conventionally fried samples were found to be similar. Since water contents of samples decreases by frying process, in order to make an accurate assessment regarding protein contents of fried samples, protein contents were calculated considering the weight loss following the frying process (Table 1). A fall in percentage of protein content (on a dry matter basis) was noted in the fried samples, except 0.5 minute microwave fried one, compared to the raw chicken meat. It is known that proteins, peptides and amino acids in foods take part in some reactions like non-enzymatic browning, generating new compounds during frying (Velasco et al. 2009; Bordin et al. 2013). It is stated in literature that thermal treatment may result in destruction of some amino acids and reduction in the amount of protein (Henry 1998; Bordin et al. 2013). Microwave frying for 0.5min did not result a significant change in protein content which is thought to be due to very low processing time.

Table 1. Moisture and protein contents of chicken breast muscle samples: microwave fried for 0.5 min (MW0.5), microwave fried for 1.5 min (MW1.5), conventionally fried for 2 min (CF2.0), conventionally fried for 5 min (CF5.0).

Sample	Moisture content (w.b.%)	Protein content (d.b.%)
Raw	72.9±0.75a*	94.8±0.23a
MW0.5	59.3±1.26b	90.9±1.70ab
MW1.5	32.7±2.26d	82.2±3.22c
CF2.0	50.3±2.56c	83.2±0.25bc
CF5.0	29.7±2.05d	84.5±0.70bc

* Values with different letters (a, b, c) in the same column are significantly different ($p \leq 0.05$).
Values are mean ± standard deviation

CIE L*, a* and b* values of samples were given in Table 2. For both frying methods, an increase in frying time resulted in significant changes in crust color as expected ($p<0.05$). There was a reduction in L* (lightness) values and an increase in a* (redness) parameter with increasing frying time for all samples which indicates that the chicken breast samples became darker and got more red. The increase in darkness with increasing frying temperature and time has been reported for fried food products such as potatoes and chicken nuggets (Innawong et al. 2006; Ngadi et al. 2007; Oztop et al. 2007). Conventional frying for 5 min provided the lowest L* and highest a* values. Although, the moisture content of 1.5min microwave fried and 5.0 min conventionally fried samples were similar, the L* and a* color parameters of these samples were found to be quite different. There was a significant increase in b* (yellowness) values with increasing frying time for both frying methods.

Textural quality is another important attribute for the acceptability of fried foods. Increasing frying time increased the hardness value of samples in conventional frying method (Table 2). However, the increase in hardness value was not statistically significant in the case of microwave frying. The highest value of hardness was obtained with 5min conventionally fried sample. Li (2005) investigated the quality changes in chicken nuggets during deep fat frying and showed that during deep fat frying at different temperatures, hardness values of chicken nuggets increased with increasing frying time, similar to this study. The textural changes of muscle foods are related to the effect of heat on major muscle proteins (Martens et al. 1982; Bertola et al. 1994; Kong et al. 2008). Bertola et al. (1994) studied the relationship between protein denaturation and textural changes in beef muscle subjected to heat treatment in a thermostatic bath in the 60-90°C range. They noted that actin denaturation caused an increase in hardness of muscle. Martens et al. (1982) stated that firmness of bovine muscle increased due to thermal denaturation of myosin and actin. During microwave heating, the temperature of chicken muscle rises more rapidly as compared to conventional frying due to internal heat generation. Moreover, Brunton et al. (2006) measured the dielectric properties of beef muscle during heating (5-8°C) to assess protein denaturation and recorded an increase in dielectric constant (ε') and also in loss factor (ε'') above 65-66°C and explained that the reason may be the fluid release on collagen and myosin denaturation. A rise in loss factor provides faster microwave energy absorption generating higher internal pressure. The higher internal pressure created in microwave fried muscle tissue resulted greater voids between muscle fibers (Figure 3) which may be a reason for its lower hardness value.

Table 2. Hardness (N) values and color parameters of chicken breast muscle samples: microwave fried for 0.5 min (MW0.5), microwave fried for 1.5 min (MW1.5), conventionally fried for 2 min (CF2.0), conventionally fried for 5 min (CF5.0).

Sample	Hardness (N)	L*	a*	b*
MW0.5	3.03±0.47b*	76.43±0.15a	4.23±0.54c	17.74±0.47b
MW1.5	3.52±0.63b	61.65±1.95b	7.02±0.77b	24.08±1.36a
CF2.0	3.67±0.46b	74.27±1.65a	5.28±0.46c	20.06±1.99b
CF5.0	6.83±0.66a	50.05±1.41c	12.28±0.39a	27.18±0.57a

* Values with different letters (a, b, c) in the same column are significantly different ($p \leq 0.05$).
Values are mean ± standard deviation.

Actin and myosin form considerable part of myofibrillar proteins. Actin forms 20-25% of myofibrillar proteins, whereas myosin forms 50-55% (Öztan 1999). The remaining are composed of regulatory proteins (tropomyosin, troponin, M-proteins, α- and β-actinin, C-protein) and scaffold proteins such as titin, nebulin, desmin, vimentin and synemin supporting the whole myofibrillar structure (Tornberg 2005).

It is shown in previous studies that molecular weight of each myosin heavy chain in chicken breast meat is 200 kDa (Hay et al. 1973; Murphy and Marks, 2000). While the molecular weight of globular actin (G-actin) in

chicken breast meat is generally accepted as 46 kDa, it has been reported to be between 42-49 kDa in different studies (Hay et al. 1973; Murphy and Marks, 2000; Kurozawa et al. 2008). In this study, molecular weights of myosin heavy chain and actin in raw chicken meat samples were found as 200 kDa and 47 kDa respectively, as it is seen in Figure 1. The results are matching with data in literature.

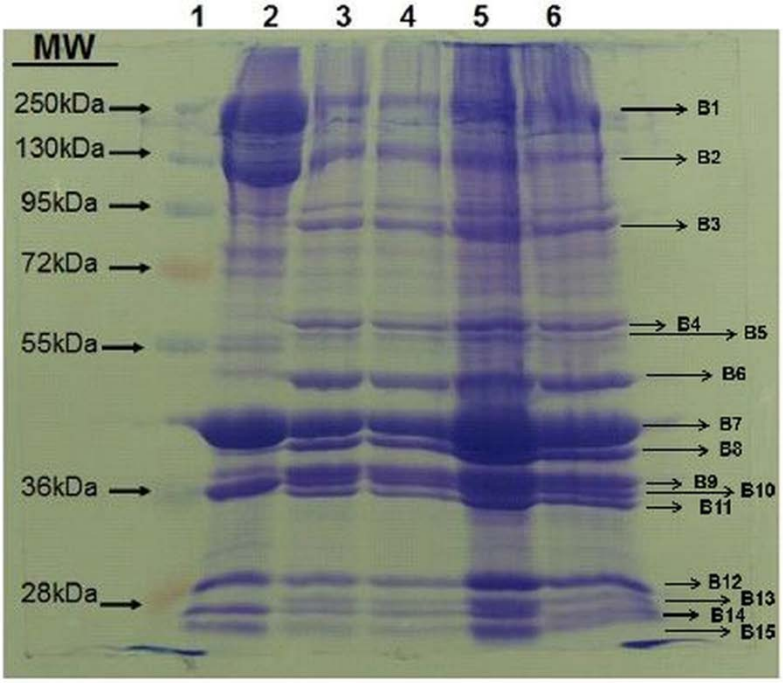

Figure 1. SDS-PAGE of the chicken breast muscle myofibrillar proteins. 1) standard, 2) raw sample, 3) microwave fried for 0.5 min, 4) microwave fried for 1.5 min, 5) conventionally fried for 2 min, 6) conventionally fried for 5 min.

Considering the intensity of the myosin heavy chain band (B1), it was seen that the intensity of band decreased considerably for both frying methods. Any significant change in the intensity of actin band (B7) was not recorded. Regarding frying time and frying methods, any remarkable difference between myosin heavy chain band and actin band of samples was not observed. In the studies in literature, it is seen that similar results are acquired from different type of heat treated meats. Huang et al. (2011), identified significant decrease in intensity of myosin band in SDS-PAGE profile of myofibrillar proteins extracted from pork meat heated to 100°C internal temperature by using water bath, while reported barely change in the intensity of actin band. In an another study, batter-coated squid ring samples were fried at 180°C for 30 seconds and 3 minutes and it was reported that the intensity of myosin heavy chain (160 kDa), M-protein and C-protein (140 kDa) bands decreased compared to raw sample, whereas frying time was ineffective (Llorca et al. 2007). They explained this reduction in the intensity of protein bands with the formation of new protein interactions as a result of denaturation which changes the extraction of proteins.

Murphy and Marks (2000) investigated the effect of temperature on chicken breast meat proteins, For this purpose, ground chicken breast patties were placed in a brass container and heated in a water bath at different temperatures (40, 50, 60, 70, 80°C). They reported that, the major remaining bands were the bands having molecular weight less than 38 kDa at 80°C. This situation was explained as increasing cooking temperature resulting in fragmentation of muscle proteins with higher molecular weight. Reviewing SDS-PAGE results of this study, it was seen that while the intensity of high molecular weighted bands decreased significantly in a similar way, these protein bands did not disappear at all. It was thought that short heat treatment time may be the reason for this. In the process of microwave frying, internal temperature of the product increases faster in comparison to conventional frying process. It was shown that internal temperature of coated chicken breast meat samples reached over 90°C in microwave oven for less than 30 seconds and in convection oven for nearly 2 minutes (Barutcu et al. 2009b).

The intensity of the high molecular weight band under the myosin heavy chain band in raw meat sample (B2) decreased with frying process, notwithstanding, the intensity of certain bands having lower molecular weights (B3, B5, B8, B9) increased and some new bands (B4, B6, B11, B13) emerged. When the literature considered,

it can be stated that the bands with molecular weights between 80-160 kDa involve α actinin, β-actinin and M-proteins (Hay et al. 1973; Maruyama 1971; Masaki and Takaiti 1972). In a study focusing on the effect of heat on protein degradation of pork muscle fibers, Huang et al. (2011) found that protein bands having molecular weights of 47–60 kDa emerged at 60°C and the density of these bands increased with increasing internal temperature up to 100°C. The band just below the actin band (B8) was reported to represent the subunits of M line of chicken breast myofibrillar proteins (Hay et al. 1973; Morimoto and Harrington 1972).

The intensity of the band having 36 kDa molecular weight (B10) in the raw meat sample was found to decrease with frying process. Hay et al. (1973) showed this band as tropomyosin. Also, molecular weight of troponin T was reported as 36kDa (Huang et al. 2011) and 33.5 kDa (Wilkinson 1978) in different studies. The post mortem degradation of troponin-T and the appearance of bands ranging from approximately 28–32 kDa has frequently been reported (Huang et al. 2009; Ho et al. 1994). It is thought that band B11 in this study is a fraction of Troponin T degraded by heat.

Additionally, it is known that myosin light chain (10-25kDa) (Hay et al. 1973; Lowey and Risby 1971), Troponin I and Troponin C (Wilkinson 1978; Ebashi et al. 1971) emerge in the region below the actin band. In this study, the intensity of certain bands having lower molecular weight than 28 kDa decreased and new bands (B13) appeared with frying.

Sarcoplasmic proteins of samples were shown in Figure 2. Sarcoplasmic proteins are globular proteins and composed of 100-200 different proteins (myoglobin, hemoglobin, some enzyme and cytochrome proteins etc.) (Öztan 1999). There are small numbers of studies in literature related to identification of sarcoplasmic protein bands in chicken breast meat. In a study, 40 bands were determined in the sarcoplasmic fraction of chicken breast muscle. It was reported that molecular weights of the most intensive bands among 40 diverging bands were 93.0 kDa, 55.2 kDa, 46.9 kDa, 42.9 kDa, 40.0 kDa and 37.8 kDa, and these bands involve glycogen phosphorylase, elongation factor-1, enolase, pyruvate kinase, creatine kinase, fructose-bisphosphate aldolase, glyceraldehyde 3-phosphate-dehydrogenase (GAPDH), and cofilin-1 (Zapata et al. 2012). Considering the results of this study, it was seen that appearing main sarcoplasmic protein bands were matching with literature. Except for the sample that was conventionally fried for 5 minutes, no considerable differences between samples were discovered. In the sample deep fried for 5 minutes, the emergence of a new band between the bands B6 and B7 was observed. It can be inferred that this difference may derived from the fragmentation of certain proteins with high molecular weight as a result of being exposed to same temperature for a longer period of time.

1.5 min microwave fried samples and 5 min conventionally fried samples were acceptable for consumption based on preliminary sensory trials. The muscle fibers of these fried samples can be seen in the scanning electron micrographs shown in Figure 3. It is clear from the figure that the muscle structure degraded in both samples. Muscle fibers were broken in different bundles. The voids between muscle fibers seem to be greater in Figure 3b. These two samples have similar moisture contents. The rate of moisture removal from the microwave fried sample was higher. The higher internal pressure created in sample during microwave frying may be one of the reasons for the increased space between the bundles. Astruc et al. (2010) detected an increase in gaps between the myofibrillar mass in bovine muscle subjected to heating at 100°C for 15 min. They also stated that the gaps between the myofibrillar mass are greater for the samples subjected to short heating at high temperatures. Hutton et al. (1981) evaluated the structural changes of beef muscle cooked by conventional heat and microwave energy to endpoint temperatures of 40, 50, 60, 70°C by scanning electron microscopy and detected more fiber fragmentation in microwave cooked samples.

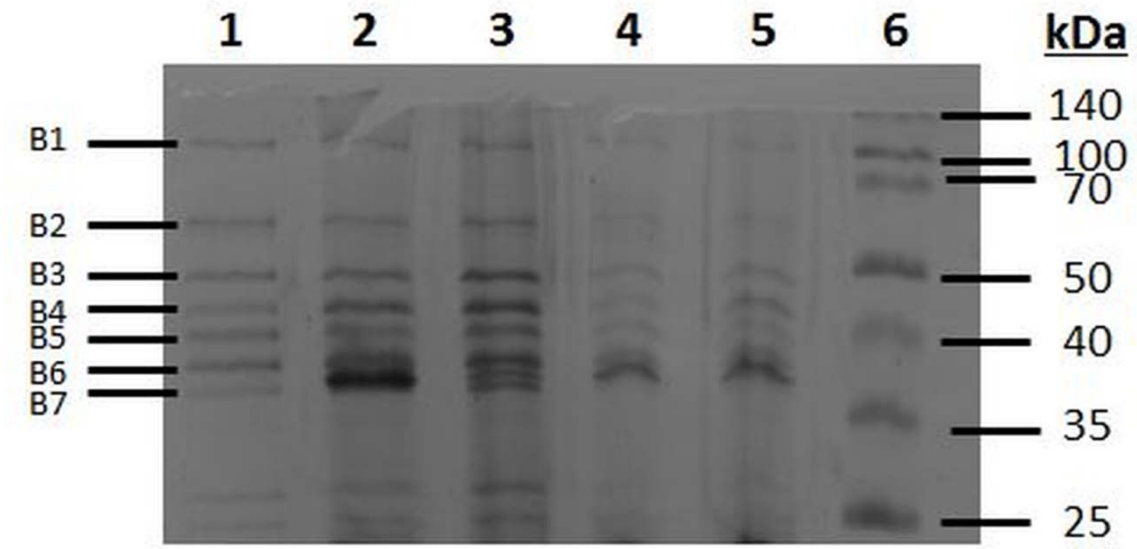

Figure 2. SDS-PAGE of the chicken breast muscle sarcoplasmic proteins. 1) standard, 2) raw sample, 3) microwave fried for 0.5 min, 4) microwave fried for 1.5 min, 5) conventionally deep fried for 2 min, 6) conventionally deep fried for 5 min.

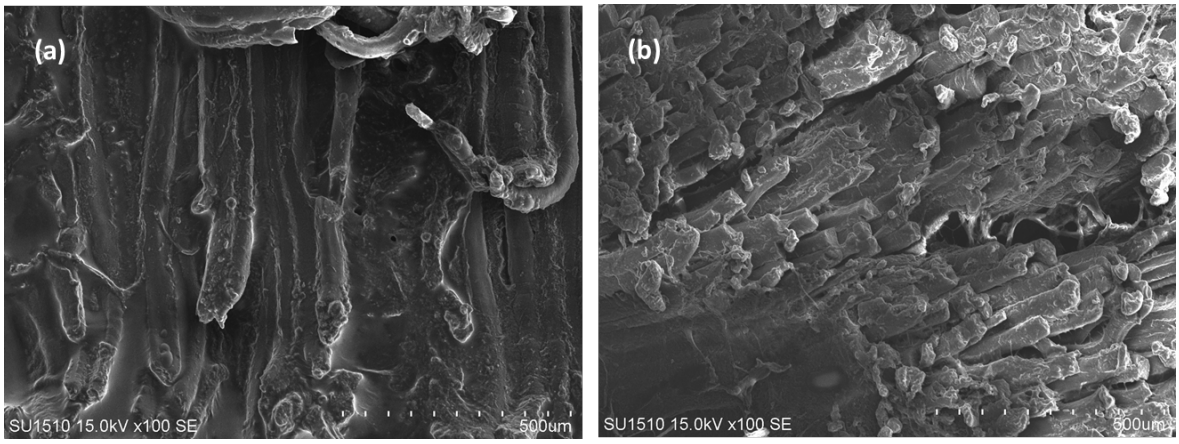

Figure 3. Microstructure of the chicken breast muscle a) conventionally deep fried for 5 min and b) microwave fried for 1.5 min. Magnification of 100× at acceleration voltage of 15 kV.

Conclusions

The samples fried for 1.5 min in microwave oven and 5 min in conventional deep fryer were acceptable for consumption. Microwave frying for 1.5 min provided light colored samples with lower hardness values compared to conventional frying for 5 min. The mechanism of frying with microwave energy is quite different from that of conventional frying. Both thermal and non-thermal mechanisms may be effective in the interaction of microwaves with food. In this study there are no observed significant effect of microwave frying on myofibrillar and sarcoplasmic protein bands compared to conventional frying. Frying time did not also result in a considerable change in SDS-PAGE pattern of fried samples. There are still a lot of debates around possible non-thermal effects of microwave irradiation and more research needs to be done in this area.

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References

AOAC (1995). Official Methods of Analysis, 16th ed., Association of Official Analytical Chemists, Washington.

Achir N, Vitrac O, Trystram G (2009). Het and mass transfer during frying. In Advances in Deep Fat Frying of Foods, (Sahin S, Sumnu SG, eds.) pp. 115-142, CRC Press, New York.

Astruc T, Gatellier P, Labas R, Lhoutellier VS, Marinova P (2010). Microstructural changes in M. rectus abdominis bovine muscle after heating. Meat Sci. 85(4): 743-51.

Barutcu I, Sahin S, Sumnu G (2009a). Acrylamide formation in different batter formulations during microwave frying. LWT--Food Sci. Technol. 42(1): 17-22.

Barutcu I, McCarthy MJ, Seo YS, Sahin S (2009b). Magnetic resonance temperature mapping of microwave-fried chicken fingers. J. Food Sci. 74(5): E234-E240.

Bertola NC, Bevilacqua AE, Zaritzky NE (1994). Heat treatment effect on texture changes and thermal denaturation of proteins in beef muscle. J Food Process Preserv.18(1): 31-46.

Bordin K, Kunitake MT, Aracava KK, Favaro-Trindade CS (2013). Changes in food caused by deep fat frying - A review. Arch Latinoam Nutr. 63 (1): 5-13.

Bradford MM (1976). A rapid and sensitive method for the quantification of microgram quantities of protein utilizing the principle of protein-dye binding. Anal Biochem, 72: 248–254.

Buffler CR (1993). Microwave Cooking and Processing: Engineering Fundamentals for the Food Scientist, 1st ed., Springer, New York.

Claeys E, Uytterhaegen L, Buts B, Demeyer D (1995). Quantification of beef myofibrillar proteins by SDS-PAGE. Meat Sci. 39(2): 177–193.

Cui ZW, Xu SY, Sun DW. (2004). Effect of microwave-vacuum drying on the carotenoids retention of carrot slices and chlorophyll retention of Chinese chive leaves. Drying Technol, 22(3): 563-575.

Dobarganes C, Marquez-Ruiz G, Velasco J (2000). Interactions between fat and food during deep-frying. Eur J Lipid Sci Tech, 102: 521–52.

Ebashi S, Wakabayashi T, Ebashi F (1971). Troponin and its components. J. Biochem. 69(2): 441-445.

Ekezie FGC, Sun DW, Han Z, Cheng JH (2017a). Microwave-assisted food processing technologies for enhancing product quality and process efficiency: A review of recent developments. Trends Food Sci Technol. 67: 58-69.

Ekezie FGC, Sun DW, Cheng JH (2017b). Acceleration of microwave-assisted extraction processes of food components by integrating technologies and applying emerging solvents: A review of latest developments. Trends Food Sci Technol. 67: 160-172.

Foegeding EA (1987). Functional properties of turkey salt-soluble proteins. J. Food Sci. 52(6): 1495-1499.

Gao H, Mao M, Liang C, Lin C, Xiang J (2009). Detection of the end point temperature of thermal denatured protein in fish and chicken meat through SDS-PAGE electrophoresis. J Ocean Univ China. 8(1): 95-99.

Granda C, Moreira RG, Tichy SE (2004). Reduction of acrylamide formation in potato chips by low-temperature vacuum frying. J Food Sci. 69(8), E405:E411.

Guo QS, Sun DW, Cheng JH, Han Z (2017).Microwave processing techniques and their recent applications in the food industry. Trends Food Sci Technol. 67: 236-247.

Hay JD, Currie RW, Wolfe FH (1973). Polyacrylamide disc gel electrophoresis of fresh and aged chicken muscle proteins in sodium dodecylsulfate. J. Food Sci. 38(6): 987-990.

Henry CJK (1998). Impact of fried foods on macronutrient intake, with special reference to fat and protein. Grasas y Aceites, 49(3-4), 336-339.

Ho CY, Stromer MH, Robson RM (1994). Identification of the 30 kDa polypeptide in post mortem skeletal muscle as a degradation product of troponin-T. Biochimie. 76(5): 369–375.

Hosseini H, Ghorbani M, Meshginfar N, Mahoonak AS (2016). A Review on Frying: Procedure, Fat, Deterioration Progress and Health Hazards. J Am Oil Chem Soc. 93(4), 445-466.

Huang M, Huang F, Xu X, Zhou G (2009). Influence of caspase3 selective inhibitor on proteolysis of chicken skeletal muscle proteins during post mortem aging. Food Chem 115(1): 181–186.

Huang F, Huang M, Xu X, Zhou G (2011). Influence of heat on protein degradation, ultrastructure and eating quality indicators of pork. J. Sci. Food Agric. 91(3): 443- 448.

Hubbard LJ, Farkas BE (2000). Influence of oil temperature on convective heat transfer during immersion frying. J. Food Process. Preserv. 24(5): 143-162.

Hutton CW, Neggers YH, Love TO (1981). Scanning electron microscopy, proteolytic enzyme activity, and acceptability of beef semitendinosus cooked by microwaves and conventional heat. J Food Sci. 46(5): 1309-1314.

Icier F, Cokgezme OF, Sabanci S (2017). Alternative thawing methods for the blanched/non-blanched potato cubes: microwave, ohmic, and carbon fiber plate assisted cabin thawing. J Food Process Eng. 40(2): e12403.

Innawong B, Mallikarjunan P, Marcy J, Cundiff J (2006). Pressure conditions and quality of chicken nuggets fried under gaseous nitrogen atmosphere. J. Food Process. Preserv. 30(2): 231-245.
Karacabey E, Özçelik ŞG, Turan MS, Baltacıoğlu C, Küçüköner E. (2017). Optimization of microwave-assisted predrying and deep-fat-frying conditions to produce fried carrot slices. J Food Process Eng. 40(2): e12381.
Koklamaz E, Palazoglu TK, Kocadagli T, Gokmen V (2014). Effect of combining conventional frying with radio-frequency post-drying on acrylamide level and quality attributes of potato chips. J Sci Food Agric. 94(10): 2002-2008.
Kong F, Tang J, Lin M, Rasco B (2008). Thermal effects on chicken and salmon muscle: Tenderness, cook loss, area shrinkage, collagen solubility and microstructure. Food Sci Technol. 41: 1210-1222.
Kurek M, Scetar M, Galic K (2017). Edible coatings minimize fat uptake in deep fat fried products: A review. Food Hydrocoll, 71, 225-235.
Kurozawa LE, Park KJ, Hubinger MD (2008). Optimization of the enzymatic hydrolysis of chicken meat using response surface methodology. J. Food Sci. 73(5): C405-C412.
Leone A, Romaniello R, Tamborrino A, Xu XQ, Juliano P (2017). Microwave and megasonics combined technology for a continuous olive oil process with enhanced extractability. Innov Food Sci Emerg Technol. 42: 56-63.
Llorca E, Hernando I, Perez-Munuera I, Quiles A, Larrea, V, Lluch M (2007). Protein breakdown during the preparation of frozen batter-coated squid rings. Eur. Food Res. Technol. 225(5-6): 807-813.
Lowey S, Risby D (1971). Light chains from fast and slow muscle myosins. Nature 234: 81–85.
Martens H, Stabursvik E, Martens M (1982). Texture and olour changes in meat during cooking related to thermal denaturation of muscle proteins. J Texture Stud. 13(3): 291-309.
Maruyama K (1971). A study of β-actinin myofibrillar protein from rabbit skeletal muscle. J. Biochem. 69: 369.
Masaki T, Takaiti O (1972). Purification of M-protein. J. Biochem. 71(2): 335-7.
Masson L, Munoz JR, Romero N, Camilo C, Encina C, Hernandez L, Castro J, Robert P (2007). Acrylamide in fried potatoes: An updated review. Grasas Aceites, 58(2): 185-193.
Mazi BG, Hamamci H, Ogrydziak DM, Dungan SR (2016). Single-step partial purification of intracellular beta-galactosidase from *Kluyveromyces lactis* using microemulsion droplets. Appl Biochem Biotechnol. 180(5): 1000-1015.
Mittal GS (2009). Physical properties of fried products. In Advances in Deep Fat Frying of Foods, (Sahin S, Sumnu SG, eds.) pp. 5-33, CRC Press, New York.
Moreira RG (2014). Vacuum frying versus conventional frying - An overview. Eur J Lipid Sci Technol. 116(6): 723-734.
Morimoto K, Harrington WF (1972). Isolation and physical chemical properties of an M-line protein from skeletal muscle. J. Biol. Chem. 247(10): 3052-3061.
Mudgett RE (1982). Electrical properties of foods in microwave processing. Food Technol. 36: 109-105.
Mudgett RE (1986). Microwave properties and heating characteristics of foods. Food Technol. 40(6): 84-93.
Murphy RY, Johnson ER, Duncan LK, Clausen EC, Davis MD, March JA (2001). Heat transfer properties, moisture loss, product yield, and soluble proteins in chicken breast patties during air convection cooking. Poult. Sci. 80(4): 508-514.
Murphy RY, Marks BP (2000). Effect of meat temperature on proteins, texture, and cook loss for ground chicken breast patties. Poult. Sci. 79(1): 99-104.
Murphy RY, Marks BP, Marcy JA (1998). Apparent specific heat of chicken breast patties and their constituent proteins by differential scanning calorimetry. J. Food Sci. 63(2): 88-91.
Ngadi M, Li Y, Oluka S (2007). Quality changes in chicken nuggets fried in oils with different degrees of hydrogenation. Lebensm. Wiss. Technol. 40: 1784-91.
Nelson SO, Kraszewski AW (1990). Grain moisture content determination by microwave measurements. Transactions of the ASAE, 33: 1303-1307.
Nishimura K, Miyamoto Y, Higasa T (2004). Tender chicken breasts vacuum-cooked at 75°C. J Home Econ of Jpn. 55: 605–615.
Ohlsson T (1983). Fundamentals of microwave cooking. Microwave World, 4(2), 4.
Okitani A, Ichinose N, Itoh J, Tsuji Y, Oneda Y, Hatae K, Migita K, Matsuishi M (2009). Liberation of actin from actomyosin in meats heated to 65°C. Meat Sci. 81: 446-450.
Li Y (2005). Quality changes in chicken nuggets fried in oils with different degrees of hydrogenation. MSc diss., McGill University, Montreal, Quebec, Canada.
Oztop MH, Sahin S, Sumnu G (2007). Optimization of microwave frying of potato slices by using Taguchi Technique. J. Food Eng. 79(1): 83-91.
Öztan A (1999). Et Bilimi ve Teknolojisi, 19. ed., Hacettepe Üniversitesi Mühendislik Bilimi Yayınları, Ankara.

Pokorny I, Dostalova J (2011). Changes of nutrients, antinutritional factors and contaminants at frying temperatures. In Frying of Food: Oxidation, Nutrient and Non-nutrient Antioxidants, Biologically Active Compounds and High Temperatures, (Boskou D, Elmadfa I, eds.) pp. 71–104, CRC Press, Boca Raton.

Sahin S, Sumnu G, Oztop MH (2007). Effect of osmotic pretreatment and microwave frying on acrylamide formation in potato strips. J. Sci. Food Agric. 87(15): 2830-2836.

Sahin S, Samli R, Tan ASB, Barba FJ, Chemat M, Cravotto G, Lorenzo JM (2017). Solvent-free microwave-assisted extraction of polyphenols from olive tree leaves: antioxidant and antimicrobial properties. Molecules, 22(7): 1056.

Schiffmann RF (1986). Food product development for microwave processing. Food Technol. 94-98.

Schreurs FJG (2000). Post-mortem changes in chicken muscle. World's Poult. Sci. J. 56(4): 319-346.

Smith DM (2001). Functional properties of muscle proteins in processed poultry products. In Poultry Meat Processing, (Sams AE, ed.) pp. 181-195, CRC Press, Boca Raton.

Sumnu SG, Sahin S (2012). Microwave Heating. In Thermal Food Processing (Sun DW ED.) pp. 555-582, CRC Press, Boca Raton.

Tang J (2005). Dielectric properties of foods. In Microwave Processing of Food (Schubert H, Regier M eds) pp. 22-40. Woodhead Publishing Limited, Cambridge, UK.

Tornberg E (2005). Effects of heat on meat proteins – Implications on structure and quality of meat products, a review. Meat Sci. 70(3): 493-508.

Velasco J, Marmesat S, Dobarganes MC (2009). Chemistry of frying. In Advances in Deep Fat Frying of Foods, (Sahin S, Sumnu SG, eds.) pp. 33-56, CRC Press, New York.

Venkatesh MS, Raghavan GSV (2004). An Overview of microwave processing and dielectric properties of agri-food materials. Biosyst Eng. 88(1): 1-18.

Wattanachant S, Benjakul S, Ledward DA (2005). Effect of heat treatment on changes in texture, structure and properties of Thai indigenous chicken muscle. Food Chem. 93(2): 337-348.

Wilkinson JM (1978). The components of troponin from chicken fast skeletal muscle. A comparison of troponin T and troponin I from breast and leg muscle. Biochem. J. 169(1): 229-238.

Wojdylo A, Figiel A, Lech K, Nowicka P, Oszmianski J (2014). Effect of convective and vacuum–microwave drying on the bioactive compounds, color, and antioxidant capacity of sour cherries. Food Bioprocess Tech. 7(3): 829-841.

Yu TY, Morton JD, Clerens S, Dyer JM (2017). Cooking-induced protein modifications in meat. Compr Rev Food Sci Food Saf. 16(1): 141-159.

Zapata I, Reddish JM, Miller MA, Lilburn MS, Wick M (2012). Comparative proteomic characterization of the sarcoplasmic proteins in the pectoralis major and supracoracoideus breast muscles in 2 chicken genotypes. Poult. Sci. 91(7): 1654–1659.

Zhang Q, Saleh ASM, Chen J, Shen Q (2012). Chemical alterations taken place during deep-fat frying based on certain reaction products: A review. Chem Phys Lipids. 165(6): 662-681.

Ziaiifar AM, Achir N, Courtois F, Trezzani I, Trystram G (2008). Review of mechanisms, conditions, and factors involved in the oil uptake phenomenon during the deep-fat frying process. Int J Food Sci Tech. 43: 1410–1423.