Original Articles

Optimizing Oil Reduction in Fried Eggplant Rings

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ABSTRACT

The effect of thermal pretreatment using water or steam blanching; and chemical pretreatment by soaking in SO₂, chitosan, carboxy methylcellulose (CMC) or sodium chloride (NaCl) on moisture content, oil uptake, sensory evaluation, colour, electronic structure and frying quality of eggplant rings were investigated. Eggplant rings were blanched for 3min in water and steam, and soaked in 2% chitosan and CMC, 4% NaCl and 0.1% SO₂ solutions (25 °C) previous to frying, to study the effect on oil uptake, moisture content, colour and structure using electronic microscope. Sensory responses indicated the best texture and lowest oil uptake at 4% NaCl solution for 20 min. Soaking had no effect (P<0.05) on color (L*, a* and b*) or moisture and oil loss during deep frying at 180 °C for 4min. Sensory acceptability was not different (P<0.05) between the soaked product and a thermal sample. Frying eggplant rings at 180°C for 4 min was able to optimize the quality of eggplant rings regarding to L*, a*, C*, BI, ΔE-values and non-enzymatic browning (A420 nm). The oil uptake effect of various thermal and chemical pretreatments on eggplant rings was found to decrease in the following order water blanching > coated CMC > steam blanching > coated chitosan > SO₂ > sodium chloride > untreated samples. The fried pre-treated eggplant rings with coated CMC and water blanching gave lower moisture (2.19) and oil (7) content (% on dry matter) compared to other pre-treated samples. It is evident that fried eggplant rings after chemical (chitosan, CMC, salt and SO₂) and thermal treatments (steam and water blanching) contained numerous types of cellular fragments using electron microscopy. These results indicate that coating CMC and water blanching exhibited oil barrier properties and did not significantly affect the flavor of the product, irregardless of breading type, thus making it a promising alternative in lowering oil content of fried foods.

Key words: Eggplant; Rings; Steam; Chitosan; CMC; SO₂, Colour, Water content, Oil uptake, Frying, electronic microscope.

Introduction

Eggplant (Solanum melongena L.) is a plant of the family Solanaceae (also known as the nightshades) and genus Solanum. It bears a fruit of the same name, commonly used in cooking and frying. The fruit is capable of absorbing large amounts of frying oil. Production of eggplant is highly concentrated, with 85% of output coming for five countries. China is the top producer (56% of world output) and India is second (26%); Egypt, Turkey and Indonesia produce the remains amount. Its World production is around 32 million tons (FAOSTAT, 2009). Poor diet and/or unhealthy lifestyles contribute to various chronic health conditions that negatively affect the quality of life. Three of the top ten leading causes of death are diet-related, including coronary heart disease (contributes 21.1% of all deaths), cancer (23.4% of deaths), stroke (6.7% of deaths), and diabetes mellitus (2.5% of deaths) according to Singh (1996). All these complications are highly correlated to fat intake (Gebhardt, et al., 2006). Fried foods contain significant amounts of fats, reaching in some cases up to a third of the total food product by weight (Mellema, 2003). Consumers increasingly are aware of the need to lower their daily fat intake. Despite the trend towards lower fat foods, health problems related to high fat intake are still on the rise. This is probably due to the increasing trend to patronize fast food restaurantism, where deep-fat frying is one of the most popular methods of cooking. In addition to frequent visits to fast food outlets and restaurants, the consumption of snack foods which include deep fried foods, is high (Kuchler et al., 2004).

Deep-fat frying is a widely used food process which consists basically of immersion of food pieces in hot vegetable oil. The high temperature causes partial evaporation of the water, which moves away from the food and through the surrounding oil, and a certain amount of oil is absorbed by the food. Frying is often selected as a method for creating unique flavors and texture in processed foods that improve their overall palatability. Frying temperatures can range from 130 °C to 190 °C, but the most common temperatures are 170–190 °C. The high temperature of the frying fat typically leads to the appreciated surface color and mechanical characteristics of fried foods, and besides, heating of reducing sugars affects a complex group of reactions, termed caramelization,
leading to browning development which defines the color of the final product (Arabhosseini et al. 2009). Oil uptake is one of the most important quality parameters of fried food, which is incompatible with recent consumer trends towards healthier food and low fat products (Bouchon and Pyle, 2004). An alternative to reduce oil uptake in fried foods is the use of edible films or coatings. The application of hydrocolloid coatings (like chitosan and carboxymethylcellulose, CMC) allows to reduce oil content of deep-fat fried products due to its lipid barrier properties. Gellan and cellulose derivatives are widely used for this purpose (Mellema, 2003). Many researchers have suggested that oil absorption on the surface of the fried product occurs when samples are removed from the frying medium (Bouchon et al., 2003; Bouchon and Pyle, 2005a,b). This study was conducted to study color characteristics, oil uptake, water loss content and sensory evaluation to select the best frying conditions in eggplant rings.

The overall objective of this research is the optimization of a different pretreatment to reduce oil absorption of fried eggplant rings by utilizing a chemical (SO2, chitosan, CMC and sodium chloride) and thermal (steam blanching and water blanching) as a postbreading dip.

Materials and Methods

Preparation and pretreatments of eggplant rings:

Eggplant (Solanum melongena L. family Solanaceae) samples were obtained from local market during winter of 2011 and stored for using at 4°C. One hr prior to use, vegetables were removed from the refrigerator and equilibrated to room temperature. Each eggplant was rinsed with water, peeled, sectioned to rings at least 1cm from the skin end (to exclude the effects of bruising), exposing fresh surface and to eliminate some starch material adhering to the surface prior to frying; then treated separately with chemical solutions (2% Chitosan, 2% Carboxy methylcellulose (CMC), 0.1% Sodium metabisulfite (SO2) or 4% sodium chloride) or with water and steam blanching for 3 minutes.

Frying experiment process:

Fresh eggplant rings samples were dipped separately in fresh prepared CMC (2%), chitosan (2%), NaCl (4%), or sodium metabisulfite So2 (0.1%) for 20 min; or blanched separately in water and steam for 3 minutes, and then the rings were drained. Primary experiments were carried out for fresh eggplant rings 4, 6 and 8 min at 170, 180 and 190 ± 0.5 °C, respectively to study the best frying conditions.

Untreated eggplant rings were fried in a controlled temperature deep-fat fryer (Philips comfort, Germany) filled with 1.5 L of purified sunflower oil (Arma Crystal Company, Egypt) enriched with vitamins A and D, and contained 1.8g saturated fat, 3.8g mono-unsaturated fat and 8.4g poly-unsaturated fatty. Oil was replaced by fresh oil after four frying batches; three eggplant rings were fried in each batch. For each selected sampling time, the slices were drained after frying over a wire screen for 5 min and let cool at room temperature before analysis. The oil was preheated for 1 h prior to frying and discarded after 6 h of use as mentioned by (Blumenthal, 1991). Frying experiments were run in triplicate. Water content, oil uptake, colour characteristics and sensory evaluation were determined in fried eggplant rings samples as shown by Garcia et al., (2002) and Bertolini et al., (2008). Untreated or pretreated best eggplant rings were fried at 180°C for 4 min to study effect of different chemical and thermal pretreatments on water content and oil uptake of egg plant rings.

Moisture and oil contents determinations:

Moisture content:

Moisture content of the samples was analyzed according to the procedure described in the AOAC (2000) by drying the samples in a vacuum oven (Shel Lab, model 1410-E, USA) for 12 h until they reached constant weight.

Moisture content was determined by drying 5 g ground samples in duplicate at 105 °C, until constant weight was attained.

Water content:

Water content (WC) was determined by measuring weight loss of fried products, upon drying in an oven at 110 °C until constant weight (Garci’a et al., 2002). At different frying times the relative variation of water retention % (WR) in the coated or treated product relative to the uncoated or untreated one was calculated as follows:
WR = ((WC treated / WC untreated) -1)*100
The equilibrium water content was defined as the humidity reached at long frying times (1080 s).

Solids content:

Each extracted oil-free sample was placed in a Petri dish, dried in a forced air oven at 105°C to constant weight, and cooled in a desiccator (AOAC, 2000). Solids content of raw rings was determined using the same procedure.

Oil content:

Total oil content of ground chips was determined gravimetrically by Soxhlet extraction with petroleum ether (AOAC, 2000).

The oil content was determined by the method of Bligh and Dyer (1959). The initial proportions of chloroform/methanol/water were 1:2:1.8 and the final proportions 2:2:1.8.

Oil uptake:

Oil uptake (OU) of fried products was determined by measuring the oil content of dried samples using a combined technique of successive batch and semi-continuous Soxhlet extractions. The first batch extraction was performed with petroleum ether: ethylic ether (1:1) followed by a Soxhlet extraction with the same mixture and another with n-hexane.

Oil uptake relative variation % (OUR) in the coated or treated product relative to the uncoated or untreated one was calculated as follows:
OUR = ((1- (OU treated / OU untreated))*100
For each frying time condition, results were obtained using all the samples from at least three different batches.

Scanning electron microscopy for Microstructure determination:

Changes in the structure of eggplant tissue were determined in untreated and treated eggplant fried, using a Leo-435VP scanning electron microscope. The samples for SEM were fixed immediately after handling, by freezing in liquid nitrogen and spraying with gold.

One drop of this dispersion was put on the glass slide, air dried and gold covered in a Pelco Model S 150 A Sputter Coater metal evaporator (Edwards Co., UK). Micrographs and determination of particle size were made in or using a Scanning Electron Microscope (Model JSM-T20, JEOL LTD Company, Tokyo, Japan). (X= 70 and 200).

Scanning electron microscopy (SEM) allowed observing the surface of eggplant rings. A gold coat (20 nm) was applied over the fried egg plant rings surface sample using a sputter coater (Sputtering System Hummer 6.2). Samples were examined at 10 kev using a Jeol JSM-S410 scanning electron microscopy (Tokyo, Japan) as described by Pedreschi et al., (2008). Scanning electron micrographs were obtained using scanning electron microscope, Joel JSM-6100 Joel ltd. Tokyo-Japan as described by (Aguilera and Stanely, 1999). These micrographs were taken to investigate the microstructure of dried eggplant rings.

Non-enzymatic browning determination:

Non-enzymatic browning was measured spectrophotometrically by 4054 - UV/Visible spectrophotometer, (LKB-Biochrom Comp., London, England), as absorbance at 420nm using ethanol as blank according to the method of Stamp and Labuza (1983) and Birk et al., (1998).

Colour determination of eggplant rings:

Untreated and pretreated fried eggplant rings colour was determined according to Hunter (1975). Colour of Egyptian untreated and fried eggplant rings was measured using spectro-colorimeter (Tristimulus Colour Machine) with the CIE lab colour scale (International Commission on Illumination) as mentioned by Hunter (1975) and Sapers and Douglas (1987).

Sensory evaluation:

Twelve trained panelists were selected for sensory evaluation of the studied pretreated and untreated fried eggplant ring samples. Colour, flavour, taste, texture, and appearance of the fried eggplant ring samples were
determined using a ten point scale (10 = excellent and 1 = bad) as described by Bertolini et al., (2008). The limit of the acceptability was 5.

Statistical analysis:

The obtained results were analyzed statistically using the analysis of variance (ANOVA with tow ways) and the Least Significant Difference (LSD) as described by Richard and Gouri, (1987).

Results and Discussion

Effect of temperature and time of frying process on sensory evaluation of eggplant rings:

Sensory Evaluation of Foods:

Table 1: Effect of temperature and time of frying process on sensory evaluation of eggplant rings. (Data are means ± standard deviation (n=3):

<table>
<thead>
<tr>
<th>T/min</th>
<th>Color</th>
<th>SD</th>
<th>Taste</th>
<th>SD</th>
<th>Flavor</th>
<th>SD</th>
<th>Texture</th>
<th>SD</th>
<th>Appearance</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>170/4</td>
<td>5.57±</td>
<td>2.44</td>
<td>5.86±</td>
<td>2.27</td>
<td>6.14±</td>
<td>2.61</td>
<td>6±</td>
<td>2.65</td>
<td>6.14±</td>
<td>2.27</td>
</tr>
<tr>
<td>170/6</td>
<td>5.86±</td>
<td>2.41</td>
<td>6.43±</td>
<td>2.07</td>
<td>6.29±</td>
<td>2.21</td>
<td>6.86±</td>
<td>2.12</td>
<td>5.73±</td>
<td>1.89</td>
</tr>
<tr>
<td>170/8</td>
<td>4.86±</td>
<td>2.19</td>
<td>5.71±</td>
<td>2.93</td>
<td>6±</td>
<td>1.83</td>
<td>6.14±</td>
<td>1.96</td>
<td>5.29±</td>
<td>2.81</td>
</tr>
<tr>
<td>180/4</td>
<td>8.14±</td>
<td>1.77</td>
<td>8.14±</td>
<td>1.35</td>
<td>8.14±</td>
<td>1.57</td>
<td>8.57±</td>
<td>0.98</td>
<td>8±</td>
<td>1.41</td>
</tr>
<tr>
<td>180/6</td>
<td>5.57±</td>
<td>1.72</td>
<td>6.43±</td>
<td>1.51</td>
<td>6.71±</td>
<td>1.25</td>
<td>7.29±</td>
<td>1.38</td>
<td>5.86±</td>
<td>1.95</td>
</tr>
<tr>
<td>180/8</td>
<td>7.57±</td>
<td>0.98</td>
<td>7.86±</td>
<td>0.9</td>
<td>7.86±</td>
<td>1.46</td>
<td>7.86±</td>
<td>0.9</td>
<td>7.86±</td>
<td>1.07</td>
</tr>
<tr>
<td>190/4</td>
<td>8.29±</td>
<td>0.76</td>
<td>7.71±</td>
<td>1.5</td>
<td>8.43±</td>
<td>0.79</td>
<td>7.86±</td>
<td>1.07</td>
<td>8.29±</td>
<td>0.76</td>
</tr>
<tr>
<td>190/6</td>
<td>7.71±</td>
<td>1.25</td>
<td>7.57±</td>
<td>0.98</td>
<td>7.71±</td>
<td>0.95</td>
<td>7.57±</td>
<td>0.98</td>
<td>7.57±</td>
<td>0.79</td>
</tr>
<tr>
<td>190/8</td>
<td>6.29±</td>
<td>1.5</td>
<td>6.57±</td>
<td>1.27</td>
<td>6.86±</td>
<td>1.07</td>
<td>6.86±</td>
<td>1.68</td>
<td>6.86±</td>
<td>1.57</td>
</tr>
</tbody>
</table>

The main role of sensory analysis is to obtain information on the sensory characteristics of the product. In the development of new food products, this process is important because it affects the decisions involved in materialization of the final product and its success (Moskowitz et al., 2006). Sensory attributes are of great importance in measuring consumer attitudes and their influence on food choice and acceptability.

Table (1) represents the statistical analysis and standard division (SD) of fried eggplant rings at different times and temperatures. The results of sensory evaluation of fried eggplant rings based on colour, odour, taste, texture and appearance are shown in Table (1). It is clear that fried eggplant rings at 180 °C for 4 minutes gave higher mean panel scores (8–8.57) than other fried samples and were the most preferred in all the sensory characteristics. The fried eggplant rings sample at 180 °C for 4 minutes generally had better score for all sensory characteristics than other ones fried. On the contrary, the fried eggplant samples at 170 and 190 °C for different times had lower score for all sensory characteristics. This could be due to the protein breakdown and dehydration at the eggplant surface. Frying showed a positive influence on the acceptability of colour and flavour of eggplant as it enhanced odour and texture acceptability of eggplant. However, all sensory scores were in the acceptable range, hence scores were greater than 5. These results confirmed the results of Gonulalan et al. (2003), who found that all sensory scores were in the acceptable range.

Effect of different temperatures and times of frying process on sensory evaluation of eggplant rings:

Objective or physicochemical analyses rely on analytical measurements of components that are believed to make up the sensory characteristics. For example, one method of characterizing color is by using the CIELAB system where three components of color are used as specified by the Commission Internationale d’Eclairage (CIE) or International Commission of Illumination. This model is based on the color perception of 92% of the population that does not have vision deficiencies (Hutchings, 1999 and Hutchings et al., 2002). The whiteness or blackness is represented by L*, redness is represented by +a*, greenness is represented by –a*, yellowness by +b*, and blueness by –b* (Hunter 1975) as shown in Figure (1). As for crunchiness, many methods have been suggested to measure and characterize this property.

Frying conditions determine colour characteristics by Hunter Labs of fried eggplant, thus, colour characteristics was performed to select time-temperature conditions. In all cases, colour could not distinguish between chemical and thermal treated samples. Colour characteristics determined that 4, 6 and 8 min at 170, 180 and 190 ± 0.5 °C were the best frying conditions for eggplant rings. Besides this was the time required to complete the fried samples.

The results in table (2) show that the L*, a* and ΔE-values (45.75, 10.66, and 59.59), respectively of 180 °C for 4mintes fried eggplant samples were lower than other samples, while the lightness (L*) decreased with frying time at 180 °C frying. No differences were observed in the other analyzed color parameters of temperatures and time fried eggplant rings sample. All other parameters closely remained constant. However,
the non-enzymatic browning on optical density 420nm of 180 °C for 4 mintes fried eggplant samples (4.13) was lower than others. Then the best fried eggplant rings sample of temperatures and time were 180 °C for 4 minutes in terms of color characteristics (L*, a*, ΔE and non-enzymatic browning), as shown in Table (2).

Surface color is a quick and often effective parameter in determining the quality of fried foods. As shown in Table (2), lightness (L*) and both chromaticity coordinates (a*, b*) were significantly different at 180 °C for 4 mintes fried eggplant than for the other samples. All L*, a*, and b* were lower at 180 °C for 4 mintes fried eggplant than those of other samples. L* and b* were lower while a* was higher at 180 °C for 4 mintes. Fried foods often exhibit increased values for a* and lower values for L* and b* when they are fried under non optimum conditions such as long frying time, in highly degraded oil, and at very high temperatures (Ngadi et al., 2007). For this reason 180 °C for 4 minutes frying eggplant was treated with chemical and thermal treatments to exhibit minimal oil inhibition properties, 180 °C for 4 minutes and they were further analyzed by sensory analysis.

Effect of different temperatures and times of frying on moisture content and oil uptake for fried eggplant rings:

Monitoring frying time and temperature has been practiced in the frying industry to ensure the consistent quality of fried foods. This may be attributed to the increased formation of surfactants due to oil degradation and its relation to oil uptake. Fat content was shown to increase with frying time in both treated and untreated foods until it reaches equilibrium (Krokida et al., 2000). Foods fried at high temperatures have been observed to have less oil uptake and this may be due to the quick pressure buildup when frying at high temperatures, which prevented capillary diffusion of oil (Yamsaengsung and Moreira, 2002). In frying, the initial warm-up period is very short, it may last one to five seconds (Garayo, 2001) and the material reaches the evaporation temperature faster than in other drying processes. Water starts evaporating as soon as the raw material is in contact with the oil. The drying rate was very fast during the first 60–100 s of the process, and then slowed down as the product reached equilibrium.

Quality attributes of fried eggplant rings samples:

Table (3) shows that after the best frying process (for 4 min. at 180 °C), lower values of oil uptake percentage and higher water loss were obtained for fried eggplant samples. In all cases, the oil uptake percentage and water loss values increased as a function of frying time, due to the formation of a dehydrated zone. However, oil uptake percentage and water loss values were 4.2 and 57.72 (g/g dried solid) 180 °C for 4 mintes fried eggplant ring samples. The frying process for 4 min. at 180 °C reduced the oil content of eggplant rings; the oil uptake was 62.47% lower than that corresponding to 8 minutes at 180 °C samples.
Oil content versus moisture content in dry basis for control slices fried at 170, 180, and 190 °C is shown in Figure (2). There is a clear effect of the frying temperature on oil uptake at moisture contents ≤1 g water/g dry solid; the higher the frying temperature the lower the oil content average values of 0.45, 0.38, and 0.52 g/g dry basis after 4 minutes for 170, 180 and 190 °C, respectively.

The final lipid content values, at long frying times, were 4.58, 13.74 and 11.30 g oil/g dry solid at 170, 180 and 190 °C for 8 minutes, respectively while 5.29, 4.2 and 7.43 g oil/g dry solid for 4 minute, respectively. With regard to water content, no differences were detected between different temperatures and times of frying for eggplant rings (Table 3). This could be attributed to the poor water vapor of eggplant ring samples as recorded by Donhowe and Fennema, (1993). The equilibrium water content values, which correspond to bound water, were 2.27, 1.58 and 1.98 g water/g dry solid at 170, 180 and 190 °C for 4 minutes samples, respectively. The best temperatures and time fried eggplant rings sample were 180 °C for 4minutes in terms of decreased oil uptake and increased water loss content values.

Table 3: Effect of different temperatures and times of frying on moisture content and oil uptake for fried eggplant rings:

<table>
<thead>
<tr>
<th>T/min</th>
<th>WC</th>
<th>% WR</th>
<th>OU before</th>
<th>% OUR</th>
<th>OU after</th>
</tr>
</thead>
<tbody>
<tr>
<td>170/4</td>
<td>2.27±0.25</td>
<td>127.29±0.53</td>
<td>0.46±0.23</td>
<td>54.17±0.86</td>
<td>5.29±0.14</td>
</tr>
<tr>
<td>170/6</td>
<td>1.99±0.15</td>
<td>98.52±0.44</td>
<td>0.78±0.43</td>
<td>22.46±0.42</td>
<td>6.08±0.45</td>
</tr>
<tr>
<td>170/8</td>
<td>2.48±0.62</td>
<td>148.26±0.22</td>
<td>0.77±0.53</td>
<td>23.13±0.58</td>
<td>4.580.13</td>
</tr>
<tr>
<td>180/4</td>
<td>1.57±0.19</td>
<td>57.72±0.14</td>
<td>0.38±0.36</td>
<td>62.47±0.36</td>
<td>4.21±0.94</td>
</tr>
<tr>
<td>180/6</td>
<td>1.57±0.29</td>
<td>56.52±0.49</td>
<td>0.56±0.02</td>
<td>43.98±0.49</td>
<td>8.14±0.24</td>
</tr>
<tr>
<td>180/8</td>
<td>2.46±0.90</td>
<td>145.90±0.10</td>
<td>0.87±0.79</td>
<td>12.93±0.28</td>
<td>13.74±0.17</td>
</tr>
<tr>
<td>190/4</td>
<td>1.96±0.38</td>
<td>97.54±0.61</td>
<td>0.52±0.84</td>
<td>47.82±0.16</td>
<td>7.43±0.63</td>
</tr>
<tr>
<td>190/6</td>
<td>2.33±0.42</td>
<td>132.99±0.44</td>
<td>0.65±0.74</td>
<td>35.0±0.21</td>
<td>13.43±0.26</td>
</tr>
<tr>
<td>190/8</td>
<td>2.26±0.14</td>
<td>125.71±0.24</td>
<td>0.69±0.97</td>
<td>30.56±0.14</td>
<td>11.30±0.91</td>
</tr>
</tbody>
</table>

Effect of thermal and chemical treatment on moisture and oil content of uncoated and coated fried eggplant rings:

The analysis of the main effects of chemical and thermal pretreatments on oil content reported in Table (4) show that the lowest final oil content was observed for eggplant rings treated with 2% CMC and thermal (water blanching). It is likely that effects of chemical and thermal pretreatments on water content showed that the lowest final water content was observed for eggplant rings treated with 2% CMC and thermal (water and steam blanching). The highest water ratio percentage was observed for eggplant rings treated with NaCl, steam and untreated samples. Also, the highest oil ratio percentage was observed for eggplant rings treated with water, steam and CMC samples. The oil uptake effect of various thermal and chemical pretreatments on eggplant rings was found to decrease in the following order water blanching > coated CMC > steam blanching > coated chitosan > SO2 > sodium chloride > untreated samples. These results are in agreement with those of Moyano and Pedreschi (2006) who found that the Blanched slices absorbed either the same or more oil than control slices, while pre-drying of the blanched samples provided fried chips with less oil content than control slices and only blanched slices.

Our results demonstrated that while pre-treating dips did inhibit oil absorption, especially at 2% CMC, water and steam blanching, there was no difference between the amount of final oil content between eggplant rings treated with solutions containing 2% chitosan, 4% NaCl and 0.1% SO2 and those untreated samples. Because a reduction in oil content was observed for CMC at 2%, water and steam blanching compared to the control, this implied that the pH of the CMC-containing pre-treating dips has a larger influence on the amount of
oil absorbed into fried eggplant than the control and other pretreatments samples. Because oil uptake during the cooling phase has been shown to account for the bulk of the oil absorption in fried foods (Moreira et al., 1997), factors that increase oil absorption through this mechanism would ultimately increase final oil content of the fried food. This is observed with the higher final oil content of eggplant rings dipped in CMC solutions compared to those untreated and other pretreated samples (Table 4). While it has been suggested that high moisture retention would lead to lower oil reduction (Moreira et al., 1997), the results from both CMC, water and steam blanching suggested that oil uptake was not only affected by the direct exchange between water and oil, but other factors as well, such as those mentioned previously. These results suggest that coated CMC and water blanching exhibits oil barrier properties that do not significantly affect the flavor of the product, regardless of breading type, thus making it a promising alternative in lowering oil content of fried foods.

Table 4: Effect of thermal and chemical pretreatments on water content and oil content of fried eggplant rings, (Data are means ± standard deviation (n=3) or Values reported are means ± standard deviations (n=3)).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>WC (%)</th>
<th>% WR</th>
<th>OU before</th>
<th>% OUR</th>
<th>OU after</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated fried eggplant</td>
<td>2.4±0.92</td>
<td>139.49±0.27</td>
<td>0.56±0.35</td>
<td>43.6±0.46</td>
<td>15.52±0.16</td>
</tr>
<tr>
<td>Chitosan 2%</td>
<td>2.14±0.79</td>
<td>114.17±0.16</td>
<td>0.51±0.018</td>
<td>48.99±0.42</td>
<td>14.04±0.55</td>
</tr>
<tr>
<td>CMC 2%</td>
<td>2.10±0.97</td>
<td>110.67±1.45</td>
<td>0.25±0.49</td>
<td>74.33±0.23</td>
<td>7.009±0.89</td>
</tr>
<tr>
<td>So2 0.1%</td>
<td>2.17±0.41</td>
<td>116.94±0.58</td>
<td>0.54±0.59</td>
<td>46.34±0.43</td>
<td>14.17±0.06</td>
</tr>
<tr>
<td>Nac1 4%</td>
<td>2.37±0.99</td>
<td>137.0±0.99</td>
<td>0.54±0.77</td>
<td>46.11±0.28</td>
<td>14.83±1.92</td>
</tr>
<tr>
<td>Water 3min</td>
<td>1.83±0.82</td>
<td>83.42±0.01</td>
<td>0.007±0.32</td>
<td>99.26±0.94</td>
<td>0.20±0.49</td>
</tr>
<tr>
<td>Steam 3min</td>
<td>2.38±0.67</td>
<td>138.12±0.72</td>
<td>0.30±0.94</td>
<td>69.51±0.93</td>
<td>8.39±0.06</td>
</tr>
</tbody>
</table>

Microstructural analysis of the thermal and chemical pretreated fried eggplant rings:

Scanning electron microscopy techniques (SEM) were used to observe the structure of the fried eggplant rings. Fig. (3) shows that 2% of CMC and chitosan coating or 4% salt (NaCl) and 0.1% SO2 treating was getting dehydrated during the frying process and remained attached to the surface of the product, explaining the lower oil content of the coated or treated product. Same figure shows the integrity of the CMC and chitosan layer and the good adhesion of this coating to the fried product. Formation of an uniform coating on the surface of the sample is essential to limit mass transfer during frying as shown by Huse et al., (1998) and Pedreschi and Aguilera (2002). The coating did not prevent the formation of a dehydrated zone on the surface of the eggplant rings.

The release of water vapor led to the formation of blisters at the outer surface of the crust being smaller in size and number in the coated rings than in uncoated ones. In the first period of frying, the CMC coating loses its water, the rings keeps its humidity and the starch gelatinizes with a higher water content than in uncoated rings, leading to a more compact network. During frying in both chemical coated or treated and uncoated or untreated systems, the core was progressively dehydrated and starch gelatinization was completed at short min. Relationship between oil uptake and microstructure changes during the frying process. Oil uptake depends on structural changes during the process; differences in the starting food microstructure can be expected to be important determinants in the evaluation of the characteristics of the end product. Microstructure changes were produced during frying time; the dehydrated zone increased allowing the oil retained by the surface to penetrate into the pores formed by water evaporation.

Also, Fig. 3 shows a cross-section of the eggplant after steam blanching. Starch present in the outer layer of the eggplant is pasted and forms an impermeable layer, which probably inhibits transport of soluble constituents of eggplant rings to water. After water blanching, starch swelling occurred in the outer layers of eggplant, along with an enormous increase in their volume. Pre-treating of eggplant rings resulted in further destruction of eggplant tissue. Swollen starch granules also could be observed, in the inner layers of rings. The reduction in hardness of the pretreated and fried eggplant rings was likely due to partial pasting of starch. Lisin’ska and Gołubowska (2005) found that the texture of potato was changing during the technological process due to water losses and damages of potato tissue and consequent changes in non-starch polysaccharides and lignin. The greatest changes in potato tissue resulted from thermal processes: blanching, pre-treating and frying.

Fig. (3 from A to G) show the microstructure of the thermal and chemical fried eggplant rings, respectively. Those figures showed a disruption of cell walls, covered with cytoplasm. Chemical pretreated of fried samples caused an important change in their microstructure levels i.e; cells became, elongated with cell wall, plasma membrane was folded and separated; as quickly as the salt content of the NaCl solution was enhanced in fried eggplant rings; (Bunger et al., 2003 and Tonon et al., 2007).

SEM was another powerful tool used to study the surface topography of eggplant rings. Fig. 3 indicates that the surface topography changed as the different frying pretreatments. The images of the blanched eggplant rings look smoother than those of control rings, since blanched rings tend to accumulate more oil that covers the surface. Fig. 3 shows that control eggplant rings lost a considerable quantity of surface oil after they were pretreated in chitosan, CMC and salt (NaCl), which allows clear observation of the cellular microstructure of the surface. This fact is confirmed by Fig. 3 (B, C and E) at different scales of observation, where the samples
pretreated in chitosan, CMC and salt showed clearer topographical details of the surface, mainly at a magnification of 70-200X. In general, SEM allows studying the surface topography of eggplant rings, and in some cases, the oil location on the surface. The same results were found by Pedreschi and Aguilera (2002). The results obtained in this study are supported by other several researchers who have explained that when starch is heated in water (as in frying), the granules go through the gelatinization process, which includes hydration, swelling, and rupture of the structure (Liu and Shi, 2006 and Carla and Moreira 2011).

Moreover, Aguilera et al. (2001) reported that, during frying, cells shrink and their walls become wrinkled and convoluted around dehydrated gelled starch but are not ruptured. During frying the cells of the potato become dehydrated as water is released from the intercellular spaces in the form of steam. However, potato slices microstructure during frying is constantly changing, since it is affected by heat transfer and moisture loss. Cells retained their shape, while the inside material changed during the heat and mass processes that occur during frying. Also, there were changes on the surface of the cell related to shrinkage. Then, the microstructure of fried eggplant rings is greatly affected by frying different pretreatments, temperature and time. Shrinkage of the cells and collapse of the wall, as well as, disruption of starch granules occur as frying progresses. From the results described above, Fig. (3 from A to G) indicate that fried eggplant rings after chemical (chitosan, CMC, salt and SO₂) and thermal treatments (steam and water blanching) contained numerous types of cellular fragments. Carla and Moreira (2011) reported similar results during microscopic examination of potato slices. According to Dana and Saguy (2006), there are three proposed mechanisms explaining oil uptake in fried foods, namely water replacement, cooling-phase effect, and surfactant theory of frying. In addition, all of these mechanisms show the strong dependence of oil absorption on the microstructure and surface characteristics of the product.

**Fig. 3:** Effect of thermal and chemical pretreatments on microstructure for fried eggplant rings. Untreated fried eggplant rings (A), coated chitosan (B), coated CMC (C), SO₂ dip (D), NaCl dip (E), water blanching (F) and steam blanching (G).
Conclusion:

Oil absorption in deep-fat frying is a complex process that involves various factors related to the food, such as composition and surface characteristics, and factors related to the frying process such as frying medium, temperature, time, prefrying handling and pretreatments.

Results indicated that fried eggplants rings at 180°C for 4 minutes were the most preferred in all studied characteristics (sensory properties, color characteristics, water content and oil content) than other time and temperature fried samples. Soaking of eggplant rings in CMC and water blanching under the best conditions found (20 min soaking time) reduced oil uptake and increased hardness and sensory quality of fries, without modifying color, moisture content nor sensory acceptability. These findings open an interesting possibility in order to produce a healthy product introducing a simple soaking step into the fries processing line. These findings confirm that oil absorption is a surface related phenomena occurring during cooling, in the case of atmospheric frying, or during cooling, in the case of frying.

Using SO₂, chitosan, CMC, water and / or steam blanching pretreatments as a pretreatment for eggplant rings were able to optimize the quality of eggplant rings during storage at room temperature for 24 hrs. Frying eggplant rings at 180°C/4 min for the previous pretreatments of SO₂, chitosan, CMC, water and steam blanching was able to optimize the quality of eggplant rings regarding to L*, a*, C*, BI, ΔE-values, non-enzymatic browning (A420 nm) and sensory evaluation. Results confirmed that the shorter times and lowest oil temperatures correspond to the pre-treatment thermal and chemical (blanching or soaking) plus frying, which could mean considerable energy saving during eggplant rings frying.

References


