LWT - Food Science and Technology 62 (2015) 1211–1219

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

A new technique to evaluate the effect of chitosan on properties of deep-fried Kurdish cheese nuggets by TOPSIS

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ARTICLE INFO

Article history:
Received 26 March 2014
Received in revised form
27 January 2015
Accepted 30 January 2015
Available online 10 February 2015

Keywords:
TOPSIS method
Sound emission
Porosity
Image processing
Chitosan

Chemical compound studied in this article:
Chitosan, Deacetylated chitin, Poly (D-glucosamine) (PubChem CID: 21896651)

ABSTRACT

Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method was used to comprehensively evaluate physicochemical properties of fried cheese nuggets so that chitosan (0, 0.5 and 1.5%) was added to batter formulation under different processing conditions namely frying temperature (150, 170 and 190 °C) and time (0–4 min). A non-destructive, image-based method was used to measured mechanical properties of fried, breaded cheese nuggets. The results of this study indicated that all the batters have shear-thinning behavior and the coating pickup was found to be directly proportional to batter viscosity. The highest reduction in oil uptake (22.7%) was observed in samples contain 1.5% chitosan. The deep fried cheese nuggets containing chitosan tended to be higher in hardness and maximum sound peak and lower in porosity in comparison to the control sample. The optimum conditions resulting in desirable physico-chemical properties and minimum oil uptake were cheese nuggets with chitosan content of 1.5%, fried at a temperature of 170 °C for 4 min.

1. Introduction

The popularity of the frying process can be attributed to certain features of fried foods. Fried foods have good odor and visual appeal due to the golden brown color (Albert & Mittal, 2002; Dogan, Sahin, & Sumnu, 2005). However, one problem in connection with batter-fried foods is the significant amount of oil absorption during frying (Salvador, Sanz, & Fiszman, 2005). The development of methods to produce fried products with less oil uptake during frying is one of the main research fields in food science and technology (Sahin & Sumnu, 2009).

Several approaches have been suggested for decreasing oil uptake during frying of battered foods. Studies have shown that using edible films is a promising option to improve the overall quality of fried foods and also to optimize the temperature and time of frying (Albert & Mittal, 2002). Chitosan is a poly-β-(1 → 4)-2-amine-deoxy-D-glucopyranose and a naturally occurring component in shells of crustaceans and the cell walls of fungi. Special functional properties include antimicrobial activity (Tsai & Su, 1999), serum cholesterol lowering ability (Tsai & Su, 1999) and emulsification. In addition, chitosan cannot be digested and absorbed in human intestine and therefore it can be regarded as a dietary fiber (Lin & Chao, 2001).

Porosity is an important physical attribute of food products that is still mostly measured using manual methods with special devices such as mercury porosimetry and helium pycnometry, which are destructive, laborious, and inherently subjective (Adedeji & Ngadi, 2010). Thus such methods cannot provide sufficient information about pore structure characteristics but visual approach is an effective way to obtain the texture features (Qiao, Wang, Ngadi, & Kazemi, 2007). Image processing has already been successfully used in food quality inspections (Du & Sun, 2006; Qiao et al., 2007). It is a rapid, non-destructive and low-cost mean of assessing quality of food products.

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http://dx.doi.org/10.1016/j.lwt.2015.01.051

Since the demand for high quality and healthy food is globally increasing, in this study a comprehensive evaluation of the physico-chemical properties of fried Kurdish cheese nuggets was performed by using Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method which was established in order to tackle problems in multiple criteria decision making (Sun, Liang, Shan, Viernstein, & Unger, 2011). The basic genuine is that the chosen alternative should have the shortest interval from the positive ideal solution and the farthest distance from the negative ideal solution (Zhu, Wang, Liang, Li, & Sun, 2012). The TOPSIS is a powerful method to evaluate several selected cases (such as formulation and frying conditions) to identify a suitable design formula.

The main objective of this study was to evaluate physico-chemical properties of fried cheese nuggets using TOPSIS method.

2. Materials and methods

2.1. Core part and coating layer preparation

In this study a Kurdish cheese was used as the core part of the product and then it was coated by batters with different formulation in laboratory of food science, Ferdowsi university of Mashhad. The characteristics of wheat flour and Kurdish cheese are presented in Table 1. A control batter was prepared by mixing wheat flour (90.8%), baking powder (3.1%), flavoring (pepper) (0.6%), and salt (5.5%). To determine the effects of chitosan on deep-fat-fried cheese nuggets, chitosan (sigma, low molecular weight) (0, 0.5 and 1.5%) were replaced with the same amount of wheat flour. The water/dry mix proportion was always 1.2:1 (w/w). The ingredients were mixed in a mixer (Moulinex, type BM4) for 2 min. The dimensions of the cheese nuggets were 4.5 cm (diameter) × 1.5 cm (thickness) ±0.2 cm. Cheese samples were immersed individually into the batter suspensions for 30 s and allowed to drip for 30 s.

2.2. Frying

Frying was performed in thermostatically temperature-controlled fryer (Black and Decker, Type 01) containing 1.5 L refined sunflower oil (Nina, Iran). Three samples were placed in a wire basket and then submerged for 0, 1, 2, 3 and 4 min at 150, 170 and 190 °C. Then, samples were allowed to drain for 30 s before being blotted gently with dry tissue paper to remove excess oil on the surface.

2.3. Rheological measurements

The flow behaviors of the batters were investigated at 25 ± 1 °C with a Bohlin rotational viscometer (Bohlin Model Visco 88, Bohlin Instruments, UK) with using proper spindles (C14, C25 & C30) according to viscosity of the samples. The sample was sheared at programmed rate linearly increasing from 14.2 to 400 s^{-1}.

Table 1
Chemical composition of Kurdish cheese and wheat flour used in the study.

(%)	Kurdish cheese	Wheat flour
Ash	7.83 ± 1.23	0.65 ± 1.85
Dry matter	46.93 ± 3.45	83.21 ± 4.25
Protein	36.23 ± 2.12	8.54 ± 1.94
Fat	34.81 ± 1.09	1.32 ± 0.36
Water	54.07 ± 3.02	13.71 ± 0.35

Values are mean ± SD (n = 3).

2.4. Batter pickup

The amount of batter adhering to the sample during immersion coating prior to frying was considered as the batter pickup and calculated as:

$$\mathit{Batter\ Pickup}(\%) = \frac{W_b - W_N}{W_N} \times 100 \tag{1}$$

W_b: the weight of the sample after immersed in batter
W_N: the weight of the sample before immersed in batter

2.5. Moisture content analysis

The coating and core portions of the cheese nuggets were carefully separated by hand for moisture and oil content analysis. Samples 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 (AOAC, 1990).

2.6. Oil extraction

Oil content was determined by the Soxhlet method using AOAC official method 991.36 (1996). The dried samples used for moisture content determination were subsequently grounded in a blender (Nasional, K039131). The ground sample (2–4 g) was weighed and placed in a thimble. Oil was extracted in solvent extractor using petroleum ether (Extra pure, ET0091). The timbels were further dried at 105 °C for 60 min to remove residue solvent and moisture. Then the timbels were cooled in a desiccator and subsequently weighed. The oil contents were obtained in terms of dry basis.

2.7. Texture and acoustic analyses

Crispness of the fried cheese nuggets was evaluated by studying the sound emitted during fracture by simulating a human bite. Texture of the cheese nuggets 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 the instrument 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 aluminum plate 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. From the force and acoustic signals the maximum sound peak (dB), maximum force (N) and the number of total sound peaks were obtained. Extensive analysis of the sound was performed using MATLAB (Mathworks, v7. 5.0., USA) as described by Castro-Prada, Primo-Martín, Meinders, Hamer, and Van Vliet (2009).

2.8. Image processing

In order to investigate the effect of the chitosan, temperature and time frying on variations color and porosity of the cheese nuggets by image processing, the following procedure was applied:

2.8.1. Image acquisition

In this research, sample illumination was achieved with conditions as described in our previous paper (Mohebbi, Ansarifar, Hasanpour, & Amiryousefi, 2011).

2.8.2. Color characterization and computation

Improvement of background contrast of images and segmentation was performed using Adobe Photoshop (Adobe, v.8.0). Then conversion of RGB chromatic space into L*, a*, b* units: Since the L*, a*, b* color is device independent and provides consistent color regardless of the input or output, the images taken were converted into L*, a*, b* units. In the L*, a*, b* space, the color perception is uniform and therefore, the Euclidean distance between two colors is almost in agreement with the color difference perceived by the human eye (Mohebbi et al., 2011). In this study, the image analysis was managed using Image J software (National Institutes Health, Bethesda, MD, USA) version 1.40 g.

2.8.3. Determination of porosity by image analysis

The acquired images were converted to gray level images (255 levels) for texture analysis by a program developed using MATLAB (Mathworks, v7. 5.0, USA) (Du & Sun, 2006). A three step image processing algorithm was developed to extract the region of ham, namely image segmentation, morphological and mask operations (Fig. 1). Output of first step is a binary image, which several morphological operations has been done on it to remove noises and gaps within the object. Output of second step of algorithm is enhanced and improvement binary image, which its contrast has been increased and its noises has been decreased. In the last step of algorithm, image gradient computation and marker detection has been employed on output of step 2 firstly, then an improved watershed algorithm has been employed to extract pores from the grey level images of nugget as precisely as possible. The concept watershed has been originally developed to solve the problem of image segmentation, which simulates a flooding process over the image surface (Fig. 1). Mechanical tests were conducted immediately after acquiring sample images.

2.9. TOPSIS evaluation method

Decision making is the study of identifying and selecting alternatives based on the values and preferences of the decision maker. A decision making matrix is applied as one of the powerful tools for decision process designed based on a rectangular array of elements, arranged in rows and columns. First, List all of your options as the row labels in the table, and list of factors that you need to consider as the column headings. For example (time, temperature and % chitosan are alternative, moisture and oil content, color and texture parameters are factors). Next, the result each option for each of the factors in your decision. In this context, the decision making matrix usually be made in two ways. Both methods will constitute a matrix for each decision maker. In the first method, each decision matrix is considered to evaluate separately. The results are integrated by using the special techniques and finally ranking scores are obtained. In the second method, the Decision making Matrix is merged and seamlessly matrix is used in the decision making process. Both of these methods have advantages and disadvantages, which are selected based on. In this paper, the second method is used. If U is defined as the weight and importance of each decision maker, then calculate the integrated matrix elements are as follow:

$$\boldsymbol{r} = \sum_{\boldsymbol{i}=1}^{\boldsymbol{I}} \boldsymbol{U_i X^i} \quad i = 1, 2, \ldots, I \tag{2}$$

where U_i is the weight decision maker i and X^i are decision maker matric i and r is the integrated matrix.

Step (1): Establish a decision matrix for the ranking.

$$\begin{array}{c|ccccc} & C_1 & \ldots. & C_j & \ldots. & C_n \\ \hline A_1 & r_{11} & \ldots. & r_{1j} & \ldots. & r_{1n} \\ \ldots & \ldots & & \ldots & & \ldots \\ A_i & r_{i1} & \ldots. & r_{ij} & \ldots. & r_{in} \\ \ldots & \ldots & & \ldots & & \ldots \\ A_m & r_{m1} & \ldots. & r_{mj} & \ldots. & r_{mn} \end{array} \tag{3}$$

where A_i illustrate the alternatives i, i = 1, 2, …, m; C_j represents jth criterion, j = 1, 2, …, n, related to alternative; and r_{ij} is value defining the performance rating of each alternative A_i with respect to each criterion C_j.

Step (2): Calculate the normalized decision making matrix N. The normalized value n_{ij} is calculated as

$$n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \quad i = 1, 2, 3, \ldots, m \quad j = 1, 2, 3, \ldots, n \tag{4}$$

$$N = \begin{matrix} n_{11} & n_{1j} & n_{1n} \\ n_{i1} & n_{ij} & n_{in} \\ n_{m1} & n_{mj} & n_{mn} \end{matrix} \tag{5}$$

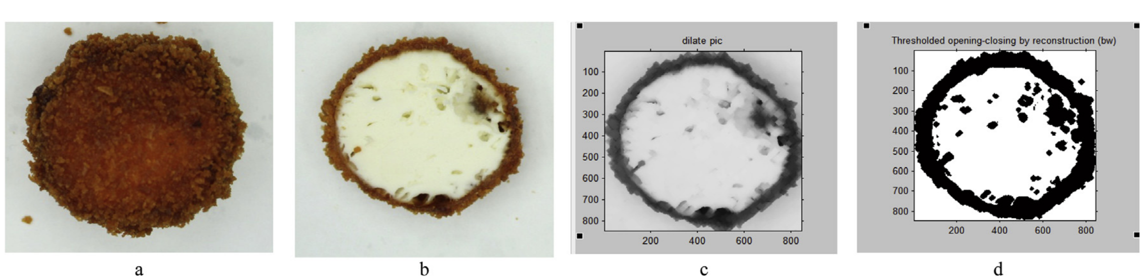

Fig. 1. Results of the image processing algorithm: (a) original image; (b) transverse incision image; (c) enhanced image; (d) segmented image.

Step (3): Calculate the weighted normalized decision making matrix by multiplying the normalized decision making matrix by it associated weights.

$$V_{ij} = W_i \times N_{ij} \quad i = 1,2,3,\ldots,m \quad j = 1,2,3,\ldots,n \tag{6}$$

where V_{ij} represents the weighted normalized value of jth indicator of the ith enterprise.

Weights are always set subjectively by experts or regulators and different methods. This research is used to entropy method for calculated the weights factors. The degree of importance of alternatives is obtained by this formula in the following four steps: (Soleimani-damaneh, 2011).

- Normalization:

$$P_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} rij} \quad i = 1,2,3,\ldots,m \quad j = 1,2,3,\ldots,n \tag{7}$$

where $A_1, A_2, \ldots, A_m$ are alternatives and $c_1, c_2, \ldots, c_n$ are the criteria.

- Compute entropy:

$$\varepsilon_j = -K \sum_{i=1}^{m} (P_{ij} {*} LnP_{ij}) \quad j = 1,2,3,\ldots,n \tag{8}$$

where K is the entropy constant and is equal to

$$K = \frac{-1}{Lnm}$$

- Set d_j as the degree of diversification

$$d_j = 1 - \varepsilon_j \quad j = 1,2,3,\ldots,n$$

- calculate the weights:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad j = 1,2,3,\ldots,n \tag{9}$$

Step (3): Calculate the weighted normalized decision matrix
Step (4): Determine the negative and positive ideal solution.

$$A^+ = \{\{\max V_{ij} | j \in B\}, \{\min V_{ij} | j \in C\}\} \tag{10}$$

$$A^- = \{\{\min V_{ij} | j \in B\}, \{\max V_{ij} | j \in C\}\} \tag{11}$$

where B is associated with benefit criteria, and C is associated with cost criteria.

Step (5): Measure the distance from the positive and negative ideal solution using two Euclidean distances.

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^+)^2} \tag{12}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^-)^2} \tag{13}$$

where d_i^+ and d_i^- represent the distance of alternative A_i from the positive and negative ideal solutions, respectively.

Step (6): Calculate the relative closeness to the ideal solution and compare Rj values to rank the alternatives Rj Є [0, 1]. cc_i factor presented the relative closeness is as follow:

$$cc_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{14}$$

where cc_i presents the relative closeness, Rj Є [0, 1].

2.10. Statistical analysis

Frying experiments were replicated 3 times under each experimental condition. Obtained data from the analyses were examined by ANOVA (analysis of variance). The statistical software program SPSS 16.0 for Windows (Version 14) was used to determine parameters. Duncan's multiple comparison tests were applied to determine the differences among the means. The level of statistical significance was determined at 95% probability.

3. Results and discussion

3.1. Rheological measurements and batter pickup

Variation of apparent viscosities of different batter formulations with shear rate at 25 °C are shown in Fig. 2. All batters were found to be non-Newtonian and showed shear thinning behavior. Experimental data provided a good fit with the power-law model ($r^2 \geq 0.97$):

$$\eta_a = k\gamma^n \tag{15}$$

The flow behavior and consistency indices of the batters are given in Table 2. The viscosity development of the dry components is related to water binding capacities in batter ingredients (Dogan

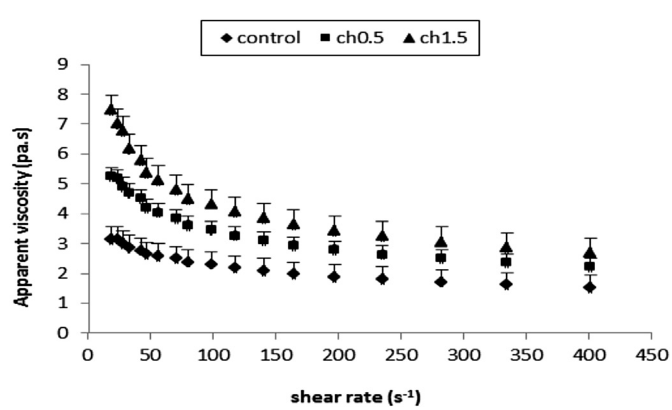

Fig. 2. Changes in batter viscosity with shear rate for chitosan at different concentrations. Control: untreated batter; ch0.5: Batter containing 0.5% chitosan; ch1.5: batter contain 1.5% chitosan. values are mean (n=3).

Table 2
Consistency index (K), flow behavior index (n), coating pickup (%), water binding capacity (WBC) of batters contain chitosan.

Formulation	K (pa.sn)	n	R^2	Coating pickup%	WBC	R^2
Control	7.64^{e}	0.73^{e}	0.999	43.65^{c}	1.028 ± 0.23^{b}	0.988
Ch0.5	13.52^{b}	0.68^{g}	0.999	48.34^{b}	1.064 ± 0.45^{b}	0.996
Ch1.5	19.15^{a}	0.64^{h}	0.997	62.72^{a}	1.257 ± 0.12^{a}	0.987

Control: untreated batter; ch0.5: batter contains 0.5% chitosan; ch1.5: batter contains 1.5% chitosan.
Means in the Superscript (horisontal) followed by different letters are significantly different ($p < 0.05$).

et al., 2005). Generally, free water has a major role in apparent viscosity. Higher apparent viscosity is due to the less amount of available water. Batters with chitosan (1.5%) showed higher consistency owing to the high water binding capacity of chitosan (Table 2). Lin and Chao (2001) found that the viscosity of concentrated chitosan solutions increases with increasing chitosan concentration that a shear thinning behavior is observed at the polymer concentrations above 0.50 g/dL. The high water absorption which is explained with its highest viscosity might be partly due to chitosan dissolution of the hydrogen bonds with water molecules which leads to formation of the gel as the result reduced the amount of free water in the batter. These results are in agreement with Ngadi, Wang, Adedeji, and Raghavan (2009).

Coating pickup is an important index in the food industry. Food quality and process yield is affected by this characteristic (Baixauli, Sanz, Salvador, & Fiszman, 2003). Batter pickup for the different batter formulations are shown in Table 2. Batters containing the highest level of chitosan (1.5%), had the highest apparent viscosity and showed the highest pickup. By the increase of chitosan content of batters from 0 to 1.5% a progressive increase in coating pickup was observed. Salvador et al. (2005) also observed similar correlation between viscosity of batter and batter pickup.

3.2. Moisture loss and oil uptake

The effect of batter formulation on the moisture content (core and breading layer) of deep-fat-fried cheese nuggets is given in Table 4. As the results show, cheese nugget coated with batter containing 1.5% chitosan provided the highest moisture content for both the core and breading layer after frying. Reduced moisture loss in these samples can be attributed to the film forming ability of chitosan which maintains moisture content on nuggets during frying. When chitosan is dissolved in water hydrogen bonds are formed and lead to formation of gel (Lin & Chao, 2001). Consequently, high strong gel reduces damage caused by the evaporation and moisture emissions to nugget surface. This is in agreement with Wu et al. (2000) who reported that batter containing chitosan (2%) was effective in retarding moisture loss for precooked beef patties. In addition, in this study chitosan increased the consistency coefficient of batter and lead to crust thickness increment and limited moisture transfer.

ANOVA showed that the batter formulations, frying time and temperature were significant ($p < 0.05$) on moisture and oil content for both the breading layer and core part of the cheese nuggets (Table 3). Samples coated with batter containing 1.5% chitosan had the lowest oil content in core and breading layer (Table 4) because less moisture loss can lead to lower oil content. During frying, moisture loss creates cavities or pores as well as passage ways in the food which are known as capillary pores and the oil penetrates to the product through these cavities (Rahimi & Ngadi, 2014). In a previous study we found a linear relationship between oil uptake and water removal (Ansarifar, Mohebbi, & Shahidi, 2012; Rahimi & Ngadi, 2014). The inclusion of chitosan to the batter formulation improved water vapor barrier properties and caused a reduction in oil absorption into the product.

The oil uptake in the breading layer was higher than the core of cheese nugget (Fig. 3). For example the mean values of the oil content of the breading layer and core portion of cheese nuggets increased from 0.02 to 0.35 g/g (db) to 0.27 and 0.50 g/g (db) for control samples, respectively at 190 °C for 4 min. Several studies have shown that oil uptake during deep-fat-frying is localized in the crust. Oil tends to concentrate to near edges, corners and broken “slots” (Ansarifar et al., 2012). Frying time is an important factor in influencing oil uptake. In this research, oil absorption (core and breading layer) was increase during frying time for all batter formulations (Fig. 3). Sahin and Sumnu (2009) reported that oil uptake is initially high, and then remains stable to become linear with time during deep-fat-frying of potatoes.

3.3. Texture and acoustic analyses

Crispiness of the fried Kurdish cheese nuggets was identified by measuring its fracture behavior and sound emission. Examples of the texture measurements and sound emission of control samples are shown in Fig. 4. The parameters evaluated were maximum force peak as index of the hardness (N), maximum sound peak (dB) and the number of total sound peaks, because hardness of the product was represented by the maximum peak force values encountered during a penetration test (Cheng, Alavi, Pearson, & Agbisit, 2007). There is a relationship between crispness and sound emitted during the biting and chewing of the food (Castro-Prada et al., 2009). When the cheese nuggets were fried at the

Table 3
Successive mean squares from the analysis of variance of the moisture content, oil content, hardness, maximum sound peak, color parameters and porosity.

Source	DF	Mean square									
		Moisture content g/g (db)		Oil content g/g (db)		Maximum force peak as index of the hardness (N)	Maximum sound peak (dB)	L*	a*	b*	Porosity (%)
		Core	Crust	Core	Crust						
A	2	2.244^{**}	0.107^{**}	0.027^{**}	0.25^{**}	21.121^{**}	2555.62^{**}	848.341^{**}	43.103^{**}	483.341^{**}	65.14^{**}
B	4	0.681^{**}	0.130^{**}	0.018^{**}	0.091^{**}	39.75^{**}	4809.86^{*}	2593.28^{**}	764.35^{**}	1304.64^{**}	935.34^{**}
C	2	0.031^{NS}	0.009^{**}	0.004^{**}	0.010^{**}	4.74^{**}	574.13^{*}	1650.98^{**}	281.26^{**}	1642.10^{**}	45.75^{**}
A × B	8	0.094^{**}	0.001^{*}	0.002^{**}	0.002^{*}	1.60^{**}	193.69^{**}	22.90^{NS}	10.27^{NS}	11.81^{NS}	1.098^{**}
A × C	4	0.003^{NS}	0.001^{*}	0.002^{**}	0.002^{*}	0.71^{**}	86.60^{**}	14.78^{NS}	3.41^{NS}	3.45^{NS}	65.146^{**}
B × C	8	0.003^{NS}	0.001^{*}	0.002^{**}	0.001^{*}	0.34^{**}	41.45^{*}	164.44^{**}	26.57^{**}	168.89^{**}	4.13^{**}
A × B × C	16	0.002^{NS}	0.001^{NS}	0.001^{**}	0.000^{*}	0.11^{NS}	13.74^{NS}	7.87^{NS}	5.47^{NS}	2.18^{NS}	0.35^{NS}
Error	45	0.021	0.000	0.0001	0.0003	0.86	10.44	627.85	215.54	370.11	0.49
Total	90										

A: Batter formulation; B: Frying time (min); C: Temperature (°C); NS: not significant; $p^* = 0.05$, $p^{**} = 0.01$.

Table 4
Effect of chitosan at different concentrations on moisture content (g/g db), oil content (g/g db), hardness (N), maximum sound peak (db), porosity (%) and color parameters of fried Kurdish cheese nuggets.

Formulation	Moisture content (g/g db)		Oil content (g/g db)		Hardness (N)	Maximum sound peak (dB)	Porosity (%)	L*	a*	b*
	Crust	Core	Crust	Core						
Control	0.1404[c]	0.3802[c]	0.1778[a]	0.4297[a]	3.312[c]	36.439[c]	16.532[a]	48.411[b]	20.901[b]	52.152[b]
Ch0.5	0.2145[b]	0.8047[b]	0.1544[b]	0.3856[b]	4.002[b]	44.022[b]	15.259[b]	45.190[c]	23.168[a]	57.200[a]
Ch1.5	0.2585[a]	0.8912[a]	0.1164[c]	0.3731[c]	4.982[a]	54.806[a]	14.469[c]	55.579[a]	21.360[b]	49.271[c]

Control: untreat batter; ch0.5: batter contain 0.5% chitosan; ch1.5: batter contain 1.5% chitosan.
Means in the Superscript (horisontal) followed by different letters are significantly different ($p < 0.05$).
Crust = Breading layer, Core = Kurdish cheese.

temperature 150 °C the fracture pattern shows only one drop in force and a smaller number sound peaks, which indicates the absence of crispy behavior. While can be seen, with increased frying temperature shows many fracture events roughly similar in size (Fig. 4; Table 5). This can be explained by the high number of small air cells as can be seen later. Hardness increased significantly with frying time. These results are in agreement with literature discussing that higher frying temperature and time enhance crust formation (Saeleaw & Schleining, 2011). Cheng et al., (2007) found that the hardness in the texture increased linearly with frying time like the observations made in this study.

A high number of sound peaks have been associated to a high sensory crispness (Varela, Chen, Fiszman, & Povey, 2006). The crispness of fried nuggets containing 1.5% chitosan batter were higher than control (Table 5). The fried samples containing chitosan had softer cores and more elastic texture, because water molecules in the crusts were absorbed by chitosan gel (Cheng et al., 2007). This is in agreement with Wu et al. (2000) who used chitosan coating (2%) as a barrier to control moisture loss in precooked beef patties. Also the breading layer containing chitosan had high pickup values and enough batter provided coating and film structure outside the cheese nuggets to formed brittle crust. The crust is formed at the surface of the food during frying. The intimate interaction between the frying medium and the food surface would lead to rapid moisture loss and other physiochemical reactions that cause crust formation. During the frying process, the batter is dehydrated until formation of a crisp texture in the outer part, thus protecting the tenderness of the inner part (Moyano & Predreschi, 2006).

3.4. Porosity

Structure has a large effect on the auditory understanding when biting into foods. In dry cellular products the sound pressure wave is produced by snapping back of walls that bend before breaking (Saeleaw & Schleining, 2011). The porosity values ranged between 6.9% and 38.9%. There was a general decrease in porosity with increased chitosan content in batter formulation (Table 6). It can relate with interrelationship between pore development, moisture and oil transfer where moisture loss and oil gained were plotted against porosity, respectively. Saeleaw and Schleining (2011) reported there were linear correlations between porosity versus moisture and oil contents. Reducing moisture loss resulted in decreasing porosity and oil content presents a negative correlation with porosity (Sahin & Sumnu, 2009).

There was a significant effect ($p < 0.05$) of frying time and temperature on porosity of the fried Kurdish cheese nuggets. Mean separation showed that there is significant difference ($p < 0.01$) between porosities at 150 °C, compared to the values at 170 and 190 °C (Table 5). Based on the enhanced image of transverse incision of cheese nugget under different frying conditions, the pores were partitioned using the method described. It can be observed that almost all the pores in the image were segmented properly as shown in Fig. 4. When cheese nuggets were in contact with oil, the moisture on the surface evaporates immediately resulting in an appearance with tiny pores. Many authors investigated the effect of oil temperature and frying time on properties of fried products. Moreover Ngadi et al. (2009) stated that the effect of temperature on moisture evaporation leading to pore development during

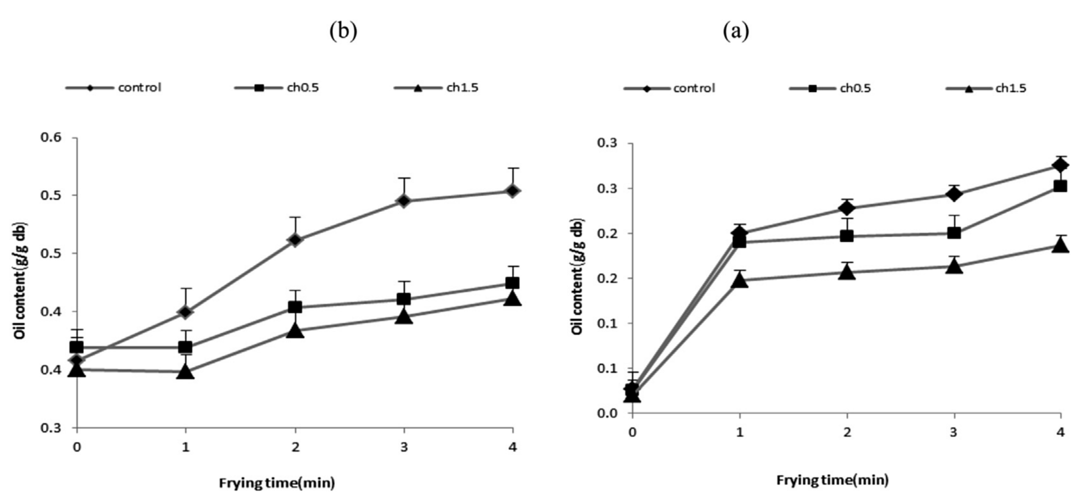

Fig. 3. Oil content (g/g db) in the breading layer (a) and core (b) of cheese nuggets fried at 190 °C for 0, 1, 2, 3 and 4 min. Control: untreated batter; ch0.5: batter containing 0.5% chitosan; ch1.5: batter contain 1.5% chitosan values are mean (n=3).

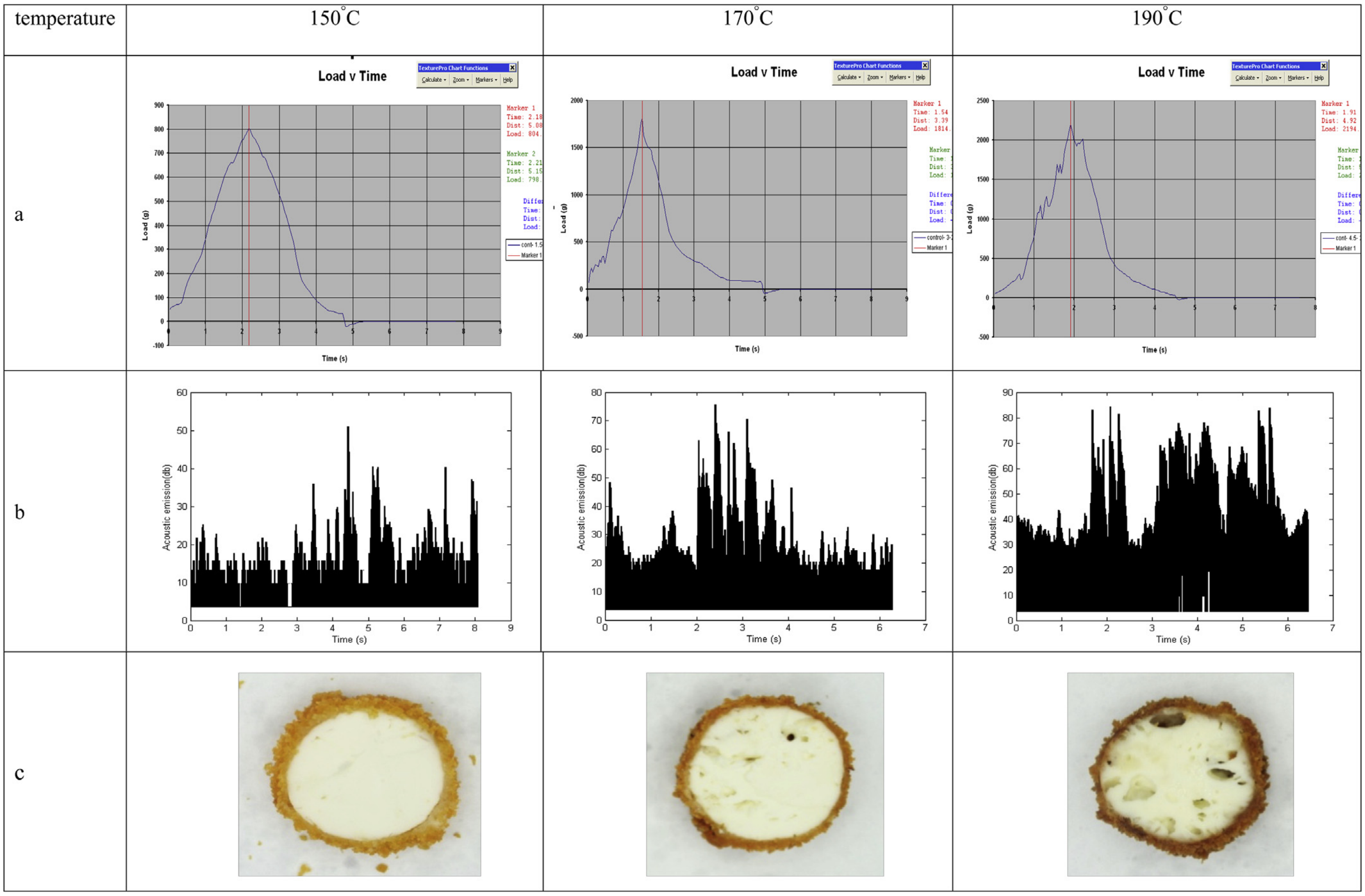

Fig. 4. Force (a) and sound (b) curves and image of transverse Incision (showed porosity) (c) of Kurdish cheese nugget at different frying temperature.

frying. Texture and brittleness of fried foods are also affected by pore size distribution (Ngadi et al., 2009). The number of acoustic events is a function of the cell density and fracture model of the treatments (Saeleaw & Schleining, 2011). This is in agreement with results of this study, where the temperature and frying time increased the number of pores as well as the number of sound and force peaks.

3.5. Color parameters

The batter formulation and frying temperature time had significant influence ($p < 0.05$) on color parameters of cheese nuggets (Table 3). Cooked color is closely related to coating appearance. It results from a combination of ingredient composition, cooking method, coating medium, and cooking oil. Lightness, redness and yellowness of fried cheese nuggets were determined as L*, a* and b* value, respectively (Table 7).

L* and b* value of fried cheese nuggets decreased with increase in chitosan content. In contrast, a* values increased with increase in chitosan content as shown in Table 7. There was a significant difference ($p < 0.05$) in L*, a* and b* values among samples with chitosan content of 0, 0.5 and 1.5%. Composition plays an important role in determining the extent of color development due to Maillard reactions. Maillard reaction, a non-enzymatic browning reaction between amino acids and reducing sugars, is the primary color formation reaction (Baixauli et al., 2003; Moyano & Predreschi,

Table 5
Effect of different conditions frying and formulation of batter on number of total sound peaks of fried Kurdish cheese nuggets.

Temperature (°C)	Formulation	Frying time				
		0	1	2	3	4
150	Control	$21.64 \pm 0.07^{d}_{b}$	$24.94 \pm 0.09^{cd}_{d}$	$28.24 \pm 0.02^{c}_{d}$	$35.17 \pm 0.03^{b}_{d}$	$42.17 \pm 0.05^{a}_{d}$
	Ch0.5	$23.34 \pm 2.38^{e}_{ab}$	$31.02 \pm 0.79^{d}_{b}$	$44.47 \pm 3.97^{c}_{c}$	$54.38 \pm 0.08^{b}_{b}$	$61.09 \pm 2.38^{a}_{b}$
	Ch1.5	$23.46 \pm 1.66^{e}_{ab}$	$37.32 \pm 1.58^{d}_{ab}$	$48.43 \pm 1.60^{c}_{b}$	$59.36 \pm 0.31^{b}_{b}$	$67.89 \pm 8.05^{a}_{b}$
170	Control	$21.65 \pm 0.77^{d}_{b}$	$34.82 \pm 0.59^{c}_{b}$	$43.08 \pm 0.79^{b}_{c}$	$48.41 \pm 0.79^{b}_{c}$	$57.40 \pm 0.06^{a}_{c}$
	Ch0.5	$24.03 \pm 1.25^{e}_{a}$	$38.91 \pm 0.82^{d}_{ab}$	$47.96 \pm 3.99^{c}_{b}$	$54.97 \pm 2.40^{b}_{b}$	$63.27 \pm 2.98^{a}_{b}$
	Ch1.5	$25.71 \pm 5.21^{e}_{a}$	$46.21 \pm 1.61^{d}_{a}$	$63.67 \pm 0.77^{c}_{a}$	$74.61 \pm 1.56^{b}_{a}$	$84.60 \pm 1.78^{a}_{ab}$
190	Control	$22.76 \pm 0.77^{c}_{b}$	$30.96 \pm 0.70^{bc}_{c}$	$39.94 \pm 0.09^{b}_{cd}$	$43.55 \pm 0.07^{b}_{c}$	$51.88 \pm 0.04^{a}_{c}$
	Ch0.5	$21.09 \pm 0.79^{e}_{b}$	$32.89 \pm 0.09^{d}_{b}$	$43.41 \pm 5.56^{c}_{c}$	$55.04 \pm 2.38^{b}_{b}$	$64.46 \pm 7.94^{a}_{b}$
	Ch1.5	$22.77 \pm 0.49^{d}_{b}$	$46.02 \pm 0.78^{cd}_{a}$	$59.80 \pm 4.96^{c}_{a}$	$71.97 \pm 6.96^{b}_{a}$	$90.28 \pm 3.11^{a}_{a}$

Control: untreated batter; ch0.5: batter contain 0.5% chitosan; ch1.5: batter contain 1.5% chitosan.
Means in the Superscript (horisontal) followed by different letters are significantly different ($p < 0.05$). Means in the Subtitles (vertical) followed by different letters are significantly different ($p < 0.05$). Values are mean ± SD (n = 3).

Table 6
Effect of different conditions frying and formulation of batter on porosity (%) of fried Kurdish cheese nuggets.

Temperature (°C)	Formulation	Frying time				
		0	1	2	3	4
150	Control	6.73 ± 0.77$^{e}_{a}$	10.54 ± 0.69$^{d}_{b}$	14.25 ± 0.72$^{b}_{b}$	18.50 ± 0.53$^{c}_{b}$	25.13 ± 0.59$^{a}_{ab}$
	Ch0.5	6.67 ± 0.71$^{d}_{a}$	10.97 ± 0.84$^{cd}_{b}$	12.94 ± 0.72$^{c}_{c}$	17.73 ± 0.70$^{b}_{c}$	22.99 ± 0.96$^{a}_{b}$
	Ch1.5	6.83 ± 0.05$^{e}_{a}$	9.60 ± 0.74$^{d}_{b}$	12.39 ± 0.85$^{c}_{c}$	16.82 ± 0.02$^{b}_{c}$	22.03 ± 0.78$^{a}_{b}$
170	Control	6.73 ± 0.77$^{d}_{a}$	10.79 ± 0.69$^{c}_{b}$	15.26 ± 0.78$^{b}_{b}$	22.12 ± 0.56$^{ab}_{ab}$	26.73 ± 0.52$^{a}_{ab}$
	Ch0.5	6.67 ± 0.71$^{c}_{a}$	11.52 ± 0.61$^{bc}_{b}$	13.81 ± 0.51$^{b}_{bc}$	19.77 ± 0.59$^{ab}_{b}$	24.20 ± 0.62$^{a}_{ab}$
	Ch1.5	6.83 ± 0.05$^{c}_{a}$	10.39 ± 0.34$^{bc}_{b}$	12.72 ± 0.63$^{b}_{c}$	18.39 ± 0.84$^{ab}_{b}$	23.49 ± 0.79$^{a}_{b}$
190	Control	6.73 ± 0.77$^{e}_{a}$	12.58 ± 0.70$^{d}_{a}$	17.51 ± 0.79$^{c}_{a}$	24.37 ± 0.50$^{b}_{a}$	30.08 ± 0.54$^{a}_{a}$
	Ch0.5	6.67 ± 0.71$^{e}_{a}$	13.51 ± 0.69$^{d}_{a}$	14.98 ± 0.23$^{c}_{b}$	20.82 ± 0.82$^{b}_{b}$	26.28 ± 0.71$^{a}_{ab}$
	Ch1.5	6.83 ± 0.05$^{e}_{a}$	11.95 ± 0.83$^{d}_{b}$	14.04 ± 0.69$^{c}_{bc}$	20.17 ± 0.61$^{b}_{b}$	24.36 ± 0.56$^{a}_{b}$

Control: untreated batter; ch0.5: batter contain 0.5% chitosan; ch1.5: batter contain 1.5% chitosan.
Means in the Superscript (horisontal) followed by different letters are significantly different ($p < 0.05$). Means in the Subtitles (vertical) followed by different letters are significantly different ($p < 0.05$). Values are mean ± SD ($n = 3$).

2006). The addition of chitosan caused an increase in the amount of sugars in the batter mixture. Thus, the Maillard browning reaction easily occurred with increase in chitosan resulting in decrease of L* and b* values, but increase of a* value. As demonstrated in Table 6 as the frying temperature increases, the lightness parameter of the fried product decreases, whereas the redness and yellowness parameters increase for the same frying time (Baixauli et al., 2003; Moyano & Predreschi, 2006; Sahin & Sumnu, 2009). Our results were consistent with the study by Sahin & Sumnu, 2009. L* and b* values of fried samples decreased with increase in frying temperature and frying time, while a* value increased as shown in Table 7.

3.6. TOPSIS method to comprehensively evaluate the properties of fried cheese nuggets

The current analysis is based on multi-attribute decision making, which is one of the main and most important functional feature of this paper. In this experiment, we use TOPSIS for group decision making to tackle multi criteria decision problems. This method allows finding the best alternatives. An application for a case study involving two decision makers (D_1, D_2) that plan to select the best formulas from chitosan as additives and frying time and temperature to improve quality, where the selection criteria are moisture (core and breading layer), oil (core and breading layer), color parameters (L*, a* and b*), hardness, sound emission and porosity. The oil (core and breading layer), porosity and color parameter (L*) are considered negative criteria; other criteria are considered positive criteria. These two decision makers respectively compare the 10 criteria and evaluate their degree of satisfaction with every formula. The weight vector for DM_1 and DM_2 is $U_1 = 0.5$ and $U_2 = 0.5$ respectively. Therefore, we present the results of calculation of the integrated matrix elements. Since our aim is to find the best alternative based on the criteria chosen here. Let us calculate A^+ represents the ideal and A^- represents the negative one. They are obtained by using Equations (9) and (10) are given.

Using Equations (11) and (12), the various distances are measured which indicates position of the different alternatives for each factor from ideal solution and negative ideal solution (Table 8). These distances are used in the calculation of relative closeness. Table 8 shows the final rankings of formulas are obtained with this methodology. As can be seen the first position is assigned to cheese nuggets with chitosan content of 1.5%, fried at a temperature of 170 °C for 4 min. Based upon Table 8, it has the nearest distance to the positive ideal (0.0345) and also the farthest distance to the negative ideal (0.0437). It may be attributed to desirable physicochemical properties and minimum oil uptake. Control nuggets fried at temperature of 190 °C for 4 min, which is located in the last position by TOPSIS method, gets the lowest ranking because this samples had the higher oil uptake and qualitative characteristics (color and texture) is not desirable than other samples and according to Table 8 it's distance to the positive and negative ideal is (0.0644) and (0.0155) respectively. By using this ranking, we can observe the logicality and predictability of the influence of this addictive on fried cheese nuggets. By Table 8 we can compare the ranking of each formula and select best alternative that it is desirable for your purpose.

4. Conclusion

The results of this study showed that water binding capacity of each ingredient in batter will affect coating pickup which is quite important for product quality. The cheese nuggets containing 1.5% chitosan had higher moisture contents (core and breading layer) and lower oil contents (core and breading layer) than the control

Table 7
Effects of frying time and temperature on L*, a* and b*of control fried Kurdish cheese nuggets.

Temperature (°C)		Frying time				
		0	1	2	3	4
150	L*	66.92 ± 0.12$^{a}_{a}$	57.94 ± 0.05$^{b}_{a}$	55.33 ± 0.97$^{c}_{a}$	52.46 ± 0.35$^{d}_{a}$	52.99 ± 1.30$^{e}_{a}$
	a*	8.63 ± 0.83$^{d}_{c}$	16.44 ± 0.31$^{c}_{c}$	18.89 ± 0.32$^{b}_{c}$	21.33 ± 0.76$^{a}_{c}$	19.56 ± 1.43$^{a}_{c}$
	b*	63.83 ± 0.05$^{a}_{a}$	61.66 ± 0.14$^{b}_{a}$	60.20 ± 0.75$^{c}_{a}$	57.50 ± 0.02$^{d}_{a}$	57.11 ± 0.38$^{e}_{a}$
170	L*	66.92 ± 0.12$^{a}_{b}$	50.29 ± 2.42$^{b}_{b}$	44.06 ± 0.39$^{c}_{b}$	40.52 ± 1.60$^{d}_{b}$	39.08 ± 0.28$^{e}_{b}$
	a*	8.63 ± 0.83$^{d}_{b}$	24.57 ± 1.77$^{c}_{b}$	26.02 ± 0.51$^{b}_{b}$	26.77 ± 0.59$^{a}_{b}$	26.20 ± 0.54$^{a}_{b}$
	b*	63.83 ± 0.05$^{a}_{b}$	56.02 ± 2.04$^{b}_{b}$	50.12 ± 0.12$^{c}_{b}$	47.02 ± 1.47$^{d}_{b}$	45.30 ± 0.09$^{e}_{b}$
190	L*	66.92 ± 0.12$^{a}_{c}$	45.34 ± 1.35$^{b}_{c}$	36.14 ± 0.82$^{c}_{c}$	27.96 ± 1.21$^{d}_{c}$	23.27 ± 1.91$^{e}_{c}$
	a*	8.63 ± 0.83$^{d}_{a}$	24.27 ± 3.16$^{c}_{a}$	27.66 ± 2.23$^{b}_{a}$	24.82 ± 0.72$^{a}_{a}$	21.58 ± 1.19$^{a}_{a}$
	b*	63.83 ± 0.05$^{a}_{c}$	50.77 ± 0.42$^{b}_{c}$	42.34 ± 0.72$^{c}_{c}$	34.13 ± 1.01$^{d}_{c}$	28.36 ± 0.46$^{e}_{c}$

Means in the Superscript (horisontal) followed by different letters are significantly different ($p < 0.05$). Means in the Subtitles (vertical) followed by different letters are significantly different ($p < 0.05$). Values are mean ± SD ($n = 3$).

Table 8
Final rankings of formulas of fried Kurdish cheese nuggets obtained by TOPSIS method on different condition of frying.

Rank	Formulation	Time (min)	Temperature (°C)	cc_i	d_i^+	d_i^-
1	Ch1.5	4	170	0.559099	0.034505	0.043755
2	Ch1.5	4	150	0.537861	0.034028	0.039603
3	Ch1.5	4	190	0.495967	0.041968	0.041296
4	Ch0.5	4	150	0.429766	0.041683	0.031415
5	Ch0.5	4	170	0.385263	0.045869	0.028747
6	Ch0.5	4	190	0.327345	0.053214	0.025896
7	Control	4	170	0.248138	0.05889	0.019436
8	Control	4	150	0.233717	0.056482	0.017227
9	Control	4	190	0.19431	0.064478	0.01555

Control: untreated batter; Ch0.5: batter contain 0.5% chitosan; Ch1.5: batter contain 1.5% chitosan; d_i^+: Positive ideal solution of Euclidean distance; d_i^-: Negative ideal solution of Euclidean distance; cc_i: The closeness coefficient.

sample. The chitosan were heated by frying to restrict moisture loss and decrease oil diffusion to the crusts and also high pickup values than other fried crusts. Therefore, enough batter provided coating and film structure outside the cheese nuggets to avoid too much water evaporation during frying. Porosity negative correlates with moisture content but negatively correlates with frying time. Cutting force may represent crust hardness, and correlation with structure of cheese nuggets. The frying temperature and time also influenced the quality attributes of fried cheese nuggets. TOPSIS analysis revealed the following order of formulation and frying temperature, according to the highest ranking: ch1.5 (170 °C) > ch1.5 (150 °C) > ch1.5 (190 °C) > ch0.5 (190 °C) > ch0.5 (170 °C) > ch0.5 (150 °C) > control (170 °C) > control (190 °C) > control (150 °C). The results demonstrated that the TOPSIS method in food industry is very significant because there are irreparable consequences by making the wrong decision. The consequences of our decisions are obvious for example having comprehensive decision making by considering the all factors affects to choose best alternative, evaluate performance of different materials or condition on cheese nugget, help to select best policies established for quality improvement, health promotion, energy management and energy optimization for the industrial consumer, increase consumer satisfaction, and enhancing of the shelf life.

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