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Original research

Effects of infrared cooking techniques and Balangu (*Lallemantia royleana*) gum concentration on quality characteristics and stress relaxation of chicken nugget

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A B S T R A C T

In the present study, the effect of Balangu gum (0, 0.25, and 0.5%) and cooking techniques (deep frying, Infrared cooking, Infrared cooking - post frying (IR-PF) and pre frying - Infrared cooking (PF-IR) on the moisture, fat content, color, weight loss, textural characteristics and stress relaxation of chicken nuggets were evaluated. Generalized Maxwell and empirical Peleg models were used to predict the stress relaxation of the nuggets. The interaction of gum concentrations in batter formulation and cooking method showed significant effect only on springiness, cohesiveness and resilience. Three elements Maxwell exponential model demonstrated a better fit to the data with higher adjusted R^2 and lower RMSE values than empirical Peleg model. So that, higher and lower elasticity and stiffness were observed in the nugget samples cooked by PF-IR and frying methods, respectively and an increase in Balangu gum concentration remarkably decreased the elasticity and stiffness of samples. Results indicated that the application of IR cooking and Balangu gum in batter formulation might result in a product with desirable texture and color and lower fat content introduced to the food industry as an efficient treatment process.

Keywords: Chicken nugget; Balangu gum; Infrared radiation; Relaxation test; Maxwell model

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1. Introduction

The current increasing demand for fried foods that are organoleptically appealing is a health concern so the three techniques were proposed for reducing the oil content of these products which involved modifying the surface of the product by coating, modifying the frying process, and combination with other cooking techniques and modification of frying medium (Liberty et al., 2019). The most convenient and simplest method to reduce the oil absorption is development of a batter formulation with specific ingredients (Mohamed et al., 1998; Priya, et al., 1996). Because of their higher water-binding capacities, hydrocolloids are among considerable ingredients that reduce the amount of oil absorption in fried products (Dziezak, 1991; Hsia et al., 1992). There were some studies which investigate some chemical and physico-mechanical properties of different local seed gum like Godoume Shirazi, Persian gum, tragacanth, locust bean and fenugreek (Mostafavi et al., 2016; Brummer et al., 2003). Balangu seed gum structural and chemical properties and its effect on pathogen population and sensory attributes of beef as an edible coating during a period were investigated by Alizadeh Behbahani and Imani Fooladi (2018). They noted that the Balanagu gum is a polysaccharide, with high molecular weight (1.19×10^6 Da) and main units of this gum are galactose and arabinose and also the gum had good antioxidant activity. Razavi et al., (2008) studied the physico-chemical and mechanical properties of Balangu seed gum and reported that this gum had high apparent volume and molecular weight. The effect of *Cydonia oblonga* gum on the physiochemical properties of hamburger was also investigated (Yoosefi et al., 2016). Mahdavian Mehr et al. (2016) showed the performance of *Lepidium perfoliatum* seed gum in reducing oil content in deep-fried battered chicken nugget and found out that 1% concentration of gum in batter formulation had the most effect on this phenomenon. Shan et al. (2018) used different ratio of xanthan gum and soybean fiber in the batter formulation of fish nugget to reduce oil adsorption. They relied to the sample with higher moisture had the lower oil content.

The use of infrared is suitable for removing oil in cooked nugget, textural properties of cooked samples by infrared might be influenced by process parameters such as heat flux, time of process, and distance between infrared lamp and sample (Turp et al., 2016). Udomkun et al. (2019) were investigated the effect of far-infrared

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frying technique on some properties of chicken nuggets. This investigator revealed that a higher heating rate and more uniform heat distribution were observed in the far-infrared frying. In the case of nugget, one of the most significant factors for consumer acceptability is appearance properties such as color and texture of a nugget, therefore rheological properties, texture, and color can offer a quantified basis for controlling the cooking process for quality control and improvement (Kim et al., 2015). The heat transfer coefficient and oil uptake decreases during the frying by application of various gums as hydrocolloid coatings (Salehi, 2020). Stress relaxation is one of the basic tests that has been employed for measuring the viscoelastic response of foods. In this test, samples are exposed to a constant strain and the stress required to maintain the deformation is measured as a function of time (Steffe, 1996). The results of stress–relaxation test can provide useful information about behaviors of material (Tabilo-Munizaga & Barbosa-Cánovas, 2005). Maxwell model and Peleg and Normand model are used to describe the stress relaxation behavior of different foods. Andrés et al. (2008) reported that the stress relaxation data of low-fat chicken sausages were fitted well by a model with seven Maxwellian elements. Karaman et al. (2016) and Sozer et al. (2008) also found that the stress relaxation data of Kashar cheese and enriched spaghetti with resistant starch were fitted well by a three-element Maxwell model.

The aim of this study was to investigate the chemical properties, stress relaxation and textural parameters of chicken nuggets prepared with different cooking methods and batter systems formulated with different concentrations of the Balangu gum. The correlation between fundamentally mechanical stress relaxation parameters and empirical textural characteristics of the chicken nuggets was also investigated.

2. Material and Methods

2.1. Extraction of Gum

Balangu seeds were purchased from a local market in Gorgan, Iran. After cleaning, they soaked in distilled water for 20 min (pH=7, temperature=25℃ and water: seed ratio 20:1). Then by passing the swollen seeds through an extractor (MJ-J176P, Panasonic, Japan), gum layer was scraped from seed surface. The crude gum was dried in a forced air dryer at 60°C (convection oven, Memmert Universal, Schwabach, Germany) for 48 h. The dried samples were milled and passed through a 35-mesh sieve. Then, the milled powder was dispersed in distilled water to prepare different concentrations (0.25 and 0.5%) of gum solution for batter formulation. The prepared gum solutions were kept at room temperature for 24 h to complete hydration process (Salehi & Kashaninejad, 2014).

2.2. Preparation of chicken nugget

Chicken breast was used as the food matrix and chopped using a Kenwood mincer (Model AWAT950A01, Japan). The chopped chicken meat (88%) mixed completely with onion (10%), salt (1.5%) and seasoning (0.5%). This mixture was formed into a cube shape (3.5 ×3.5 ×1.5 ± 0.2 cm) and frozen to below −10℃. The batter was made of wheat flour (98%), salt (1.5%) and baking powder (0.5%) as a leavening agent. Balangu seed gum at different concentrations (0, 0.25 and 0.5%) was used in the batter formulation by replacing the wheat flour. The pre-blended powders were mixed with water (25°C) at 5:3 ratio in a mixer. The frozen nuggets were immersed in the batter (25℃) for 15 s and then allowed 10 s at room temperature to drip out the excessive batter. Immediately afterwards, the battered nuggets were individually immersed in rusk powder for 30 s. The nuggets packed into the polyethylene bags and stored at −10°C until cooking treatments (Mahdavian Mehr et al., 2016).

2.3. Cooking treatment

2.3.1. Deep fat frying

Chicken nugget samples were defrosted overnight (4℃) and deep fat fried individually for 4 min in refined frying oil at 180℃ (Sergio Professional domestic fryer). Deep fat frying of the nugget was selected as a control method. After frying, the sample was immediately removed from the oil and its excess surface oil was removed using tissue paper. Before further analysis, the samples were allowed to cool down to the room temperature (about 25℃).

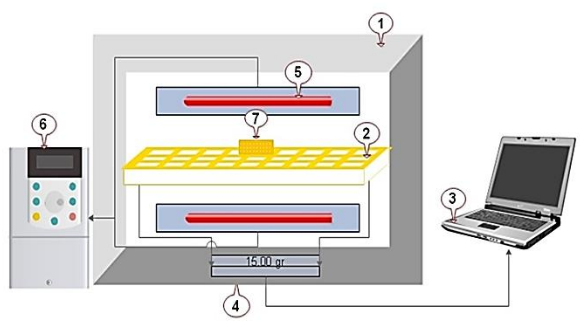

Fig. 1. Schematic diagram of designed IR heating oven used for cooking the chicken nuggets: 1) cooking chamber; 2) sample holder; 3) computer; 4) electronic balance; 5) IR lamp; 6) variable; 7) sample.

2.3.2. IR treatment

An IR heating oven (Fig. 1) was developed at the Department of Food Process Engineering, Gorgan University of Agricultural Sciences and Natural Resources to study cooking of chicken nuggets. One piece of chicken nugget was placed in a sample holder which was between two far-infrared lamps (1000 W). The distance between the sample and IR lamps was adjusted to 5 cm and samples were exposed to the heat flux of 24.7 kW/m^2. To achieve a constant heat flux, the lamps were turned on 5 min before starting the cooking treatment. In this study, three different IR processing conditions were applied: 1) IR cooking (IR) using heat flux of 24.7 kW/m^2 for 12 min in designed IR oven, 2) Pre frying-IR cooking (PF-IR) which samples first pre-fried for 30 s at 180℃ (similar to section 2. 3. 1) and then finally cooked in the IR oven using heat flux of 24.7 kW/m^2 for 12 min, 3) IR cooking - post frying (IR-PF) which samples were cooked in the IR oven in heat flux of 24.7 kW/m^2 for 12 min and then post fried for 30 s at 180℃ (similar to section 2. 3. 1). Fig. 2 shows the final nuggets which cooked by different cooking condition (Rahimi et al., 2018).

2.4. Chemical analysis

2.4.1. Moisture content

The processed nuggets were dried to a constant weight at 105 ± 1°C in a hot-air convection oven (FD53, Binder, Germany) according to AOAC standard method to calculate the moisture content (wet basis) (AOAC, 1986).

2.4.2. Fat content

The oil content of the cooled fried nugget was determined using the Soxhlet extraction method by hexane as extraction solvent. Oil content was estimated as a percentage on the dry-weight basis of the sample (AOAC, 1990).

2.4.3. Total weight loss

The chicken nuggets were weighed with a Sartorius electronic balance (GM-300p, Taiwan) before and after frying treatment to calculate the total weight loss. The total weight loss (L_T) was determined using Eq. 1:

$$L_T = \frac{W_i - W_f}{W_i} \times 100 \tag{1}$$

where, W_i and W_f represent the weight (g) of the chicken nugget before and after thermal processing, respectively (Braeckman et al., 2009).

2.5. Physical analysis

2.5.1. Color measurement

Image processing was used to determine the effect of cooking method and batter formulation on the color of the chicken nuggets. Sample illumination was achieved with four LED lights, which were placed in a wooden box (0.4×0.4×0.4 m). The interior walls of the box were painted black to minimize background light. A color digital camera (Canon, sx150, Japan) was located vertically at a distance of 25 cm from the sample. Image J software (version 1.42e, USA) converted the RGB signals of the taken picture to L^*, a^*, b^* coordinates. The calculation of color changes (ΔE) for total color difference was made with the following equations (Turp et al., 2016):

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{2}$$

2.5.2. Textural properties

A TA- XT plus texture analyzer (Stable Micro Systems, UK) was used to evaluate the texture of the chicken nuggets after final processing. Chicken nuggets were cut into a cube (1.5 × 1.5 × 1.5 cm) and compressed by cylindrical plate (diameter of 3.6 cm) and 5 kg power cell to perform the TPA test which consists of two cycles of compression. The samples compressed twice, with 15 s delay between the descents at a rate of 1 mm/s. Various parameters including hardness, springiness, chewiness, gumminess and resilience were estimated from force-time curve of TPA by means of at least ten reproducible runs for each sample.

2.6. Stress relaxation of nuggets

The stress relaxation tests were measured on the cubes of cooked nuggets (1.5×1.5×1.5 cm) at room temperature by a TA-XT plus Texture analyzer (Stable Micro Systems, Surrey, UK) with the Texture Expert Exceed software. The samples were compressed to a constant strain of 20% with a test speed of 0.5 mm/s. When the sample strained to 20%, the probe was stopped and force was continuously recorded as a function of time for 480 s (every 0.25 s).

2.7. Mathematical modeling of stress relaxation

Although nugget is a complex matrix, it could be described with a certain approximation on the base of simplified models like other meat products. The model usually used to represent most food products subjected to stress relaxation is a generalized Maxwell model composed of a finite number of Maxwell elements (a spring and a dashpot in series) in parallel with each other (Steffe, 1996). Generalized Maxwell model compared with single Maxwell model could better described the viscoelastic behavior of food (Ak & Gunasekaran, 1996; Gunasekaran & Ak, 2002; Singh et al., 2006; Steffe, 1996). For many foods, three terms involving six constants are sufficient. The equation representing the Maxwell elements in parallel are shown as follows:

$$\sigma(t) = \sigma_1 \exp\left(-\frac{t}{\lambda_1}\right) + \sigma_2 \exp\left(-\frac{t}{\lambda_2}\right) + \cdots + \sigma_n \exp\left(-\frac{t}{\lambda_n}\right) \tag{3}$$

where t is time, λ_1 to λ_n are the relaxation times constants corresponding to various elements in the Maxwell model, σ_1 to σ_n are the decay stresses, and $\sigma(t)$ is the actual stress as a function of time in a stress relaxation test (Khazaei & Mann, 2004). In this model, we can use applied stress (f(t)) instead of stress.

One of the other models applied for stress relaxation data is Peleg and Normand (1983) model. In this model, stress relaxation data were calculated as a normalized stress and fitted to the following linear equation:

$$\frac{\sigma_0 . t}{\sigma_0 - \sigma(t)} = k_1 + k_2 . t \tag{4}$$

where, t is time, k_1 and k_2 are the constants, $\sigma(t)$ and σ are the stress at time t and zero, respectively (Andrés et al., 2008). Fitting the experimental data to the equation (Eq. 4) is a quick and effective way to handle stress–relaxation data (Steffe, 1996).

The number of Maxwell elements required to represent the sample efficiently was determined by comparing the R^2 values for relaxation data fit individual model equations. Values of parameters calculated with nonlinear regression by Curve Expert professional 1.6.5. The best model describing the data of stress relaxation tests were chosen as the one with the highest coefficient of determination (R^2) and the least residual mean square (RMSE).

2.8. Sensory evaluation

Sensory testing was performed by 7 panelists. Five different parameters included color, taste, texture, juiciness and total acceptance were evaluated through 5-point hedonic scale which 5 to 1 represent extremely desirable to extremely undesirable (Keeton, 1983).

2.9. Statistical analysis

Full factorial experimental design with 2 factors (cooking method and Balangu concentration in the batter) was used to perform the experiments. All measurements were performed in three replicates. The effects of process parameters on physico-chemical properties of nuggets were analyzed by ANOVA using the SPSS software version 22 (SPSS, 2013). Differences among the means were compared using Duncan's Multiple Range Test. A significance p-value of 0.05 was used for the all evaluations.

3. Results and Discussion

3.1. Approximate composition of chicken nugget

The approximate composition of the chicken nuggets prepared with different Balangu gum concentrations in the batter (0, 0.25 and 0.5%) and cooked with various methods (IR, PF-IR, IR-PF and frying) is shown in Table 1.

3.1.1. Moisture content

The moisture content of nuggets was significantly affected by the method of cooking and Balangu gum concentrations in batter formulation ($p<0.05$), so that an increase in Balangu gum concentrations resulted in an increase in the moisture content of samples and higher moisture content was related to deep fat frying, followed by IR, IR-PF and PF-IR methods, respectively. Datta and Ni (2002) reported that infrared radiation can reduce surface moisture of product.

However, the interaction of cooking method and concentration of gum had no significant effect on moisture content. As shown in Table 1, the highest moisture content was seen in the samples cooked by infrared heating with 0.5% gum concentration and the lowest moisture content was related to the nuggets cooked by the IR-PF method with 0% Balangu gum in the batter. Also, there was no difference between the moisture content of the nuggets that cooked using IR and frying methods with 0 and 0.25% gum concentrations and also nuggets cooked by IR-PF and PF-IR methods with 0.25% and 0.5% gum concentrations in batter. This observation was in agreement with those of Sahin et al. (2005) and Mahdavian Mehr et al. (2016) who reported that all the added gums to batter were able to control moisture migration because of their ability to bind water. Therefore, they are able to reduce vapor removing during cooking process of nuggets. Use of gums in edible coating formulation results high firmness in the surface of fried product and inhibit moisture evaporation. Therefore, reducing oil uptake in these type of foods (Hua et al., 2015).

3.1.2. Fat content

Fat content in all nuggets cooked by different methods decreased significantly with increasing the Balangu gum concentration in batter formulation ($p< 0.05$). In all treatments, the highest fat content was related to the sample without Balangu gum and the lowest fat content was observed in nuggets covered with batter containing 0.5% gum (Table 1). Fat content was also significantly affected by the method of cooking ($p< 0.05$), as IR cooked samples had the lowest fat content followed by samples cooked using IR-PF. The highest fat content was considered in control samples (fried nuggets). In addition, significant differences were observed for their interaction (cooking method and Balangu gum concentrations) in fat content of samples (Table 1). IR cooked nugget with 0.5% gum and fried nugget without gum had the lowest and highest fat content, respectively. Fat content of the samples cooked by infrared system was 17% lower than the control approximately.

Many of hydrocolloid substances used as ingredients in batters known as gums. Whereas hydrocolloids can tightly bind to water, they may result to products containing less oil because there is a strong relation between oil uptake and moisture loss during frying (Altunakar et al., 2006). The use of hydrocolloids in batter formulation can reduce the oil absorption in chicken nuggets and other coated fried products (Akdeniz et al., 2005; Ferrero & Zaritzky, 2000; Xue & Ngadi, 2006; Yogesh et al., 2013). For example, Meyers and Conklin (1990) reported the effectiveness of HPMC to reduce oil absorption in fried battered products such as chicken pieces, fish and vegetables. Also, Patil et al. (2001) used guar gum (0.25- 1%) in batter formulations and showed that 9.7 – 22% oil content reduction over the control during frying. In recent work the fat content reduced by applying infrared radiation instead of part or full cooking by conventional method (frying) (Rahimi et al., 2018). The hydrocolloids make the surface of product smother and results less porous crust. This phenomenon reduced fat content because of the oil cannot penetrate into the microstructure of fried product during cooling period (Lumanlan et al., 2019).

Regarding to cooking methods, the main reason of lower fat content in IR cooking method than the frying is absence of the oil in making procedure. Love and Goodwin (1974) stated that the role of batter in preventing of oil absorption is due to the rapid formation of a hard crust, which is being relatively impervious to the movement of water and oil. Similarly, in case of IR-PF method, when sample initially exposed to IR, the surface of sample probably dried and a thick crust formed on the surface of nuggets which prevents from oil diffusion and absorption during frying step. The crust serves as a barrier to prevent water loss and, as a result, contributes to reduction in oil absorption (Shih & Daigle, 1999).

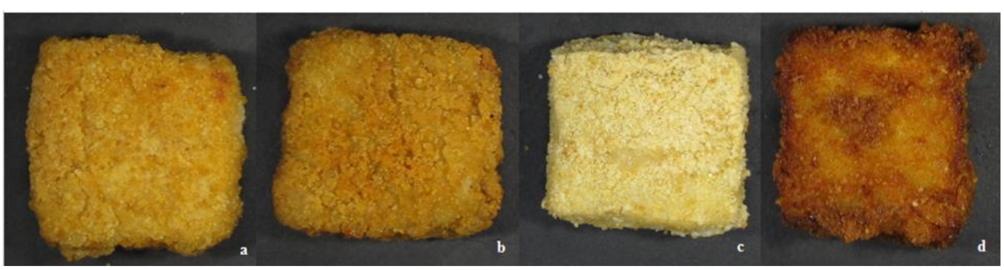

Fig. 2. Different cooked nuggets including a: pre frying- IR cooking, b: IR cooking - post frying, c: IR cooking, and d: deep fat frying.

Table 1. Approximate composition of chicken nuggets prepared with various Balangu gum concentrations in batter and different cooking methods.

Cooking method	Balangu gum concentration (%)	Moisture content (%)	Fat (%)	Total weight loss (%)
Frying	0.00	49.63 ± 1.90^{abc}	30.69 ± 0.47^{a}	19.84 ± 2.45^{bc}
	0.25	50.48 ± 4.27^{abc}	27.13 ± 0.67^{b}	19.47 ± 2.08^{bc}
	0.50	51.78 ± 4.41^{ab}	25.54 ± 0.04^{b}	18.19 ± 1.00^{c}
IR	0.00	46.68 ± 0.90^{abc}	12.30 ± 0.30^{fg}	22.96 ± 0.09^{abc}
	0.25	49.58 ± 0.70^{abc}	10.54 ± 0.73^{gh}	19.65 ± 0.17^{bc}
	0.50	52.62 ± 0.85^{a}	9.93 ± 0.21^{h}	18.17 ± 0.74^{c}
PreFrying-IR	0.00	42.51 ± 1.06^{c}	21.71 ± 0.81^{c}	23.81 ± 2.05^{ab}
	0.25	44.80 ± 0.30^{abc}	18.14 ± 0.11^{d}	22.17 ± 2.39^{bc}
	0.50	47.28 ± 1.65^{abc}	13.96 ± 0.58^{ef}	21.11 ± 2.76^{bc}
IR-PostFrying	0.00	44.56 ± 1.74^{bc}	17.82 ± 0.11^{d}	27.77 ± 0.45^{a}
	0.25	45.35 ± 0.59^{abc}	15.08 ± 1.16^{e}	19.84 ± 0.51^{bc}
	0.50	47.53 ± 1.41^{abc}	14.14 ± 0.77^{ef}	18.88 ± 0.78^{bc}

Same letters in each column indicate no significant difference (p>0.05).

Table 2. The interaction effects of different cooking methods and Balangu gum concentration in batter formulation on color properties of nuggets.

Cooking method	Balangu concentrations in batter (%)	Color attribute			
		L*	a*	b*	ΔE
Frying	0.00	46.23 ± 0.90^{h}	28.43 ± 0.43^{a}	49.78 ± 0.79^{e}	0.00 ± 0.00^{h}
	0.25	47.34 ± 2.52^{h}	25.62 ± 2.96^{a}	52.02 ± 3.22^{de}	6.54 ± 3.46^{fg}
	0.50	48.25 ± 2.10^{gh}	25.23 ± 2.40^{a}	52.99 ± 1.91^{bcde}	5.00 ± 2.45^{gh}
IR	0.00	63.07 ± 0.19^{c}	3.04 ± 0.37^{f}	51.90 ± 1.44^{de}	30.54 ± 1.02^{b}
	0.25	72.66 ± 1.23^{b}	2.71 ± 0.24^{f}	55.15 ± 0.03^{bcd}	37.28 ± 2.09^{a}
	0.50	77.37 ± 1.52^{a}	1.90 ± 0.25^{f}	52.18 ± 1.91^{cde}	41.07 ± 2.44^{a}
Pre-Frying-IR	0.00	62.20 ± 0.66^{c}	10.06 ± 1.00^{e}	61.52 ± 0.17^{a}	27.03 ± 0.02^{b}
	0.25	55.61 ± 0.16^{e}	14.53 ± 0.99^{cd}	56.66 ± 0.57^{bc}	18.12 ± 1.73^{cd}
	0.50	57.54 ± 0.56^{d}	11.65 ± 0.32^{de}	56.48 ± 0.14^{bcd}	21.42 ± 1.16^{c}
IR-Post-Frying	0.00	57.43 ± 0.18^{d}	14.51 ± 0.05^{cd}	57.44 ± 0.18^{ab}	19.43 ± 1.01^{cd}
	0.25	53.42 ± 1.00^{f}	16.18 ± 0.20^{cd}	53.95 ± 0.78^{bcde}	14.80 ± 0.48^{de}
	0.50	51.55 ± 0.18^{fg}	20.12 ± 0.06^{b}	54.20 ± 0.33^{bcde}	10.77 ± 0.82^{ef}

Same letters in each column indicate no significant difference (p>0.05).

Table 3. Effects of cooking methods and Balangu gum concentration in batter on the textural properties of the nuggets.

Cooking method	Balangu concentrations in batter (%)	Textural parameters					
		Hardness (N)	Springiness (cm)	Cohesiveness	Gumminess (N)	Chewiness (N.cm)	Resilience
Frying	0.00	20.67 ± 6.21^{abc}	0.63 ± 0.03^{cd}	0.68 ± 0.01^{a}	10.23 ± 1.06^{abc}	6.46 ± 0.32^{ab}	0.27 ± 0.00^{a}
	0.25	17.94 ± 1.04^{abcd}	0.55 ± 0.02^{d}	0.50 ± 0.01^{bcd}	10.48 ± 3.30^{ab}	5.86 ± 2.09^{ab}	0.18 ± 0.01^{c}
	0.50	13.96 ± 0.80^{d}	0.58 ± 0.01^{cd}	0.54 ± 0.02^{bc}	11.95 ± 1.42^{abc}	6.96 ± 0.66^{ab}	0.21 ± 0.01^{b}
IR	0.00	21.99 ± 1.96^{abc}	0.74 ± 0.02^{ab}	0.42 ± 0.02^{efg}	7.99 ± 0.23^{bcd}	5.98 ± 0.33^{ab}	0.16 ± 0.01^{cde}
	0.25	19.81 ± 0.27^{abc}	0.74 ± 0.04^{ab}	0.40 ± 0.02^{fg}	7.28 ± 0.70^{cd}	5.45 ± 0.85^{ab}	0.14 ± 0.01^{e}
	0.50	14.90 ± 1.22^{cd}	0.72 ± 0.02^{ab}	0.39 ± 0.01^{g}	5.53 ± 0.49^{d}	4.01 ± 0.19^{b}	0.14 ± 0.01^{e}
Pre-Frying-IR	0.00	23.67 ± 1.19^{a}	0.58 ± 0.02^{cd}	0.55 ± 0.03^{b}	8.56 ± 1.11^{abcd}	7.61 ± 0.54^{a}	0.20 ± 0.02^{b}
	0.25	23.03 ± 2.24^{ab}	0.59 ± 0.01^{cd}	0.54 ± 0.01^{bc}	8.08 ± 1.18^{bcd}	7.40 ± 0.76^{a}	0.21 ± 0.006^{b}
	0.50	20.38 ± 0.59^{abcd}	0.80 ± 0.02^{a}	0.46 ± 0.02^{de}	7.23 ± 0.12^{cd}	7.66 ± 0.46^{a}	0.15 ± 0.004^{de}
IR-Post-Frying	0.00	22.64 ± 1.09^{abcd}	0.72 ± 0.01^{ab}	0.48 ± 0.03^{cde}	13.03 ± 1.28^{a}	6.21 ± 0.86^{ab}	0.17 ± 0.002^{cd}
	0.25	16.50 ± 2.37^{abcd}	0.72 ± 0.02^{b}	0.49 ± 0.00^{bcd}	12.39 ± 1.10^{ab}	5.84 ± 1.01^{ab}	0.11 ± 0.003^{f}
	0.50	14.86 ± 0.18^{cd}	0.66 ± 0.03^{c}	0.46 ± 0.01^{def}	9.49 ± 0.78^{abcd}	4.80 ± 0.33^{ab}	0.16 ± 0.003^{cde}

Same letters in each column indicate no significant difference (p>0.05).

3.1.3. Total weight loss

Weight loss of most treatments was not significantly different from control. This phenomenon is pleasant from economic point of view. According to Table 1, all the samples cooked with infrared radiation had a little higher weight loss than the fried nuggets. Higher weight loss in contributed methods (IR-PF, PF-IR) was probably resulted from longer exposure time (plus of fried time+ cooked IR) and lower sorption of oil especially in IR-PF method.

Although moisture loss and oil uptake in frying nuggets take place simultaneously but weight loss in frying shows that the rate of moisture loss is higher than the oil uptake (Dogan, 2004). The total weight loss was also decreased by increasing of gum concentration in batter formulation. This result may be related to the high moisture retention capability of Balangu seed gum. Khodaei et al. (2014) and Salehi and Kashaninejad (2014) reported that the Balangu gum gel has a strong and stable water holding capacity.

3.2. Color analysis

Table 2 provides the results of the different color parameters of chicken nuggets including lightness (L*), redness (a*), yellowness (b*) coordinates and ΔE. All of the color parameters of the nuggets were significantly affected by different methods of cooking ($p < 0.05$). However, the results of statistical analyses indicated that Balangu gum concentrations had no significant effect on the color parameters (L*, a*, b* and ΔE). Interaction effect of different cooking methods and Balangu gum concentrations on color parameters was also determined statistically significant ($p<0.05$). The lowest L* value ($p< 0.05$) and the highest a*value ($p< 0.05$) were observed in fried nuggets with different concentrations of Balangu gum in batter formulation. The color of the fried nuggets had the highest a* value (28.43±0.43) but the reddish color tone of the samples was the minimum for the nuggets coated with batter formulation contained 0.5% Balangu gum and cooked by IR (1.90±0.25). Also, the highest L* value was related to the samples cooked by IR treatment. It was also found that the nuggets cooked by PF-IR method showed higher yellowness (b*) value than the other treated nuggets. As it can be seen from Table 2, application of infrared heating for cooking of nugget resulted in higher ΔE values, demonstrating that type of cooking method had more effect on total color change than the Balangu gum concentration. Based on a*/b* (data not shown) the nearest sample par with Control (0.47±0.06) in terms of colour was the PF-IR sample with 0.5% Balangu gum concentration in the batter (0.37±0.003 but the difference was significantly different ($p<0.05$).

Color of fried product is one of the important factors which influences on consumer acceptability. Absorption of oil and chemical reactions of browning of reducing sugars and protein sources affect on fried samples color (Baixauli et al., 2002). Ngadi et al. (2007) reported that the darker and the more redness tone of color were detected in the fried chicken nuggets. The effect of cooking methods on color parameters probably is due to the occurrence of Maillard reaction through heating process. During this non-enzymatic browning phenomenon, the carbonyl groups of the reducing sugars react with nucleophilic amino group of the amino acids, which causes alteration in the chemical properties of the proteins and formation of brown pigments (Pedreschi et al., 2007; Wong et al., 2015). Al-Asmar et al., (2018) demonstrated hydrocolloid coating with increasing water retention during frying process causes a reduction in Maillard reaction and subsequently decreases the producing carcinogenic substances in fried foods.

3.3. Texture profile analysis

Effects of cooking methods and Balangu gum concentrations in batter formulation on textural properties of nugget samples have been shown in Table 3. Cooking methods had a significant effect on hardness, springiness, cohesiveness, gumminess, chewiness and resilience aspects of nuggets ($p<0.05$). But, Balangu gum concentrations did not significantly affect on textural parameters except cohesiveness and hardness. However, the interaction of Balangu gum concentrations and cooking method had significant effect only on springiness, cohesiveness and resilience. The cooked nuggets by PF-IR method had significantly higher hardness, cohesiveness, gumminess, and chewiness values compared to the cooked nuggets by other cooking methods. As reported in Table 3, the highest cohesiveness and resilience values were observed for fried nuggets. Regarding the cohesiveness, the lowest value observed for cooked nuggets by IR with 0.5% Balangu gum (0.39±0.01). In all of the samples, gumminess values decreased as a result of an increase in Balangu gum concentrations in batter formulation ($p<0.05$). The highest springiness (0.80±0.02) was observed for cooked nuggets by PF-IR methods with 0.5% Balangu gum in the batter formulation.

One of the most important quality characteristics of chicken nuggets is textural properties which can change the organoleptic aspects and consumer's acceptance. The results indicated that the hardness decreased by rising Balangu gum concentrations so that the coated nuggets by batter without gum and with 0.5% Balangu gum in formulation had the highest and the lowest hardness, respectively. Similar results were obtained by Altunakar et al. (2006) and Sahin et al. (2005) who they reported addition of gums (HPMC and xanthan gum) to batters resulted in softer products, improvement of the texture and enhancing batter flexibility. Sahin et al. (2005) expressed that the consistency of gum-containing batters was correlated to the texture of chicken nuggets, although gums can create a film around the fried sample that makes the surface crispy and reduce the hardness of the fried sample construction. The recent action might be influenced by the water-holding ability of gums too (Weerasekera & Navaratne, 2015).

Cooking the nuggets by IR or combined IR methods resulted in harder nuggets. So that, the highest hardness was related to cooked nuggets by PF-IR method following by IR cooked nuggets. There was not any difference between cooked nuggets by IR-PF and fried nuggets. These findings may be due the effect of IR heating on denaturation of structural proteins of the chicken meat, formation of hard surface and alteration in fat content and water holding capacity (Bennion & Scheule, 2004). In the study have been performed on IR cooked donut, Melito and Farkas (2013) reported that the crust of the donuts became harder as the fat content of the products decreased by exposing to the IR heating treatment. They also explained Infrared radiation (IR) can simulate the heat flux created during the frying process, yielding products with fried-like textures but lower fat content.

3.4. Stress relaxation analysis

After performing the stress relaxation tests, stress- time curves of each treatment were drawn using the mean of triplicates data. One sample of the stress relaxation curves for cooked nuggets by different methods and coated with various batter formulations (cooked nugget by IR method and coated with batter containing 5% Balangu gum) is shown in Fig. 3. As it can be seen in Fig. 3, after achievement of a constant strain, a sharp decrease in force values occurred to maintain this constant deformation. This behavior was similar to reports of other authors who studied on stress relaxation data of different food systems (Del Nobile et al., 2007; Singh et al., 2006). However, in order to fit the stress relaxation data, only a part of curves was considered that it was started at maximum force (initial point) and ended in point 2 (Fig. 3). The stress relaxation data were fitted to Peleg and generalized Maxwell models. The fitting parameters of the Peleg model for cooked nuggets by different cooking methods and various Balangu gum concentrations are shown in Table 4. In according to the results, the experimental data of samples were fitted well by the Peleg model (R^2> 0.978 and RMS= 7.93- 31.53%).

The initial stress (max stress) indicated solid-like behavior. The results demonstrated that the both of cooking method and Balangu gum concentrations in batter formulation had a significant effect on initial stress ($p<0.05$). The highest σ_0 value was associated with the cooked nuggets by PF-IR followed by cooked nuggets by IR and fried nuggets (there was no significant difference between fried samples and cooked samples by IR-PF). In all of the cooking methods, coated nuggets by 0.5% Balangu gum showed lower σ_0 value than the coated nuggets by 0.25% gum and without gum in batter formulation. These results may be related to the higher holding capacity of water in batter containing more gum than the batters without Balangu gum. Interaction of cooking methods and Balangu gum concentrations had a significant effect on maximum stress, too (Table 4). The highest initial stress was observed in cooked sample by PF-IR with 0 and 0.25% gum and the lowest initial stress was related to nuggets cooked using IR-PF and fried with 0.5% gum in batter formulation.

Reciprocal of k_1 represents the initial decay rate. The k_1 values were significantly affected by cooking methods, Balangu gum concentrations and their interaction ($p<0.05$).The highest k_1 value was related to the cooked nuggets using PF-IR. This indicates that the initial decay rate to reach the asymptotic residual stress was slowest for cooked samples by this method. Therefore, these samples have more resistance to elastic deformation than the cooked samples by other methods. The coated samples with 0.25% and without Balangu gum showed the highest k_1 values. However, their interaction (cooking methods × gum concentrations) showed that highest and lowest of k_1 was related to cooked samples using PF-IR containing 0.25% gum and cooked nuggets by IR-PF that coated with batter included 0.5% gum. As previously mentioned an increase of gum concentration in batter resulted in more moisture conservation. Therefore, reduction of k_1 values in high gum concentration depends on higher amount of moisture conservation that resulted to reduce elastic behavior in cooked nuggets. These results are similar to findings of Zare et al. (2012) who reported that the highest values of k_1 were in dates with the lowest moisture values.

The k_2 value indicates the elastic component present in the sample. Similar to k_1 values, the cooking method, gum concentrations and their interaction had a significant effect on k_2 values ($p<0.05$), so that it was increased by rising of gum concentrations in batter formulation from 0.25 to 0.5%. The highest and lowest k_2 values observed in fried nuggets and cooked samples by IR, respectively. According to Table 4, the interaction of cooking method and gum concentrations showed that fried nuggets with 0 and 0.25% gum had the highest k_2 values and cooked nuggets by IR-PF methods with 0.5% gum in crust had the lowest k_2 values.

As seen in Table 5, all the experimental data were fitted with three elements generalized Maxwell model. Although, required stress for keeping a constant deformation in the cooked nuggets is the sum of stress of each element of generalized Maxwell but research had displayed that the first element of generalized Maxwell model had a main contribution (90%) to the total elements as stress relaxation constants, σ_e, σ_1 and λ_1, are often used for analyzing results (Campus et al., 2010).

Considering to above mention, statistical analysis performed only for σ_e, σ_1 and λ_1 of the samples. The results of statistical analysis showed the cooking methods, gum concentrations in batter formulation, and their interaction had a significant effect on σ_e and σ_1 ($p<0.05$) but λ_1 only affected by concentration of gum in batter formulation.

The magnitude of σ_e indicates the amount of initial stress that remains unrelaxed and is called the residual modulus and it is also considered as a scale of ‘‘stiffness” of the material (Campus et al., 2010). The results of statistical analysis showed that the σ_e values of fried nuggets and cooked nuggets by IR method were not significantly different, although they were lower than cooked nuggets by IR-PF and higher than treated nuggets by PF-IR ($p<0.05$). The lower of σ_e values in cooked nuggets by IR-PF may be caused by formation of hard crust on surface of nuggets that prevents from exhausting vapour and probably formation more bulbs in texture of nuggets. However, the σ_e values of nuggets coated with 0.5% gum were the lowest among the all nuggets cooked by different methods.

According to Table 5, in all of cooking methods, coated nuggets by the batter containing 0.5% Balangu gum had the lowest σ_1 values. As can be seen the fried nuggets and cooked nuggets using IR-PF had the lowest σ_1 values and the highest σ_1 values was observed in cooked nuggets by PF-IR. The relaxation time (λ) is the time that the viscoelastic material dissipates its force to about 36.8% of the originally applied force (Bhattacharya & Narasimha, 1997; Hassan et al., 2005). High λ indicates slow decay during relaxation, which is a typical behavior for a viscoelastic matrix with more solid-like structure. λ_1 parameter of cooked nuggets significantly decreased with increasing Balangu gum concentration ($p<0.05$). Higher initial stress and relaxation time of IR and PF-IR cooked nuggets without Balangu gum in batter formulation indicated that these products had a more rigid and elastic behavior than cooked nuggets by other methods.

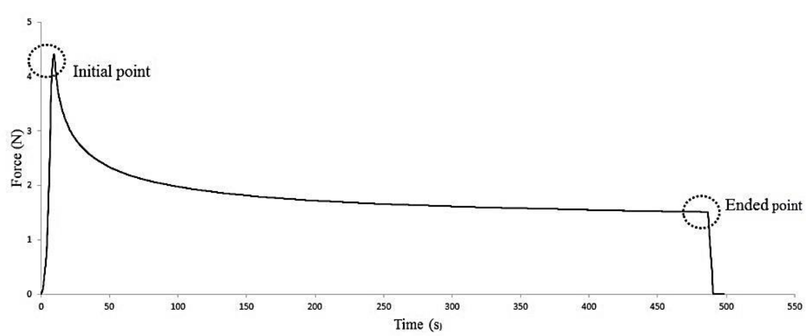

Fig. 3. A full run of the stress relaxation test for cooked nugget using IR method 0.5% Balangu gum in the batter formulation.

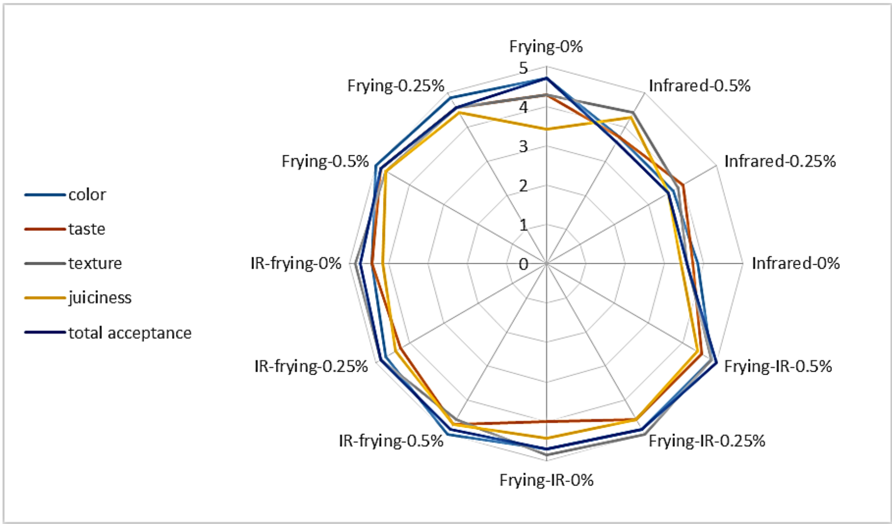

Fig.4. sensory evaluation of chicken nugget with diverse batter formulation cooked in different conditions.

Table 4. Fitting parameters of Peleg model stress relaxation data of cooked nuggets.

Cooking method	Balangu concentrations in batter (%)	σ_0 (Kpa)	K_1(s)	K_2	R^2	RMS (%)
	0.00	11.82 ± 0.92[cd]	20.44 ±1.78[cd]	1.74 ± 0.03[a]	0.984 ± 0.000	17.37 ± 3.43
Frying	0.25	14.71±0.11[bcd]	24.95 ± 0.62[cd]	1.76 ± 0.19[a]	0.978 ± 0.010	7.93 ± 2.80
	0.50	10.65 ± 1.58[d]	20.46 ± 1.07[cd]	1.60 ± 0.01[abc]	0.987 ± 0.011	10.61 ± 1.46
	0.00	19.27 ± 1.32[ab]	28.50 ± 0.02[b]	1.49 ± 0.20[abcd]	0.992 ± 0.010	21.41 ± 1.36
IR	0.25	15.33 ± 0.30[bc]	29.69 ± 0.10[ab]	1.38 ± 0.02[bcd]	0.989 ± 0.002	20.50 ± 0.59
	0.50	10.92 ± 0.48[cd]	24.29 ± 0.97[c]	1.33 ± 0.16[cd]	0.997 ± 0.001	7.99± 1.37
	0.00	21.07 ± 1.59[a]	29.77 ± 2.79[ab]	1.60 ± 0.01[abc]	0.985 ± 0.004	31.53 ± 3.07
Pre-Frying-IR	0.25	20.92 ± 0.99[a]	34.02 ± 0.30[ab]	1.66 ± 0.11[ab]	0.986 ± 0.001	26.79 ± 3.77
	0.50	19.45 ± 1.18[ab]	28.01 ± 0.39[b]	1.56 ± 0.13[abcd]	0.985 ± 0.001	17.87 ± 10.94
	0.00	15.45 ± 0.83[bc]	32.80 ± 2.25[ab]	1.55 ± 0.06[abcd]	0.979 ± 0.006	29.13 ± 5.00
IR-Post-Frying	0.25	11.05 ± 3.26[cd]	29.19 ± 0.15[b]	1.69 ± 0.04[ab]	0.984 ± 0.003	15.53 ± 3.66
	0.50	10.36 ± 1.05[d]	24.21 ± 1.87[c]	1.24 ± 0.09[d]	0.983 ± 0.004	31.53 ± 3.25

Same letters in each column indicate no significant difference (p>0.05).

Table 5. Fitting parameters of generalized Maxwell model stress relaxation data of cooked nuggets.

Cooking method	BC* (%)	σ_e (kpa)	σ 1 (Kpa)	σ 2 (Kpa)	σ3 (kpa)	λ 1 (s)	λ 2 (s)	λ 3 (s)	R^2	RMS
	0.00	3.75±0.38[bc]	2.27±0.37[cd]	2.85±0.44	3.02±0.13	173.28±0.05[bc]	27.69±0.56	4.07±0.03	1.00±0.00	0.07±0.01
Frying	0.25	4.83±0.30[b]	2.99±0.35[bcd]	2.83±0.42	3.17±0.28	180.65±31.47[bc]	35.83±6.04	3.85±0.34	1.00±0.00	0.05±0.02
	0.50	3.61±0.13[bc]	1.93±0.63[d]	2.78±0.76	2.18±0.11	148.88±6.59[c]	28.21±0.23	3.99±0.03	1.00±0.00	0.01±0.00
	0.00	6.43±0.11[a]	3.38±0.06[abc]	5.00±0.14	4.54±0.10	261.83±39.02[a]	27.39±1.73	4.39±0.72	1.00±0.00	0.01±0.00
IR	0.25	4.06±0.12[bc]	3.95±0.27[ab]	3.98±0.10	3.58±0.07	215.72±7.09[abc]	32.09±2.97	4.16±0.31	1.00±0.00	0.01±0.00
	0.50	3.17±0.44[cd]	1.81±0.11[d]	3.60±0.82	2.39±0.21	150.18±27.88b[c]	29.43±6.17	3.96±0.11	1.00±0.00	0.01±0.00
	0.00	7.68±0.12[a]	4.84±0.49[a]	4.67±0.77	4.01±0.26	205.62±21.24[abc]	30.36±1.03	5.18±0.78	1.00±0.00	0.03±0.01
Pre-Frying-IR	0.25	7.10±0.73[a]	4.50±0.39[ab]	4.42±0.33	3.88±0.54	200.26±20.37[abc]	28.91±2.18	3.89±0.01	1.00±0.00	0.02±0.00
	0.50	6.63±0.26[a]	4.10±0.01[ab]	4.06±0.03	3.77±.42	180.77±0.87[bc]	27.23±0.50	3.71±0.20	1.00±0.00	0.02±0.00
	0.00	3.49±0.22[c]	4.06±0.48[ab]	4.01±0.04	3.90±0.51	208.53±3.63[abc]	32.53±0.32	4.65±0.30	1.00±0.00	0.03±0.01
IR-Post-Frying	0.25	3.23±0.05[cd]	2.02±0.47[d]	2.70±0.47	2.69±0.89	201.91±21.19[abc]	28.38±3.79	3.74±2.07	1.00±0.00	0.01±0.00
	0.50	2.18±0.33[d]	2.12±0.26[d]	2.34±0.59	3.45±0.37	189.50±18.79[bc]	24.05±0.59	3.55±0.05	1.00±0.00	0.01±0.00

*Balangu concentrations in batter.
Same letters in each column indicate no significant difference (p>0.05).

The stress relaxation data showed that the behavior of product probably depended on volume of moisture loss, amount of oil sorption and the formation of a hard crust on surface of samples that inhibited to exhaust gases and sorption oil in cooked samples. Amount of oil and average moisture in cooked nuggets by IR, IR-PF and PF-IR was lower than fried nuggets that they could effect on solid-like behavior, as previously described. Although, behavior of samples treated by IR-PF was more complex, we guess that this result can be caused by the remaining of evaporated gases in the frying stage under the hard crust. Application of a generalized Maxwell model resulted in better fit of the stress relaxation data. Similar results were previously observed by other researchers who reported a generalized Maxwell model was the best fit for stress relaxation data of meat products such as low fat chicken sausage and muscle tissues from Gilthead Sea Bream (Campus et al., 2010).

Decreasing the relaxation time (λ) which occurred with increasing Balangu gum concentration may be related to the effect of Balangu gum in holding of more water in composition of chicken nuggets. Baranowska et al. (2005) stated that relaxation time of ground meat is affected by the amounts of free and bound water. Products with a higher content of unbound water are characterized by longer relaxation time. In thermally processed meat products, water bound by protein is captured in gel, and the higher the protein content, the more water is bound. As the result, such products have shorter relaxation time. According to our results, we found out adding of gums to batter formulation due to preservation of moisture affects on viscoelastic properties and cooked methods of nuggets have effected on myofibrillar proteins (Myhan et al., 2015; Smith, 1988).

3.5. Sensory evaluation

Sensory testing results were shown in Fig. 4. The highest total acceptances belong to fried sample with 0.5% gum concentration. The samples cooked with just infrared radiation have lowest scores in different parameters significantly ($p<0.05$). These results indicated that oil content have critical role in palatability of chicken nugget. Melito and Farkas (2013) who used infrared radiation for final cooking of pre fried donuts also found out overall acceptance of donuts were not nearly as acceptable to the panelists as the control. Recent work approved these results too (Rahimi et al., 2018). Salehi (2020) relied that coating reduces the moisture loss, lipid oxidation, and oil uptake of deep fat fried products and consequently this product will have better textural characteristics, chewiness, juiciness, and higher total acceptability scores.

4. Conclusion

The chicken nugget is a popular fast food in the world but it includes high amount of oil. In this study, we used two methods to reduce the oil sorption of chicken nugget including application of Balangu gum in the batter formulation and IR cooking method. In this regard, the effect of various IR treatments methods (IR alone, PF-IR and IR-PF cooking methods) and different concentration of Balangu gum in batter formulation on some physicochemical and textural properties of the chicken nuggets were compared with the conventional deep fat frying method. Moisture and fat contents, total weight loss, color and textural properties of the nuggets were affected by different treatment methods. These effects were directly related to the holding of water and changing of myofibril structure during heat processing. According to the results, textural properties of IR-PF cooked nuggets were similar to the deep fat fried sample although they had significantly lower fat content. Our results indicated that when IR cooking and adding of Balangu gum in batter formulation were used simultaneously in preparation of nuggets, oil sorption reduced and desirable texture and color of the chicken nuggets was kept similar to fried nuggets. Therefore, our results suggested that the IR cooking method can be considered as an effective approach to produce healthier chicken nuggets. However, it seems that more studies are also needed to study this issue in a more comprehensive way.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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