Journal of Food Measurement and Characterization
https://doi.org/10.1007/s11694-018-9944-8

ORIGINAL PAPER

Performance of lentil and chickpea flour in deep-fried crust model (DFCM): oil barrier and crispy properties

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Received: 3 August 2014 / Accepted: 21 December 2015

Abstract

In this research, the effects of frying time (0, 1.5, 3, 4.5 and 6 min) and different batter formulations were investigated on the quality of deep-fried crusts (DFCs) through a DFC model. Moisture and oil content, texture and color parameters of the crusts were determined. In order to determine the effects of the batter formulation, 10, 25 and 50 % w/w of wheat flour was replaced with lentil and chickpae flours. The Control batter formulation contained only wheat flour. Our results showed that batter formulations and frying time significantly ($p < 0.01$) affected the moisture and oil content, color parameters, acoustic properties and texture of DFCs. The increase in the concentration of lentil or chickpea flours from 10 to 50 % in batter formulation, led to an increase in a* and b* values as well as a decrease in moisture loss, oil uptake, L* value and textural properties. DFCs containing 50 % of the lentil flour showed the lowest oil content and the highest moisture content among all formulations. Samples containing 10 % of the lentil or chickpea flour had a higher hardness. Also, It has been indicated that as the frying time increased, the moisture content, L*and b*, decreased, while the oil content, a*, number and maximum of force and acoustic peaks, increased.

Keywords Deep fried crust model (DFCM) · Batter · Lentil flour · Chickpea flour · Acoustic measurements

Introduction

In recent decades, the consuming fried and fast foods have increased significantly as a result of industrial life. Easy and rapid preparation, desirable sensory attributes including good color, texture, aroma and flavor in fried foods, have resulted in more interests [25, 34, 49]. However, such foods contain high amount of fat. Excessive use of fat, especially saturated fats and trans fatty acids, is one of the important factors that increases heart diseases, weight gain and cancers [41, 49]. By increasing the awareness over the effect of dietary fat on health, tendency to production and consumption of low fat foods is increasing significantly. Therefore, Nowadays, the main challenge is to enhance the frying process by controlling and lowering the final fat of the fried foods.

One of the methods which is used for decreasing of oil absorption during frying process is to change the food formulation and implement the methods such as coating with batter to trap water and form barrier films. Subsequently, this will reduce the moisture loss and subsequent oil absorption [2, 3, 12, 14, 35, 47]. The batter's ingredients affect the properties including viscosity, moisture loss, oil absorption and final quality of coated foods [17, 36]. Dogan et al. (2005) reported that adding soy flour to the formulation of chicken nugget batter, decreases oil absorption [13]. Lee and Inglet (2006) reported that addition of barely flour to batter formulation increases its batter pick up and viscosity, and leads to a significant decrease in moisture loss and oil absorption in fried products [19]. Dehghan-Nasiri et al. (2012) investigated the effect of adding soy flour (10 % of w/w) and corn flour (5 % of w/w) to batter formulation of fried shrimp batter. Results of this study indicated that soy flour significantly decreased the oil uptake of shrimp nugget. The batter containing 5 % of corn flour had the lowest amount of moisture and the highest fat absorption compared to other formulas [12].

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Published online: 26 October 2018

Addition of lentil and chickpea flour to batter formulation, as an important enriched plant resources protein (17–38 %), have a different effect on moisture loss and oil absorption. Also because of complementary amino acids, its combination with cereal increases the nutritional value [8]. Researchers have investigated the effects of adding soy, rice and corn flours on the rheological and quality properties (batter's reolology, moisture and oil content, texture, color and porosity) of fried samples [12, 13, 47]. However, few studies have been carried out on evaluating the effect of different types of pulse flour on formulation of batter and quality parameters of fried products.

On the other hand, crust characteristics in fried products affect quality attributes and acceptance of the products. However, the oil in fried products usually tends to be absorbed in the crust pores [5, 29, 46, 49]. Different characteristics of core (moisture, porosity and surface roughness) and different batter stickiness decreased the possibility of repeated production of fried product in the same conditions [5, 46]. To solve those problems, deep fried crust model (DFCM) system can be useful during frying, for quick making of fried crust. Some of the advantages of this model include repeatable crust formation, easy removal of crust from core, using different cores and batters and economical considerations for sample preparation.

Crispness is a desirable textural attribute and an important parameter for fried products [27, 40, 43]. One way to determine the changes in crispiness during fracture of crispy products is the simultaneous recording of the sound and fracture/mechanical events produced during the application of fracture force [32, 33, 44, 45, 48]. For this purpose, a microphone was attached to a Texture Analyser. Chaunier et al. (2005), Chen et al. (2005),Varela et al. (2006) and other researchers found a very good correlation between some recorded sound parameters, mechanical properties and the crispness of cornflakes, biscuits, potato chips and crust model, respectively [10, 11, 29, 32, 37]. Thus the sound emission technique has been used for determining textural properties in crispy product [15] and has been proposed to be a good approach to determine the crispness level [16, 31, 33, 42].

Therefore, the purpose of this research is to study the effect of different batter formulation [replacing different levels of lentil and chickpea flour (10, 25 and 50 %)] and frying time on the physicochemical characteristics (oil absorption, moisture loss, color parameters and texture) of fried crusts.

Materials and methods

Batter preparation

Wheat flour was purchased from local market in Mashhad, Iran. Lentil and chickpea flour were obtained from Shirvan Agricultural Research Center, Shirvan, Iran. The solid content of batter formulations contained wheat flour, salt, leavening agents, and pepper as flavoring agent. To determine the effects of lentil and chickpea flour on the quality properties of simulated crispy deep-fried crusts, 10, 25 and 50 % w/w of wheat flour was replaced with lentil and chickpae flours. As a Control, a batter with wheat flour was used. The characteristics of the flour samples are presented in Table 1. The thoroughly pre-blended powders were mixed with cold water (15 °C) with a mixer (Moulinex, type BM4) for 2 min to ensure uniform mixing. The water/dry mix proportion was always 1.2:1 (w/w).

Crust model preparation

Deep-fried crusts were prepared using a model system [5, 46]. Batters were deep-fried using a stainless steel device that holds two aluminum cups (64 mm diameter, 28 ml volume). Each cup was covered by gauze with a mesh diameter of 0.18 mm and a wire diameter of 0.14 mm. The gauze was coated with Teflon to prevent the crust from caking to the gauze during frying, in which 2 samples can be fried simultaneously. Each crust model was prepared by depositing first 4 ml of batter on Teflon-coated gauze that was placed above a cup containing 5 g of silica gel. The presence of a core is essential to simulate the crust formation of a real product. Water evaporation from the core during frying plays an important role in crust formation. This vapor will have an effect on crust temperature. Conditioned silica powder provided an ideal core while the moisture content was easily adjusted, and properties of the powder were highly reproducible [5]. Silica is inert, thus, apart from the moisture evaporating, no other reactions are taking place during frying. The moisture content of the silica powder was set 80 % by storing the powder on a flat surface in a germinator (Altus 400- Iran, 375 litet) to simulate the wet core characteristic of deep-fried battered nugget, in 22 °C for at least 2 days. Crust models were prepared by frying in refined sunflower oil (Nina, Iran) due to its high smoking point, in a thermostatically temperature controlled fryer (Black & Decker, Type 01) for 1.5, 3, 4.5 and 6 s at 180 °C. Crusts were separated from the gauze. After frying, the crusts could be separated easily from

Table 1 Chemical composition of wheat, lentil and chickpea flour used in the study

	Wheat flour (%)	Lentil flour (%)	Chickpea flour (%)
Moisture content	11.24 ± 1.23	8.16 ± 1.85	7.26 ± 1.3
Protein	10.8 ± 1.45	34.21 ± 2.25	40.93 ± 1.05
Ash	1.27 ± 0.25	2.25 ± 0. 4	2.4 ± 0.3
Fat	3.35 ± 0.04	4.85 ± 0.06	7.25 ± 0.04

the gauze for further analysis. All examinations of the crust models were carried out 30 min after frying.

Water and oil absorption capacity of flour

Water absorption capacity of flours was measured by the method of Kaur and Singh (2007) with minor modifications. The sample (1 g) was dispersed in 15 ml of distilled water and placed in preweighted centrifuge tubes. The dispersions were stirred after interval of 5 min, held for 30 min, followed by centrifugation for 25 min at 4000 g. The supernatant was decanted, excess moisture was removed by draining for 25 min at 50 °C, and sample was reweighed [18]. For the determination of fat absorption the method of Sosulski (1987) was used. Samples (0.5 g) were mixed with 6 ml of corn oil in preweighed centrifuge tubes. The contents were stirred for 1 min with a thin brass wire to disperse the sample in the oil. After a holding period of 30 min, the tubes were centrifuged for 25 min at 4000×*g*. The separated oil was then removed with a pipette and the tubes were inverted for 25 min to drain the oil prior to reweighing [39]. The water and oil absorption capacities were expressed as grams of water or oil bound per gram of the sample on a dry basis.

Moisture content analysis

Moisture content analysis was performed according to the procedure described in the AOAC (1984). The crust models were dried in a conventional oven (Memmert, 154 Beschickung loading, model 100–800) at 105 °C for 24 h. The samples were cooled in desiccators and moisture contents were determined by difference in weight in terms of dry basis [7].

Oil content

Oil content determination was carried out by soxhlet extraction technique using AOAC (1990). The dried samples used for moisture content determination were subsequently ground using a blender. The ground sample (2–4 g) was weighed with an electronic balance (TR-4102D, Denver Instrument Co., Denver, CO) and placed in a thimble. Fat was extracted in solvent extractor using petroleum ether (Extra pure, ET0091) during a period of 6 h. The thimbles were further dried at 105 °C for 60 min to remove residue solvent and moisture. Then the thimbles were cooled in a desicator and subsequently weighed. The oil contents were obtained in terms of dry basis [6].

Color

Color of crust models was measured using an image processing technique [5]. The color parameters L^* (lightness), a^*(redness), b^*(yellowness) values of the samples were obtained.

Texture and acoustic analyses

Crispness of the fried crusts was evaluated by studying the sound emitted during fracture by simulating a human bite. Texture of the crusts was measured 30 min after frying, using a texture analyzer (QTS25 CNS; Farnell, UK) interfaced with a personal computer, measuring the acoustic emission simultaneously with a penetration test. A Blade probe was attached to theinstrument for the penetration test. The test settings were: test speed 120 mm/min, trigger force 10 g, travel distance of the probe 7 mm. The microphone was positioned at 3 cm distance and with an angle of 0° to the sample. The samples were placed on an Aluminiumplate with a hole (HDP/CFS Crisp Fracture Support Rig) to allow the probe (ball P/0.25 s) to pass through after punching the sample. Hardness was defined as the peak force for this penetration.The maximum sound peak (db) and number of peaks, obtained From the acoustic signals. Extensive analysis of the soundwas performed using MatLab (Matworks 7.5.0) as described by Castro-Prada and et al. (2007) [9].

Statistical analysis

Frying experiments were replicated three times under each experimental condition. Data obtained from analysis were assessed by analysis of variance (ANOVA) to determine the significant differences between the effects of frying time and batter formulation on quality parameters of the crust models using the statistical software program Minitab for Windows (Version 16) to find out which parameters are significant for the specified quality parameters. Duncan's multiple comparison tests were applied to determine the difference among the means. The level of statistical significance was determined at 95 % probability. Besides, principal component analysis (PCA) was done to correlate sensory and instrumental parameters. The relationship between the moisture and oil contents, and sound characteristics was studied using principal component analysis (PCA) with the XLSTAT program (v 2009.4.03).

Results and discussion

Moisture content

ANOVA showed that the batter formulations, frying time and interaction between treatments had a significant effect ($p < 0.05$) on the moisture content of DFCMs (Table 2). The moisture content of DFCMs decreased by rising of the frying time with an initial rapid decrease in the 1.5 min of

Table 2 Successive mean squares from the analysis of variance of the moisture contents, oil contents, color parameters

Source	DF	Mean squares				
		Moisture content g/g (db)	Oil content g/g (db)	L*	b*	a*
A	6	0.46**	0.003**	71.77**	172.84**	49.58**
B	4	4.08**	0.72**	804.73**	1308.88**	487.16**
A × B	24	0.015*	0.0005**	10.08 NS	9.15*	9.36**
Error	35	0.005	0.00008	5.352	0.815	2.059
Total	69					

A Batter formulation, *B* frying time (min), *NS* not significant

* p = 0.05, ** p = 0.01

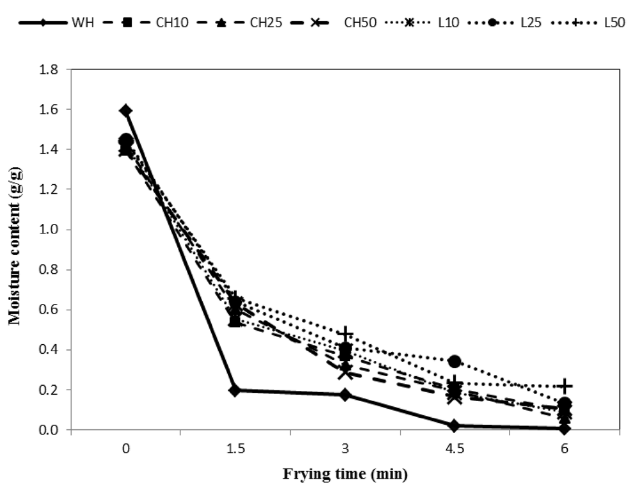

Fig. 1 Effects of lentil and chickpea at different concentrations on moisture content g/g (db) of DFCMs fried at 180 °C for 0, 1.5, 3, 4.5 and 6 min (*Control* untreated batter; *L10* batter contain 10 % lentil flour; *L25* batter contain 25 % lentil flour; *L50* batter contain 50 % lentil flour; *CH10* batter contain 10 % chickpea; *CH25* batter contain 25 % chickpea; *CH50* batter contain 50 % chickpea)

frying and then slowly decreased due to the rapid moisture loss from the crust part and surface water loss in all samples (Fig. 1). Other researchers have reported similar results with different fried products [5, 12, 24].

The results indicated that addition of chickpea and lentil flour decreased moisture loss of DFCM, which could be attributed to reduction of the amount of free moisture available for removal during frying. As demonstrated in Table 2, Duncan's multiple range test showed that addition of lentil and chickpea flour had a significant effect on the moisture content of DFCMs. The control batter lost the highest amount of water during frying, because wheat flour had less water-binding capacity compared to chickpea and lentil flour. Therefore, there was more free water available to facilitate the evaporation of water during deep fat frying and control crust lost the highest amount of water during frying. The highest moisture retention in each frying time was reported when 50 % lentil flour was replaced in the batter formulation, which might be due to its higher water binding capacity [13]. As shown in Table 3, water binding capacity (WBC) of lentil flour was higher than other flours. According to Ravi et al. (2009), WBC values were put in a range between 1.97 and 2.06 g/g for lentil flour [30]. WBC, sometimes also referred to as water absorption capacity (WAC), may be defined as the amount of water that can be absorbed per gram of protein material [8]. WBC/WAC measurements are important for food processing applications. Materials with low WBC/WAC may not be able to hold water effectively. Also, high water retention in the kind of batter containing lentil or chickpea flour could be due to the potential formation of intermolecular disulfide cross-links in lentil and chickpea proteins that would improve the water vapor barrier properties of flour-added batters.

Table 3 Water absorption capacity (WAC) and oil absorption capacity of wheat, lentil and chickpea flour

(%)	WAC	FAC
Wheat flour	1.078 ± 0.23	0.726 ± 0.85
Lentil flour	1.993 ± 0.45	0.713 ± 0.25
Chickpea flour	1.587 ± 0.12	0.981 ± 0.94

Oil content

Oil content of DFCMs were significantly ($p < 0.05$) affected by formulation and frying time (Table 2). Finding can be attributed to the fact that oil uptake increases during frying. While the temperature of the interior food increases, moisture travels from the substrate, through the coating, into the air as steam. It creates various potential problems: it can negatively affect the sample texture and eating quality, result in the lower yield of finished product, and change in the crust texture or affect its adhesion [38]. Several researches' works deal with the relationship between moisture content and oil uptake, and most results claim that the higher initial moisture content is, the higher fat uptake will be resulted [4, 21]. The addition of both lentil and chickpea flours to the batter formulation reduced oil absorption significantly during frying in comparison with the control. The final fried control had less moisture contents (1.57–0.008 g/g) and higher oil contents (0.043–0.287 g/g) and the DFCMs containing 50 % lentil flour had higher moisture contents (1.542–0.273 g/g) and lower oil contents (0/068–0.215 g/g) which is related to higher protein content and higher water-binding capacity of lentil flour [12, 13].

Furthermore, it may be related to the formation of covalent links during heating. The reduced oil uptake may also be related to thermal gelation and the film-forming ability of lentil protein. An increase in replacement percentage of lentil flour in the formulation from 0 to 50 % led to a rise of WBC factor. Since the moisture content is an important factor in determining of oil uptake during deep fat frying, the addition of lentil flour to the batter formulation reduced oil absorption significantly during frying compared to the control (Table 2). While an increase in replacement percentage from 0 to 50 % in chickpea flour caused higher oil uptake due to its high FAC factor of chickpea compared to the wheat flour (Table 3). Fat or oil absorption capacity (FAC, OAC), also sometimes referred to as fat or oil binding capacity (FBC, OBC), is calculated as the weight of oil absorbed per weight of protein powder or legume flour [8]. The results in this study agree with Kaur and Singh (2007) that reported OAC of 2.08–3.96 g/g for chickpea. OAC for the chickpea flour was significantly ($p < 0.05$) higher than those of the corresponding flour [18].

Texture and acoustic analyses

Texture of fried foods is important for the general consumer acceptability. The texture of the finished-product depends upon the ingredients, formulation (proper balance among ingredients), and processes such as batter mixing system, coating methods, and frying conditions [33]. Crispiness of the DFCMs was determined by measuring their fracture behavior and the associating sound emission. Examples of the texture measurements and sound emission of fried samples are shown in Fig. 2. In order to compare the behavior of different DFCMs, specific parameters extracted from the force and sound curves. This parameters were maximum peak (as index of the hardness), maximum sound peak and the number of total sound peaks (Table 4). When the force is applied to a crisp structure, it is stressed until a critical point is reached, starting to vibrate and generate the sound [28]. Results indicated that an increase in frying time produced an increase in the jaggedness of the force curves, as well as an increase in the number of sound events (Fig. 2). Both the increase in the number of high range force events and in the number and maximum of sound events reflect an increase in crispness [37]. Being in agreement with Moreira et al. (1995), it is also attributed to the moisture content decreased with frying time. They conducted a study over the effect of frying time on the textural properties of fried tortilla chips, and reported that two textural parameters, fracture ability, increased over time to a certain frying time and then decreased during longer frying times [23].

In this study, there was a maximum peak of sound between 44.30 and 67.50 dB as shown in Table 4. Duncan's multiple range test indicated that DFCMs containing 10 % of lentil or 10 % of chickpea flour had higher numbers of sound peak and force. Chen et al. (2005) reported that a high number of force and sound peaks have been associated with a high sensory crispness [11]. Moisture content was not significantly different and was 0.529 and 0.521 for L10 and CH10, respectively. The fracture pattern of samples containing 50 % lentil and 50 % chickpea showed only one drop in force and a smaller number of sound peaks, which, in turn, indicates the absence of crispy behavior. This finding can be attributed to the fact that 50 % of lentil flour and 50 % of chickpea flour contain a high level of protein and absorption oil which led to soft texture of the samples. In the less crisp samples, less total sound was produced. On the other hand, a louder sound and/or a greater density of sound occurrence seem to characterize the crisper samples [45]. There is no research on the crispiness properties of crust formulated with lentil and chickpea flour, but other researches were carried out as follows: Mohamed et al. (1998) reported that crispiness was positively correlated with amylose content [22]. The addition of rice flour improved crispness, but resulted in increased oil absorption because of the porous nature of the fried product [1, 3]. Matsunaga et al. (2003) studied the influence of physicochemical properties of starch on crispness of tempura-fried batter. They found the crispiness (favorable eating texture) of tempura coating depended largely on the starch [20].

Color

Color is a very important characteristic of deep-fat-fried foods. The color of fried products affects consumer purchasing. The batter formulation and frying time had a highly significant influence ($p < 0.05$) on the color parameter of DFCMs (Table 2).

As demonstrate in Fig. 3, lightness L* of the DFCMs decreased with frying time. Composition has an important role in determining the extent of color development due to Maillard reactions. Therefore, protein and sugar sources are important to the final coating color. Different researches have demonstrated that the color of coating depends on cooking time and temperature, breading material composition, and cooking oil characteristics and composition [26].

The effect of lentil and chickpea flour on the color of DFCMs was examined in terms of L*, a* and b* values. As frying time increased in the all of formulation, the

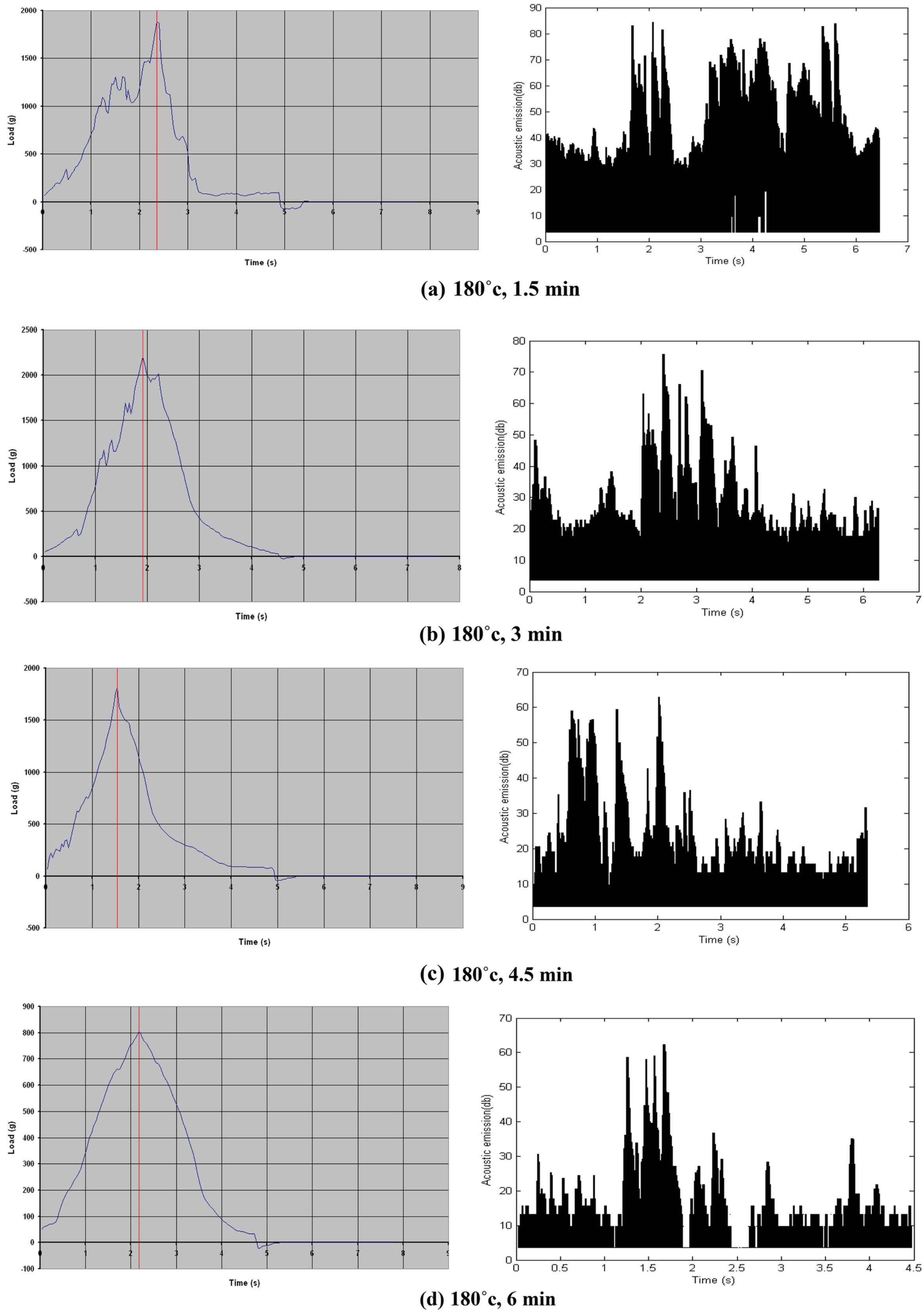

Fig. 2 Force and sound curves of DFCMs at different frying time

Table 4 Moisture content (g/g db), oil content (g/g db), maximum force peak as index ofthe hardness (g), number of sound peaks and maximum sound peak (dB) as affected by batter compositions after frying

Formulation	Moisture content (g/g db)	Oil content (g/g db)	Maximum force peak as index of the hardness (g)	Maximum sound peak (dB)	Number of sound peaks
Control	0.397[c]	0.203[a]	1384[c]	53.50[c]	51238[c]
L10	0.529[b]	0.182[c]	1933[b]	62.75[ab]	78449[a]
L25	0.595[a]	0.171[d]	1408[c]	57.50[bc]	66743[b]
L50	0.605[a]	0.161[e]	1354[c]	44.50[d]	47265[cd]
CH10	0.521[b]	0.166d[e]	2152[a]	67.50[a]	86298[a]
CH25	0.520[b]	0.194[b]	1538[c]	55.50[bc]	66541[b]
CH50	0.518[b]	0.202a[b]	633[d]	44.75[d]	42061[d]

Mean with different letter superscript in the same column are significantly different at $p < 0.05$

Control: untreated batter; L10: batter contain 10 % lentil flour; L25: batter contain 25 % lentil flour; L50: batter contain 50 % lentil flour; CH10: batter contain 10 % chickpea; CH25: batter contain 25 % chickpea; CH50: batter contain 50 % chickpea

lightness (L*) of DFCMs decreased, while redness (a*) and yellowness (b*) increased significantly with frying time. The color of deep-fat fried chicken nuggets was studied by Dogan et al. (2005b) [14]. They found that as frying time increased, L* values decreased and a* value increased. DFCMs containing chickpea flour had higher L*, a* and b* values and the increasing substitution in the formulation from 0 to 50 % raised the color values. It could be related to the higher amount of protein in chickpea flour undergoing Maillard reactions. Chickpea flour was useful in respect of adding brown notes and adding flavor through caramelization. Also, when the replacement percentage of lentil flour in batter increased, the brownish color increased in the coated samples. These may be due to the browning reaction of polysaccharide with protein complex when it was heated at a high temperature [1, 26].

Correlation between chemical and instrumental parameters

To evaluate the correlation between the chemical and instrumental parameters used to characterize the DFCMs principal component analysis (PCA) was applied. The first two components together explained 74.44 % of the variance (Fig. 4). The first one explained 55.22 % of the variance and showed a significantly positive correlation with the hardness, maximum and number of sound, L^*, and a negative correlation with the moisture and oil content, a^*, b^*. The results of this work showed that the force peaks are correlated with the maximum and number of sound peaks. In general, a higher number of total force peaks are correlated [37].

These parameters were opposed to oil and moisture content. In other words, the samples with higher oil absorption or moisture content were less crisp. As the a* and b* values

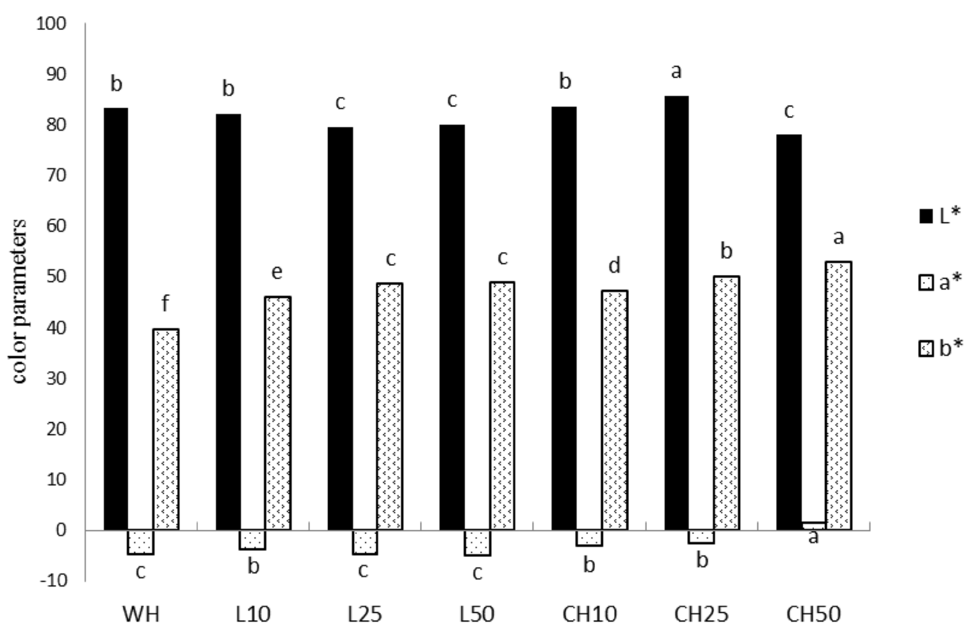

Fig. 3 Effects of lentil and chickpea at different concentrations on color parameters of DFCMs fried at 180 °C for 0, 1.5, 3, 4.5 and 6 min (*Control* untreated batter; *L10* batter contain 10 % lentil flour; *L25* batter contain 25 % lentil flour; *L50* batter contain 50 % lentil flour; *CH10* batter contain 10 % chickpea; *CH25* batter contain 25 % chickpea; *CH50* batter contain 50 % chickpea)

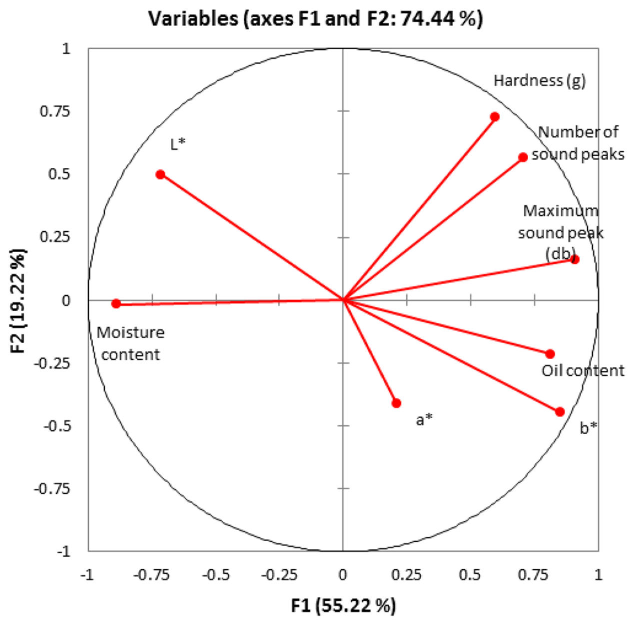

Fig. 4 First two dimensions of the PCA from the sensory and instrumental parameters used to characterize the DFCMs

increased, the color of samples got darker. The second component explained 19.22 % of the variance and was significantly positively correlated with the moisture content, L^*, and negatively correlated with the oil content and sound parameters. It can be concluded that there is a linear and indirect relationship between water loss and oil uptake [2, 24]. Moisture content prevents dehydration and inhibits the Maillard browning reaction, thus the colors remain lighter.

Conclusions

The major advantages of working with the DFCM are the better reproducibility of the crusts, the ease by which crusts can be separated from the core. In this study, addition of 10, 25 and 50 % of lentil and chickpea to the batter formulations was examined during deep fat frying of crusts. A summary of the findings showed that the samples containing 50 % lentil flour had the highest moisture content and the lowest oil absorption. Details of the force/deformation and, simultaneously, sound recording during fracturing of DFCMs formed an effective instrumental tool to predict sensory crispness. In general, sensory crispness is positively correlated with the number and maximum of fracture and acoustic events. On the other hand, a low number of force and acoustic events are normally regarded as an index of low crispness; however, a careful observation and analysis of the fracture pattern is necessary. Duncan's multiple range test indicated that DFCMs containing 10 % lentil or 10 % chickpea flour had a higher number of sound peaks and forces. The multiple analytical correlations, presented in this paper, indicate a positive correlation with the hardness, maximum and number of sounds, L^*, and a negative correlation with the moisture and oil content, a^*, b^*. The study strongly supports the idea that crispness is a complex phenomenon of several combined parameters, including fracture characteristics, sound and geometry.

References

1. A.A. Adedeji, M.O. Ngadi, Microstructural properties of deep-fat fried chicken nuggets coated with different batter formulation. Int. J. Food Prop. **14**(1), 68–83 (2011)
2. N. Akdeniz, S. Sahin, G. Sumnu, Functionality of batters containing different gums for deep-fat frying of carrot slices. J. Food Eng. **75**(4), 522–526 (2006)
3. B. Altunakar, S. Sahin, G. Sumnu, Functionality of batters containing different starch types for deep-fat frying of chicken nuggets. Eur. Food Res. Technol. **218**, 318–322 (2004)
4. M.R. Amiryousefi, M. Mohebbi, F. Khodaiyan, Kinetics of mass transfer in microwave precooked and deep-fat fried ostrich meat plates. Food Bioprocess. Technol. **5**, 939–946 (2012)
5. E. Ansarifar, M. Mohebbi, F. Shahidi, Studying some physicochemical characteristics of crust coated with white egg and chitosan using a deep-fried model system. J. Food Nutr. Sci. **3**, 685–692 (2012)
6. AOAC, *Official Methods of Analysis, Association of Official Analytical Chemists*, (Washington, 1990)
7. AOAC, *Official Methods of Analysis, Association of Official Analytical Chemists*, 14th edn. (Washington, 1984)
8. J. Boye, F. Zare, A. Pletch, Pulse proteins: processing, characterization, functional properties and applications in food and feed. Food Res. Int. **43**, 414–431 (2010)
9. E.M. Castro-Prada, H. Luyten, W. Lichtendonk, R.J. Hamer, T. Vliet, An improved instrumental characterization of mechanical and acoustic properties of crispy cellular solid food. J. Texture Stud. **38**(6), 698–724 (2007)
10. L. Chaunier, P. Courcoux, G.D. Valle, D. Lourdin, Physical and sensory evaluation of cornflakes crispness. J. Texture Stud. **36**(1), 93–118 (2005)
11. J. Chen, C. Karlsson, M. Povey, Acoustic envelope detector for crispness assessment of biscuits. J. Texture Stud. **36**(2), 139–156 (2005)
12. F. Dehghan Nasiri, M. Mohebbi, F. Tabatabaee Yazdi, M. Haddad Khodaparast, Effects of soy and corn flour addition on batter rheology and quality of deep fat-fried shrimp nuggets. Food Bioprocess. Technol. **5**, 1238–1245 (2012)
13. S.F. Dogan, S. Sahin, G. Sumnu, Effects of soy and rice flour addition on batter rheology and quality of deep fat-fried chicken nuggets. J. Food Eng. **71**, 127–132 (2005)
14. S.F. Dogan, S. Sahin, G. Sumnu, Effect of containing different protein types on the quality of deep fat-fried chicken nuggets. Eur. Food Res. Technol. **220**, 502–508 (2005)
15. B.K. Drake, Food crushing sounds. An introductory study. J. Food Sci. **28**(2), 233–241 (1963)
16. L.M. Duizer, Sound input techniques for measuring texture, in *Texture in Food*, ed. by K. David (Woodhead Publishing Ltd, England, 2004), pp. 146–166
17. S.M. Fiszman, A. Salvador, Recent developments in coating batters. Trends Food Sci. Technol. **14**(10), 399–407 (2003)

18. M. Kaur, N. Singh, Characterization of protein isolates from different Indian chickpea (*Cicerarietinum* L.) cultivars. Food Chem. **102**, 366–374 (2007)
19. S. Lee, G.E. Inglett, Functional characterization of steam jet-cooked-glucanrich barley flour as an oil barrier in frying batters. J. Food Sci. **71**(6), 308–313 (2006)
20. K. Matsunaga, S. Kawasaki, Y. Takeda, Influence of physicochemical properties of starch on crispness of tempura fried batter. Cereal Chem. **80**(3), 339–345 (2003)
21. M. Mellema, Mechanism and reduction of fat uptake in deep-fat fried foods. Trends Food Sci. Technol. **14**(9), 364–373 (2003)
22. S. Mohamed, N.A. Hamid, M.A. Hamid, Food components affecting the oil absorption and crispness of fried batter. J. Sci. Food Agric. **78**(1), 39–45 (1998)
23. R. Moreira, J. Palau, X. Sun, Simultaneous heat and mass tranfers during the deep fat frying of tortilla chips. J. Food Process. Eng. **18**(3), 307–320 (1995)
24. M. Ngadi, Y. Li, S. Oloka, Quality changes in chicken nuggets fried in oils with different degrees of hydrogenation. LWT Food Sci. Technol. **40**, 1784–1791 (2007)
25. M.H. Oztop, S. Sahin, G. Sumnu, Optimization of microwave frying of potatoslicesbi using Taguchi Technique. J. Food Eng. **79**, 83–91 (2007)
26. F. Pedreschi, J. León, D. Mery, P. Moyano, R. Pedreschi, K. Kaack, K. Granby, Color development and acrylamide content of pre-dried potato chips. J. Food Eng. **79**(3), 786–793 (2007)
27. F. Pedreschi, R. Moyano, Oil uptake and texture development in fried potato slices. J. Food Eng. **70**(4), 557–563 (2005)
28. L. Piazza, J. Gigli, D. Ballabio, On the application of chemometrics for the study of acoustic-mechanical properties of crispy bakery products. Chemom. Intell. Lab. Syst. **86**(1), 52–59 (2007)
29. C. Primo-Martín, N. Sözer, R.J. Hamer, T. Van Vliet, Effect of water activity on fracture and acoustic characteristics of a crust model. J. Food Eng. **90**(2), 277–284 (2009)
30. R. Ravi, J.B. Harte, Milling and physicochemical properties of chickpea (*Cicerarietinum* L.) varieties. J. Sci. Food Agric. **89**, 258–266 (2009)
31. G. Roudaut, C. Dacremont, B. Vallès Pàmies, B. Colas, M. Le Meste, Crispness: a critical review on sensory and material science approaches. Trends Food Sci. Technol. **13**(6–7), 217–227 (2002)
32. M. Saeleaw, G. Schleining, Effect of blending cassava starch, rice, waxy rice and wheat flour on physico-chemical properties of flour mixtures and mechanical and sound emission properties of cassava crackers. J. Food Eng. **100**(1), 12–24 (2010)
33. M. Saeleaw, G. Schleining, Effect of frying parameters on crispiness and sound emission of cassava crackers. J. Food Eng. **103**(1), 229–236 (2011)
34. S. Sahin, G. Sumnu, *Advances in Deep-Fat Frying of Foods* (Taylor and Francis, New York, 2009), p. 91
35. A. Salvador, T. Sanz, S.M. Fiszman, Effect of the addition of different ingredients on the characteristics of a batter coating for fried seafood prepared without a pre-frying step. Food Hydrocoll. **19**, 703–708 (2005)
36. A. Salvador, T. Sanz, S.M. Fiszman, Rheological properties of batters for coatingproducts. Effect of addition of corn flour and salt. Food Sci. Technol. Int. **9**(1), 23–27 (2003)
37. A. Salvador, P. Valera, T. Sanz, S.M. Fiszman, Understanding potato chips crispy texture by simultaneous fracture and acoustic measurements, and sensory analysis. LWT Food Sci. Technol. **42**(3), 763–767 (2009)
38. M. Soorgi, M. Mohebbi, S.M. Mousavi, F. Shahidi, The effect of methylcellulose, temperature, and microwave pretreatment on kinetic of mass transfer during deep fat frying of chicken nuggets. Food Bioprocess. Technol. **5**, 1521–1530 (2011)
39. W.F. Sosulski, R.A. McCurdy, Functionality of flours, protein fractions and isolate from field peas and faba bean. J. Food Sci. **52**, 1010–1014 (1987)
40. P. Thanatuksorn, K. Kajiwara, T. Suzuki, Characterization of deep-fat frying in a wheat flour-water mixture model using a state diagram. J. Sci. Food Agric. **87**(14), 2648–2656 (2007)
41. E. Troncoso, F. Pedreschi, Modeling water loss and oil uptake during vacuum frying of pre-treated potato slices. LWT Food Sci. Technol. **42**, 1164–1173 (2009)
42. T. VanVliet, J.E. Visser, H. Luyten, On the mechanism by which oil uptake decreases crispy/crunchy behaviour of fried products. Food Res. Int. **40**(9), 1122–1128 (2007)
43. P. Varela, J. Chen, S. Fiszman, M.J.W. Povey, Crispness assessment of roasted almonds by an integrated approach to texture description: texture, acoustics, sensory and structure. J. Chemom. **20**(6–7), 311–320 (2006)
44. Z. Vickers, M.C. Bourne, Crispness in foods—a review. J. Food Sci. **41**(5), 1153–1157 (1976)
45. Z.M. Vickers, Crispness and crunchiness textural attributes with auditory components, in *Food Texture Instrumental and Sensory Measurement*, ed. by M.H.R. Macel (MacelDeckker Inc, New York, 1987), pp. 145–165
46. J.E. Visser, H. DeBeukelaer, R.J. Hamer, T. VanVliet, A new device for studying the deep-frying behavior of batters and resulting crust properties. Cereal Chem. **85**, 417–424 (2008)
47. J. Xue, M. Ngadi, Rheological properties of batter systems formulated using different flour combinations. J. Food Eng. **77**, 334–341 (2006)
48. A. Zdunek, J. Cybulska, D. Konopacka, K. Rutkowski, New contact acoustic emission detector for texture evaluation of apples. J. Food Eng. **99**, 83–91 (2010)
49. A.M. Ziaiifar, N. Achir, F. Courtois, I. Trezzani, G. Trystram, Review of mechanisms, conditions, and factors involved in the oil uptake phenomenon during the deep-fat frying process. Int. J. Food Sci. Technol. **43**, 1410–1423 (2008)