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Development of High-Fiber, Low Fat Chicken Nuggets

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Abstract

Dietary fiber intake is significantly below the recommended daily allowances worldwide, making fortification of foods with dietary fiber a vital strategy. Simultaneously, there is a trend towards increased consumption of processed meat products containing substantial amounts of fat, making processed meat products an excellent vehicle to deliver fiber. In this study, the effects of adding four types of dietary fiber (Resistant Starch (RS), Polydextrose (POD), Fructooligosaccharides (FOS) and Galactooligosaccharides (GOS)) to chicken nuggets were investigated. Fibers were added at three levels (5, 10 and 15%) to replace 33.33, 66.66, and 100%, respectively, of the chicken skin. The difference between the removed quantity of chicken skin and added fiber was compensated with water. Chicken nuggets were evaluated by measuring color, texture, proximate composition, yield and consumers' acceptability. Results indicated that replacement of the chicken skin entirely with dietary fiber is possible without negatively affecting the final product quality.

Keywords: Nuggets; Resistant starch; Polydextrose; Fructooligosaccharides; Galactooligosaccharides; Texture; Color

1 Introduction

Meat and processed meat products occupy a significant proportion of food consumed daily (Felisberto et al., 2015). One of these products is chicken nuggets, which are acceptable to adults and children. Chicken nuggets are considered battered meat products which are produced from comminuted chicken meat, with the addition of other ingredients to extend the product and consequently reduce its cost. Among these ingredients are chicken skin, starch and soy proteins. In addition to its content of valuable nutrients like other meat products, this product is available in a partially pre-cooked form, which makes it a convenient food. However, these products are considered a source of saturated fat and cholesterol, and a poor source of dietary fiber, which make these products a risk factor for coronary heart disease (CHD), obesity, diabetes (Stender et al., 2007), cancer (Bolger et al., 2017) and cardiovascular diseases (Lairon et al., 2005). It has been estimated that more than 80 million people have been affected by coronary heart disease, stroke and hypertension. These diseases are the primary causes of morbidity and mortality in the United States (Rosamond et al., 2008). However, in Jordan, the statistical data showed that 30% of the population were overweight, 36% obese and 20.6% suffered from hypertension (Takruri & Alkurd, 2014). The weight of scientific evidence about the association between the consumption of processed meat products and some diseases pushed the International Agency for Research on Cancer to declare that processed meat is carcinogenic to humans (Shan et al., 2017).
There are two ways to solve this problem: the first way is making health campaigns to edu-

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cate consumers about the health risks associated with these products, and the second way is reformulating these products to decrease the amount of fat and increase the amount of dietary fiber which converts these products to healthy products "functional food" (Shan et al., 2017). Each way is complementary to the other one. In other words, health campaigns alone will not reduce these products' consumption to a great extent. It succeeded in raising consumer awareness about the health risk without giving the "healthy" alternative to these products. The consumer will still choose these products for many reasons such as taste, texture, and easy-to-create and serve features (Polizer et al., 2015). Knowing that dietary fiber intake is significantly below the recommended daily allowances throughout the world makes fortifying foods with dietary fiber a vital strategy to bridge the gap in dietary fiber consumption and convert the processed meat product into functional food (Sathu et al., 2017). Dietary fiber addition could fulfill multiple roles, such as having positive health effects after consumption, and at the same time, they may have some functional properties that modify the sensory properties of the developed product. One of the essential functional properties is their ability to perform as a fat replacer (Mehta et al., 2015; Yadav et al., 2018). This property is critical because previous studies indicated that eliminating or reducing the amount of fat during the formulation of processed meat products negatively affected the sensory properties and yield (Mallika et al., 2009). Formulating processed meat products with dietary fiber is a relatively new concept in manufacturing functional processed meat products (Polizer et al., 2015). Significant work has been performed in this field, but still, there is a need to explore the functionality and consumer acceptability of isolated and synthetic fiber in new food products (Bolger et al., 2017).

The definition of dietary fiber was recently reviewed several times as the number of digestion-resistant materials increased significantly, either in the isolated or synthetic form. The new definition includes any substances that behave like fiber regardless of the method used in manufacturing them if they exhibit positive physiological benefits (Bruno-Barcena & Azcarate-Peril, 2015; Raigond et al., 2015; Veena et al., 2016). Using commercially available isolated or synthetic dietary fiber has several advantages: cost reduction and consistent quality (Ibrahim, 2018). This study aimed to produce low-fat and high-fiber chicken nuggets by adding dietary fiber and, at the same time, reducing chicken skin in varying proportions.

2 Materials and Methods

2.1 Ingredients

The following ingredients were used in this study: frozen deboned skinless broiler chicken breast (21.24% protein, 2.28% fat, 74.07% moisture as tested by Foodscan meat analyzer) and chicken skin (10.80% protein, 34.19% fat, 53.87% moisture as tested by Foodscan meat analyzer) obtained from the national poultry company slaughterhouse (Al Karak-Jordan); Soya protein concentrate (70% protein concentration; Arcon SJ, USA); Sodium triphosphate (Anhul Kemfood international CO.LTD, China), Corn starch (Trakya, Turkey), Refined salt (Amra, Jordan), Spices (Alcest, China); and RS (48% Dietary fiber, Germany), POD (>90% Dietary fiber. Tailijie, China), FOS (92.5% Dietary fibers, USA), and GOS (43.2% Dietary fiber, USA).

2.2 The basic formula used in the production of chicken nuggets

A commercial chicken nuggets recipe was adapted from one of the meat producers in the local market (National Poultry Company, meat processing plant, Al Karak-Jordan). The formula had the following composition: deboned skinless broiler chicken breast (40.0%), chicken skin (30.0%), water (18.0%), soya 70% (0.60%), sodium triphosphate (0.03%), corn starch (0.20 %), salt (0.10%) and spices (11.07%).

2.3 Development of high fiber low-fat chicken nuggets

Thirteen chicken nuggets formulas were used in this experiment (Table 1). One formula was the original formula (Control) described previously (section 2.2). The other formulas were adapted from the basic recipe (Control) using four dietary fibers (RS, POD, FOS, and GOS). Each fiber was added to chicken nuggets formulas with three levels: 5, 10, and 15% to replace 33.33, 66.66, and 100% of the chicken skin. The difference between the removed quantity of chicken skin and added fiber was compensated with water.

2.4 Chicken nuggets processing steps

Figure 1 shows the steps used to prepare chicken nuggets. The first step was to weigh all the required ingredients using top loading balance (Mettler Toledo, ICS226-QA15FCL Max=15kg, China). The frozen deboned skinless broiler chicken breast (-7 to -9 ^{o}C) and frozen chicken skin (-7 to -9 ^{o}C) were ground using a commercial frozen meat cutter (Auto-grind machine, CFS, Denmark) equipped with a 20 mm grinding plate.
After grinding, the meat and skin temperature ranged between -4 and -6 ^{o}C. Next, the meat and skin were minced through a meat mincer (K&G WATTER, 419/E130, Germany) equipped with a 3 mm mince plate. The weighed non-meat ingredients (including dietary fiber) were added and mixed with meat and skin - if it was included in the formula- manually for 1 minute to obtain a uniform mixture before freezing.
After mincing, the meat temperature ranged between 0 and -2 ^{o}C. Minced meat and skin were placed in a shock freezer (-20 ^{o}C) for 30 minutes until the meat's temperature reached -5 to -6 ^{o}C, which is the optimum temperature for the nugget pieces to form. A circular Teflon mold (2 cm diameter and 1 cm thickness) was used to form chicken nugget pieces. A specific amount of meat mixture (35 grams) was placed in the mold manually and pressed to ensure no air spaces were left in the nugget pieces.
Formed nugget pieces were immersed in the batter (Super batter W, Jada'l, Jordan). Batter temperature ranged between 0-2 ^{o}C, and battered pieces were manually breaded before flash-frying. The nugget pieces were flash-fried using a commercial fryer (CFS, Model 1627, Denmark) at 184 to 188 ^{o}C for 25 seconds.

Nugget pieces were then frozen using a spiral freezer (Jack stone, freezing system LFD, model 100075, USA) at -25 to -27 ^{o}C for 1 hour and a half. The core temperature of the product reached -15 to -18 ^{o}C. Finally, frozen nuggets were stored in a deep freezer room at -16 to –18 ^{o}C for six days before evaluation.

2.5 Cooking of Chicken Nuggets

Frozen nugget pieces were removed from the freezer and fried directly using a continuous commercial fryer (CFS, Model 1627, Denmark). The frying temperature ranged from 184 to 188 ^{o}C for 180 seconds. After that, nuggets pieces were strained to remove oil, cooled and packed in plastic bags for further evaluation.

2.6 Color Evaluation

The color of cooked samples was measured after removing the breading layer using a non-contact spectrophotometer (X-rite VS-450, UK) equipped with Oncolor software (CyberSoft, UK). The CIE Lab color values and color difference were calculated where: $L*$ represents the reflection of light; $a*$ values represent the red/green colors (+ values for red color and – values for green color); $b*$ values represent yellow/blue color (+ values for yellow color and – values for blue color). Five nugget pieces were tested for each treatment, and the results were averaged for statistical analysis (Akesowan, 2016).

2.7 Texture Profile Analysis (TPA)

TPA was performed using a texture analyzer (TVT 6700, Perten, Sweden), previously calibrated with a standard weight of 2 kg and using a load cell of 5 kg and a 40mm diameter cylinder probe. Four cooked chicken nugget pieces were tested from each treatment. Circular samples (2 x 1 cm) were cut from nugget pieces and tested using the following profile: sample compression=50%, starting distance from the sample=5 mm, initial speed=2mm/s, test speed=2 mm/s and the trigger force=10g. Figure 2 shows

Table 1: Formulas developed to study the effects of type and level of added dietary fiber on the quality of chicken nuggets

Ingredient	Control	Treatment*		
	Without Fiber	Fiber 5%	Fiber 10%	Fiber 15%
Frozen chicken breast	40	40	40	40
Soya 70%	0.60	0.60	0.60	0.60
Sodium triphosphate	0.03	0.03	0.03	0.03
Corn starch	0.20	0.20	0.20	0.20
Salt	0.10	0.10	0.10	0.10
Spices	11.07	11.07	11.07	11.07
Frozen chicken skin	30.0	20.0	10.0	0.00
Water	18.0	23.0	28.0	33.0
Fiber	0.00	5.00	10.0	15.0
Total	100%	100%	100%	100%

*Four types of fibers were used

a typical TPA curve, from which the following parameters were calculated: firmness, cohesiveness, chewiness and resilience (Bonato et al., 2016). Table 2 summarizes how each parameter was tested.

2.8 Shear Test

The shear test was performed using a texture analyzer (TVT 6700, Perten, Sweden) equipped with a 30 mm knife blade probe and a 5 kg load cell. Test profile was starting distance from sample=5 mm, sample compression=30mm, initial speed=2 mm/s and trigger force=5 g. Four cooked chicken nugget pieces were used as-is for the test. The software (TexCal, Perten, Australia) drew the time-force curve from which two parameters were calculated: cutting force and the work of cutting (Bonato et al., 2016).
Figure 3 shows a typical shear test curve where the cutting force is the maximum peak force (g), and the work of cutting is the total area under the curve (J).

2.9 pH

A five grams sample of chicken nuggets, taken before the battering step, was homogenized with 45 mL distilled water using a blender. Then, pH values were determined using a portable pH meter (Cyberscan 510, Singapore) (Polizer et al., 2015).

2.10 Batter Pickup

Batter pickup was recorded after the battering and breading step was carried out through the following equation (Kilincceker & Kurt, 2018).

$$\text{Batter Pickup}_{\text{ after breading}}(\%) = (W_2/W_1) \times 100 \tag{1}$$

where:
W_1 = weight of the sample before the battering and breading step.
W_2 = weight of the sample after the battering and breading step.

2.11 Cooking Yield

The yield was recorded after the final cooking step was carried out through the following equation (Kilincceker & Kurt, 2018).

$$\text{Yield}_{\text{ after cooking}}(\%) = (W_3/W_4) \times 100 \tag{2}$$

where:
W_4 = weight of the sample after the flash-frying step.
W_3 = weight of the sample after the final cooking step.

Table 2: Parameters measured using multiple/ double cycle test

Parameter	Definition	Formula	Unit
Firmness	The maximum force recorded during the first compression/extension cycle	F_A	g
Cohesiveness	The total area (work) of the second compression/extension cycle, divided by the total area (work) of the first compression/ extension cycle.	$\frac{A2}{A1}$	-
Chewiness	The product of Force A, cohesiveness, and springiness.		g
Resilience	The retract area in the first cycle divided by the compression area in the first cycle		-

2.12 Proximate Composition

Moisture, Protein, Fat and Ash of the final product were determined according to the Association of Official Agricultural Chemists (AOAC, 2002) and International Organization for Standardization ISO (1973) procedures: Moisture% (AOAC 950.46), Protein% (AOAC 981.10), Ash% (AOAC 920.153) and Total Fat% (ISO 1443-1973).

2.13 Sensory Evaluation

Based on the results of the previous tests, three treatments were selected for sensory evaluation. Thirty untrained panelists were recruited from a meat production plant (National Poultry Company, Al-Karak). Panelists were asked to evaluate the samples and record the results on the sensory evaluation form. A 9-point hedonic scale was used to evaluate the samples, where one denotes dislike extremely and nine denotes like extremely (Dethmers et al., 1981). Three sensory parameters (color, taste and texture) were evaluated for each sample. To avoid bias, each treatments (RS, GOS, and control) were coded with randomly selected 3-digit numbers. Before serving, chicken nuggets were warmed in a microwave oven for 30 seconds (Gedikoglu, 2015).

2.14 Statistical Analysis

For the multi-factor experiment (the type of dietary fiber and the level of addition), a completely randomized design (CRD)-factorial design (4x3) with two replicates was used to analyze the data using a statistical analysis system (SAS-University edition, SAS Institute Inc., Cary, NC, USA). Means' separation for the main effects and interaction effect was performed using a Duncan's multiple range test ($P < 0.05$). For one factor experiments (sensory analysis and proximate composition), CRD design with three replicates was used to analyze the data using the SAS system (SAS-University edition, SAS Institute Inc., Cary, NC, USA). Means' separation was performed using a Duncan's multiple range test ($P < 0.05$).

3 Results

In the following presentation of the factorial experiment results, only the results of the significant interaction effect are presented. When the interaction effect between the types of fibers and the addition level was not significant, the significant main effects will be presented.

3.1 Color Evaluation

L^* values of chicken nuggets were significantly ($P<0.05$) affected by the level of dietary fiber and the interaction between the main effects. However, the type of dietary fiber did not significantly affect it ($P \geq 0.05$). Therefore, only the results of the interaction effect are presented in Figure 4. Only RS dietary fiber, added at different levels, significantly ($P < 0.05$) affected the L^* values.

However, all levels of RS used did not differ significantly from the control treatment.

a^* values of chicken nuggets were significantly (P<0.05) affected by the type of dietary fiber only (RS, POD, FOS, and GOS). The effect of the type of dietary fiber on a^* value is presented in Table 3. The use of RS dietary fiber significantly (P<0.05) decreased the a* values as compared to control and other treatments. No significant effects were observed for other dietary fibers.

b^* values of chicken nuggets were significantly (P<0.05) affected by the type of dietary fiber only. Table 3 summarizes the effect of the type of dietary fiber on b^* value. The effect of the type of dietary fiber on b^* values showed the same pattern as the effect of the type of dietary fiber on a^* values. Only RS dietary fiber reduced the b^* value significantly (P< 0.05) compared to control, and there were no significant effects of other dietary fibers.

ΔE^*ab values of chicken nuggets were significantly (P<0.05) affected by the type of dietary only. The highest total color difference values were for RS dietary fiber, which differs significantly (P< 0.05) from other treatments, as shown in Table 3. Other dietary fibers did not significantly (P≥ 0.05) affect the total color difference values compared to the control treatment.

3.2 Texture Profile Analysis (TPA)

Firmness values were significantly (P<0.05) affected by the type of dietary fiber and the interaction effect. The effects of type and level of added dietary fiber are summarized in Figure 5. Firmness values were not significantly affected (P≥ 0.05) by RS, FOS or GOS in all used levels. Using POD, with a level of addition above 5%, significantly (P<0.05) reduced the firmness values compared to the control treatment.

Cohesiveness values were significantly (P<0.05) affected by the main effects (dietary fiber and addition levels) with no interaction effect (Table 4 and 5, respectively). POD dietary fiber significantly (P<0.05) reduced the cohesiveness. Other fibers did not significantly affect cohesiveness compared to the control (Table 4). The addition of dietary fiber up to 10% did not affect the cohesiveness significantly (P≥0.05). At a 15% addition level, the cohesiveness decreased significantly (P<0.05) (Table 5).

Chewiness values were significantly (P<0.05) affected by the main and interaction effects. Figure 6 shows the effects of type and level of added dietary fiber on chewiness values. The addition of RS dietary fiber at different levels did not affect the chewiness values compared to the control treatment. However, there was a significant (P<0.05) reduction in the chewiness for RS at a 15% addition level compared to other levels. Other dietary fibers significantly (P<0.05) reduced the chewiness values compared to the control treatment, where the chewiness decreased with increasing the addition levels to varying degrees.

Resilience was significantly affected by the main effect, with no significant interaction effect. Table 4 shows the effect of type of dietary fiber on resilience. The addition of RS or FOS did not affect the resilience values significantly (P<0.05) compared to the control, and GOS reduced the resilience values significantly (P<0.05) compared to the control. POD had the lowest resilience value that differed from other treatments significantly (P<0.05). The effect of the addition level on resilience is shown in Table 5 Up to 5%, resilience did not change significantly (P≥0.05) compared to control. At a 10% addition level or higher, the resilience value decreased significantly (P<0.05) compared to the control treatment.

3.3 Shear Test

Firmness was affected by the main effects, with no interaction effect. Table 6 shows the effect of type of dietary fiber on firmness values. The highest firmness values were for RS, which differ significantly (P<0.05) from other treatments. POD had the lowest firmness values that significantly (P<0.05) differed from other treatments except for FOS. The effect of the addition level is shown in Table 7. A 5% addition level significantly (P<0.05) increased the firmness values compared to the control treatment. Nuggets

Table 3: Effect of the type of dietary fiber on the color values of chicken nuggets[1]

Type of Fat Replacer	Color Values						
	$L*$	$a*$	$b*$	ΔL	Δa	Δb	$\Delta E*ab$
Control	77.47 ± 0.18^{a}	2.83 ± 0.78^{a}	21.69 ± 0.20^{a}	77.47 ± 0.00^{a}	00.00 ± 0.00^{a}	00.00 ± 0.00^{a}	00.00 ± 0.00^{b}
RS	73.21 ± 8.74^{a}	1.44 ± 0.36^{b}	19.02 ± 1.80^{b}	-04.25 ± 8.74^{b}	-01.37 ± 0.33^{b}	-02.66 ± 1.80^{b}	46.86 ± 47.83^{a}
POD	74.10 ± 2.99^{a}	2.50 ± 0.57^{a}	21.24 ± 1.32^{a}	-03.36 ± 2.99^{b}	-00.32 ± 0.57^{a}	-00.44 ± 1.32^{a}	10.40 ± 12.13^{ab}
FOS	74.06 ± 2.47^{a}	2.26 ± 0.34^{a}	21.78 ± 0.59^{a}	-03.40 ± 2.47^{b}	-00.56 ± 0.34^{a}	00.09 ± 0.59^{a}	08.72 ± 8.20^{ab}
GOS	77.51 ± 1.11^{a}	2.22 ± 0.45^{a}	21.84 ± 1.24^{a}	00.04 ± 1.11^{b}	-00.38 ± 0.68^{a}	00.15 ± 1.24^{a}	01.44 ± 1.12^{b}

[1] All values are mean ± standard deviation; Values followed by the same letter in the same column are not significantly different (P≥0.05) according to Duncan's multiple range test.

Table 4: Effect of the type of dietary fiber on the TPA of chicken nuggets[1]

Type of Fat Replacer	TPA			
	Firmness (g)	Cohesiveness	Chewiness (g)	Resilience
Control	3906.25 ± 45.43^{b}	0.50 ± 0.00^{a}	1972.83 ± 65.99^{a}	0.23 ± 0.00^{a}
RS	4463.48 ± 622.09^{a}	0.47 ± 0.15^{a}	2072.04 ± 510.16^{a}	0.19 ± 0.02^{ab}
POD	2230.88 ± 993.00^{d}	0.36 ± 0.05^{b}	840.48 ± 543.41^{c}	0.14 ± 0.05^{c}
FOS	2446.39 ± 107.85^{d}	0.47 ± 0.07^{a}	1152.61 ± 213.95^{b}	0.20 ± 0.04^{ab}
GOS	3076.22 ± 228.55^{c}	0.44 ± 0.04^{ab}	1369.72 ± 160.44^{b}	0.18 ± 0.03^{b}

[1] All values are mean ± standard deviation; Values followed by the same letter in the same column are not significantly different (P≥0.05) according to Duncan's multiple range test.

Table 5: Effect of the level of dietary fiber on the TPA of chicken nuggets[1]

Level of Fat Replacer	TPA			
	Firmness (g)	Cohesiveness	Chewiness (g)	Resilience
Control	3906.25 ± 48.43^{a}	0.50 ± 0.00^{a}	1972.83 ± 65.99^{a}	0.23 ± 0.00^{a}
5%	3204.27 ± 648.33^{b}	0.51 ± 0.08^{a}	1661.17 ± 474.20^{b}	0.22 ± 0.02^{a}
10%	3046.73 ± 1216.62^{b}	0.44 ± 0.08^{a}	1368.05 ± 744.32^{c}	0.17 ± 0.04^{b}
15%	2911.76 ± 1295.11^{b}	0.36 ± 0.06^{b}	1046.91 ± 395.14^{d}	0.15 ± 0.03^{b}

[1] All values are mean ± standard deviation; Values followed by the same letter in the same column are not significantly different (P≥0.05) according to Duncan's multiple range test.

with a 10% addition level did not differ significantly ($P \geq 0.05$) from the control treatment but it was significantly ($P<0.05$) lower than the 5% addition level. Increasing the addition level to 15% decreased the firmness value significantly ($P<0.05$) compared to other treatments.
The cutting work was affected by the main effects, with no significant interaction. The effect of type of dietary fiber on cutting work is shown in Table 6. RS dietary fiber had the highest work of cutting values that differ significantly ($P<0.05$) from other treatments, whereas POD dietary fiber had the lowest cutting work that was significantly ($P<0.05$) different from other treatments except for GOS. FOS and GOS were not significantly ($P \geq 0.05$) different from the control treatment. Table 7 shows the effect of addition level on the work of cutting values. Addition level up to 10% did not significantly ($P \geq 0.05$) affect cutting work compared to the control treatment. At a 15% addition level, the work of cutting values decreased significantly ($P<0.05$).

3.4 pH

pH values were significantly ($P<0.05$) affected by the addition level and the interaction effect with no significant effect by the type of dietary fiber (Table 8). Figure 7 shows the interaction effect between the type of dietary fiber and the addition level on pH values. There are significant differences between some treatments; however, all treatments did not significantly ($P \geq 0.05$) differ from the control treatment.

3.5 Yield

Yield values after breading (batter pickup) were significantly ($P<0.05$) affected by the type of dietary fiber only. Table 8 shows the effect of type of dietary fiber on yield after the battering step. The addition of RS dietary fiber did not significantly ($P \geq 0.05$) affect the yield values compared to the control treatment, whereas other treatments increased the yield values significantly ($P<0.05$) compared to the control treatment, with no significant differences between them.
Yield values after cooking were significantly ($P<0.05$) affected by the type of fiber only. Table 8 shows the effect of type of dietary fiber on yield after the final cooking step. Only POD dietary fiber significantly ($P<0.05$) increased the yield values compared to the control treatment, whereas other treatments did not significantly ($P \geq 0.05$) affect the yield values compared to the control treatment.

3.6 Sensory Evaluation

Sensory evaluation scores for the three treatments (RS, GOS and control) were not significantly ($P \geq 0.05$) differed (Table 10).

3.7 Proximate Composition

Moisture, ash, protein and fat were significantly ($P<0.05$) affected by GOS addition. Table 9 shows samples formulated with 15% GOS had significantly ($P \leq 0.05$) lower moisture (40.53%), ash (2.91%), fat (10.21%) and protein (13.77%) compared to the control treatment (44.07%, 3.84%, 14.85% and 14.72% respectively).

4 Discussion

4.1 Formulation of chicken nuggets

Dietary fibers were added to increase the level of dietary fiber in the final product and, at the same time, to compensate for negative sensory attributes resulting from chicken skin removal (Mehta et al., 2015). For this purpose, four commercially available dietary fibers were used: RS, POD, FOS and GOS. These fibers were recently declared to meet dietary fiber's new definition by the Center for Food Safety and Applied Nutrition (2018), and consequently, there is little scientific work on their use in nuggets' production (Felisberto et al., 2015). The use of fiber in an isolated and purified form offers several advantages: consistent quality, low cost, availability, and better functional and health properties (Ibrahim, 2018). Most of the work done to enhance fiber content in chicken nuggets was performed by adding fruit and vegetable flour or waste by-products. However, these natural sources of dietary fiber were

Table 6: Effect of the type of dietary fiber on the shear test of chicken nuggets[1]

Type of Fat Replacer	Shear Test	
	Firmness (g)	Work of Cutting (J)
Control	1679.72 ± 180.06^{b}	23078.17 ± 2757.68^{b}
RS	2715.89 ± 620.67^{a}	32987.11 ± 8983.25^{a}
POD	1167.52 ± 481.48^{c}	14612.69 ± 6070.01^{c}
FOS	1456.25 ± 309.10^{bc}	20902 ± 3550.92^{b}
GOS	1511.49 ± 176.84^{b}	18817 ± 2430.35^{bc}

[1] All values are mean ± standard deviation; Values followed by the same letter in the same column are not significantly different (P≥0.05) according to Duncan's multiple range test.

Table 7: Effect of the level of dietary fiber on the shear test of chicken nuggets[1]

Level of Fat Replacer	Shear Test	
	Cutting Firmness (g)	Work of Cutting
Control	1679.72 ± 180.06^{b}	23078.17 ± 2757.68^{a}
5%	2100.54 ± 753.24^{a}	26456.11 ± 9250.23^{a}
10%	1749.83 ± 689.09^{b}	22340.74 ± 8447.18^{a}
15%	1287.99 ± 563.87^{c}	16692.33 ± 6723.60^{b}

[1] All values are mean ± standard deviation; Values followed by the same letter in the same column are not significantly different (P≥0.05) according to Duncan's multiple range test.

Table 8: Effect of the type of dietary fiber on the batter pickup, pH and cooking yield values of chicken nuggets[1]

Type of Fat Replacer	Batter pickup, pH, Cooking yield		
	Batter Pickup	pH	Cooking Yield
Control	123.60 ± 0.00^{b}	6.12 ± 0.00^{a}	89.10 ± 0.00^{b}
RS	123.18 ± 2.00^{b}	6.15 ± 0.07^{a}	92.68 ± 1.11^{ab}
POD	131.06 ± 7.20^{a}	6.17 ± 0.09^{a}	94.55 ± 2.41^{a}
FOS	133.15 ± 5.21^{a}	6.09 ± 0.04^{a}	89.36 ± 3.70^{b}
GOS	133.91 ± 1.46^{a}	6.12 ± 0.08^{a}	91.08 ± 1.43^{ab}

[1] All values are mean ± standard deviation; Values followed by the same letter in the same column are not significantly different (P≥0.05) according to Duncan's multiple range test.

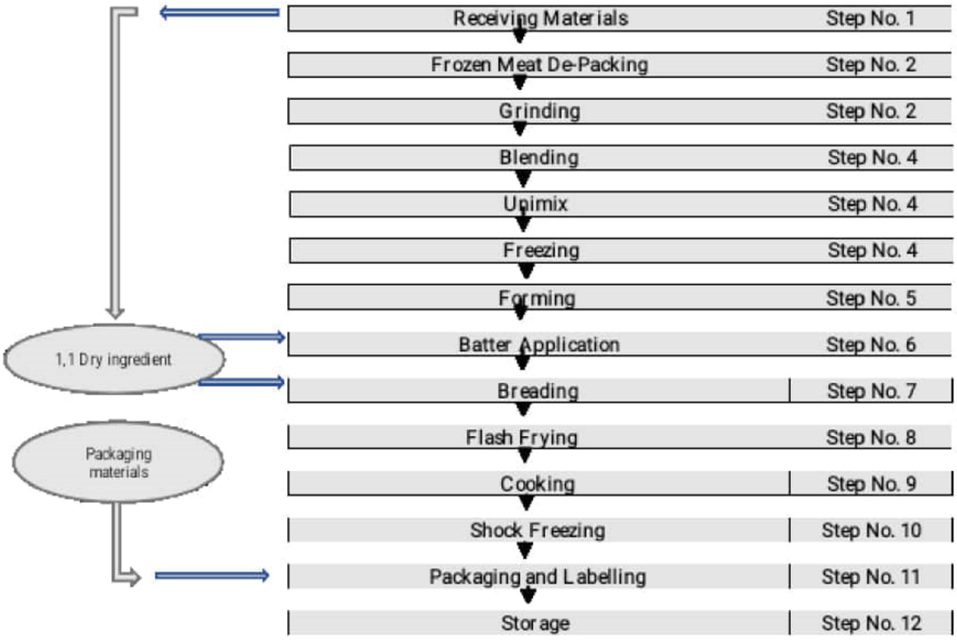

Figure 1: Flow chart for production of chicken nuggets

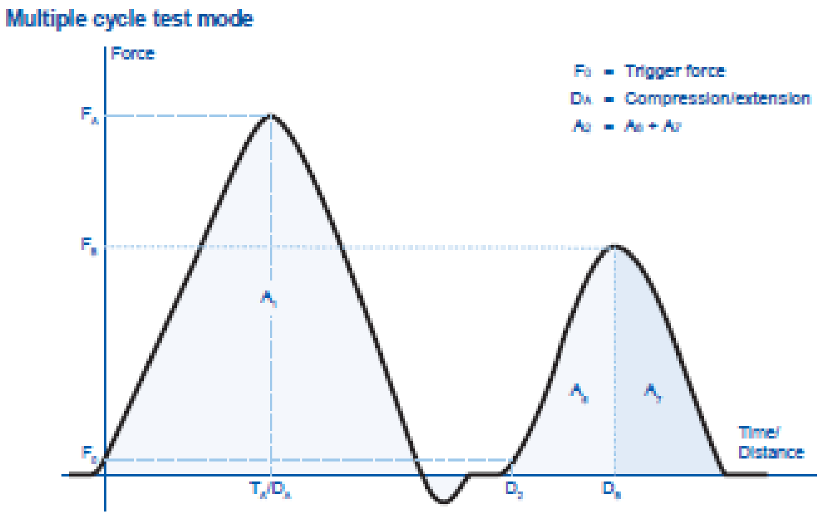

Figure 2: A typical TPA curve

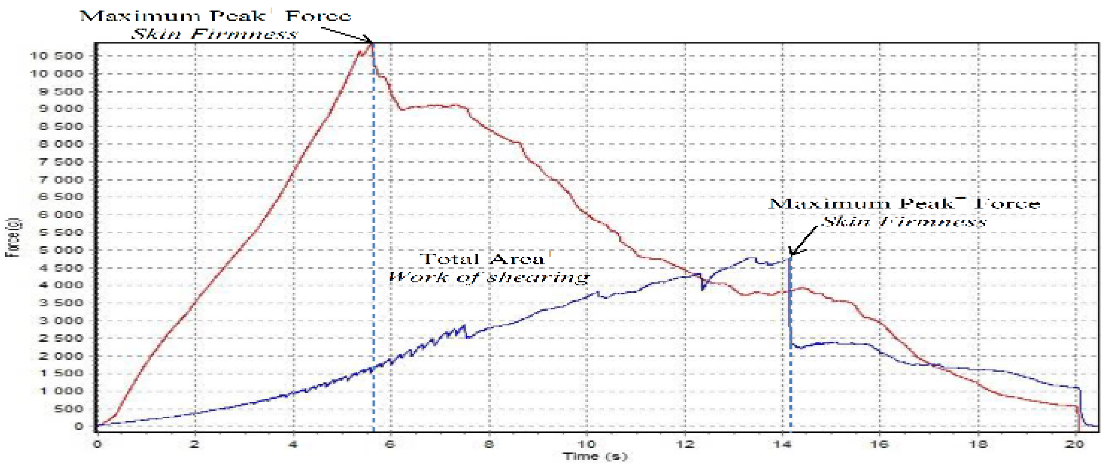

Figure 3: A typical shear test curve

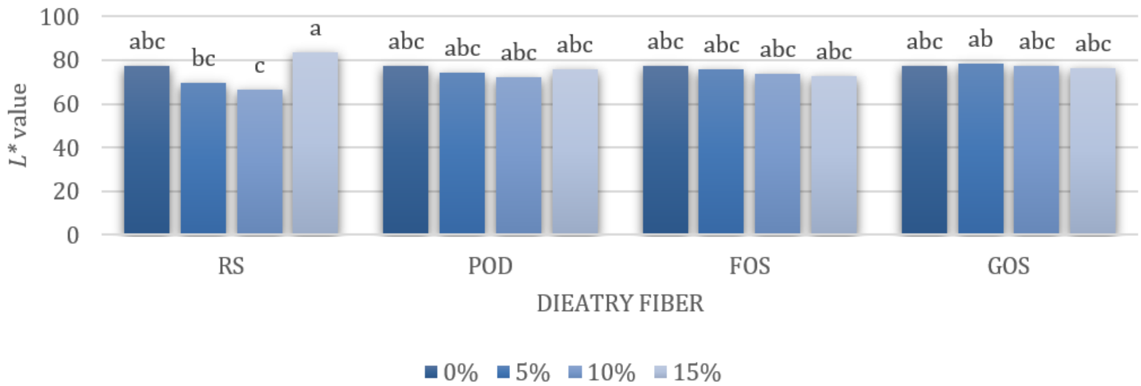

Figure 4: Effects of type and level of added dietary fiber on the $L*$ value of chicken nuggets

Table 9: Proximate composition of chicken nuggets formulated with 15% GOS and control[1]

	Proximate Composition			
Treatment	Moisture	Ash	Fat	Protein
Control	44.07 ± 0.04^a	03.84 ± 0.10^a	14.85 ± 0.16^a	14.72 ± 0.26^a
GOS 15%	40.53 ± 0.67^b	02.91 ± 0.04^b	10.21 ± 0.29^b	13.77 ± 0.02^b

[1] All values are mean ± standard deviation; Values followed by the same letter in the same column are not significantly different (P≥0.05) according to Duncan's multiple range test.

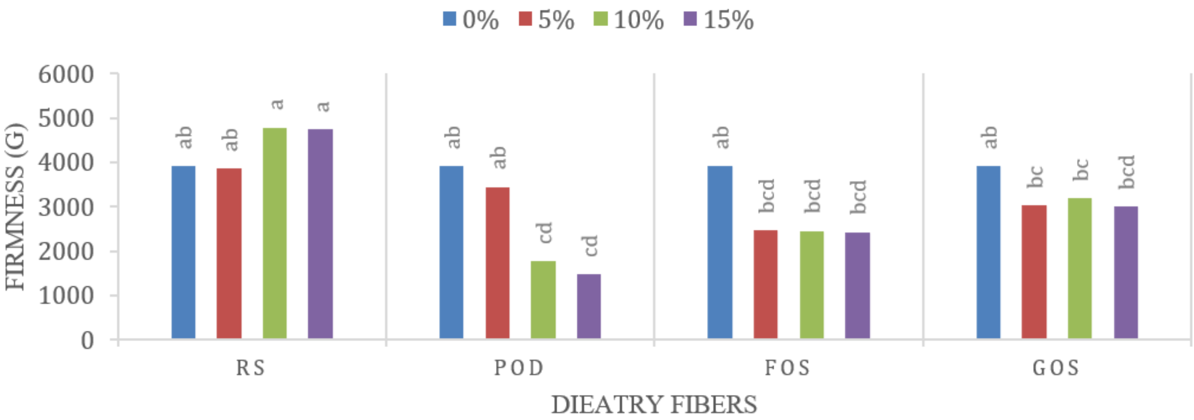

Figure 5: Effects of type and level of added dietary fiber on the firmness value of chicken nuggets

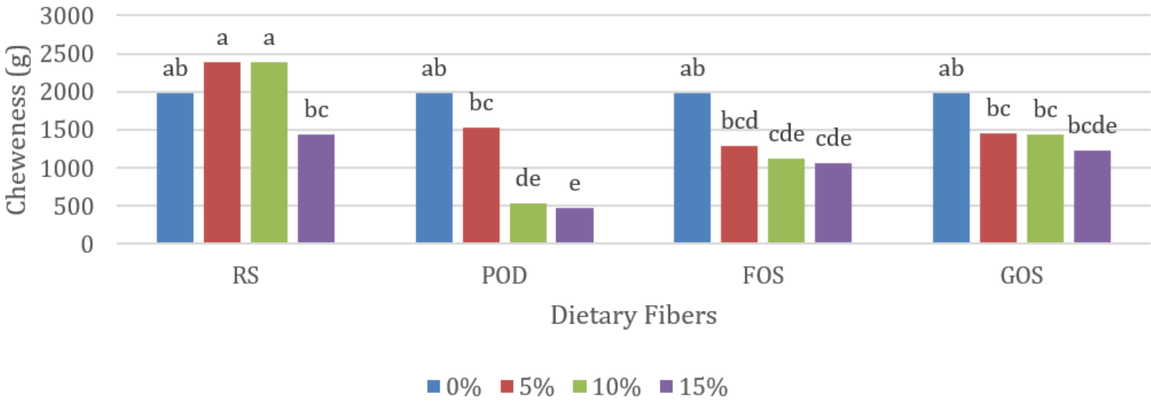

Figure 6: Effects of type and level of added dietary fiber on the chewiness value of chicken nuggets

Table 10: Sensory evaluation of chicken nuggets formulated with 15% RS or GOS and control[1]

	Sensory Evaluation		
Treatment	Color	Taste	Texture
Control	7.13 ± 0.73^a	7.00 ± 0.87^a	7.30 ± 3.34^a
RS*15%	7.10 ± 0.71^a	7.13 ± 0.77^a	7.13 ± 1.53^a
GOS*15%	7.23 ± 0.67^a	7.16 ± 0.74^a	7.30 ± 0.62^a

[1] All values are mean ± standard deviation; Values followed by the same letter in the same column are not significantly different (P≥0.05) according to Duncan's multiple range test.

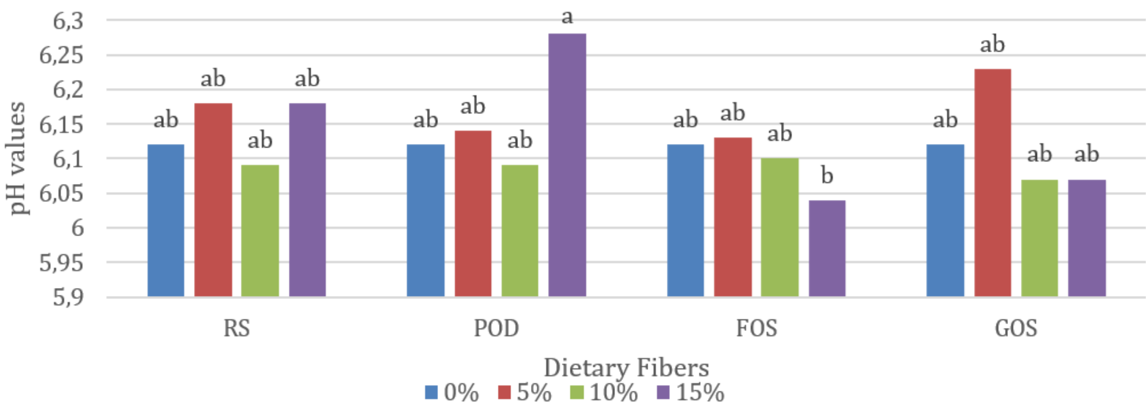

Figure 7: Effects of type and level of added dietary fiber on the pH value of chicken nuggets

found to affect final product sensory attributes (Ibrahim, 2018; Pérez-Chabela & Hernández-Alcántara, 2018). To the best of our knowledge, the fibers used in this study were not tested before in chicken nuggets' production.

The chicken nugget recipe was produced based on a local company bill of material (BOM) (Table 1). Different studies used different proportions of chicken breast and skin: 70% of chicken meat and 20% of skin (Polizer et al., 2015), 100% of chicken meat (Nath et al., 2016), 91% of chicken meat and 3.5% of chicken skin (Akesowan, 2016), 70% of chicken breast and 10% of chicken skin (Kim et al., 2015), and 70% of chicken breast and 10 of skin (Fang, 2015). Perhaps cost is the main factor affecting the proportion of different components. In the previous studies, fibers were added in different proportions ranging from 2 to 10% (Akesowan, 2016; Fang, 2015; Kim et al., 2015; Polizer et al., 2015; Taşbaş et al., 2016).

Due to consumers' low fiber intake and the low fiber content of processed products like chicken nuggets, the fibers mentioned previously have been incorporated into the chicken nuggets in this study. So, the present study relied on these materials due to their new declaration by the FDA to meet the definition of dietary fiber (Center for Food Safety and Applied Nutrition, 2018), consistent quality and low cost (Felisberto et al., 2015).

Some earlier research reported the use of different types of fiber from different sources, such as flours processed from fermented cowpeas and fermented partially defatted peanuts (Prinyawiwatkul et al., 1997), roasted pea flour (Singh et al., 2008), pea hull flour, gram hull flour, bottle gourd and apple pulp (Verma et al., 2010, 2019). However, none of these previous studies used commercial dietary fiber products with high purity of specific types of soluble fiber like RS, POD, FOS and GOS, which could provide more health benefits and better sensory properties.

4.2 Instrumental Color Analysis

Consumer acceptance is commonly dependent on the product's color (Fang, 2015). Color analysis is a very important parameter to investigate since many studies rely on it to evaluate the quality of low-fat food products (Cáceres et al., 2004; Jimenez-Colmenero et al., 2010). In this study, the CIE Lab color values (L^*, a^*, b^*, and ΔE^*ab) were determined for samples of chicken nuggets (Figures 4 and Table 3). Results indicated that all fibers used (RS, POD, FOS and GOS) did not affect the color values L^*, a^*, b^* significantly ($P \geq 0.05$) compared to the control treatment regardless of the addition level used except RS fiber, which reduced the a^* and b^* values significantly ($P<0.05$) compared to control and other treatments. As a result, the highest ΔE^*ab was for RS (Table 3).

There was no agreement in the literature about the effects of fiber addition on final product color. Alves et al. (2016) found that the replacement of pork back fat (up to 60% of reduction) for pork skin and green banana flour gel (PSGBF) in bologna-type sausage did not affect the color parameters. Bis-Souza et al. (2018) reported a reduction in L^* value in a low-fat beef burger with added FOS and dietary inulin fiber at 3 and 6% levels. The addition of chickpea flour to chicken nuggets increased a^* and b^* values (Sharima-Abdullah et al., 2018). Kilincceker and Yilmaz (2016) found that adding wheat and apple fibers increased the a^* values, and pea fiber increased the b^* values of fried chicken meatballs. It has been suggested that the natural color of fiber, source of fiber (Kilincceker & Yilmaz, 2016), the addition level (Kilincceker & Kurt, 2018) and type of meat (Mittal & Barbut, 1994) affect the final product color.
Although the instrumental color evaluation in our study showed color differences between samples with added RS and other samples, these differences were undetectable by panelists who evaluated the color (Table 10), where no significant differences were found between different treatments' color scores. This result was in agreement with previous studies (Fang, 2015; Polizer et al., 2015).

4.3 Instrumental Texture Analysis

Many studies determined the final product's texture due to its importance to customers and most of the studies evaluated the texture using TPA. From the results of this study, it can be concluded that POD fiber addition had the highest impact on nuggets' texture compared to other fibers. POD significantly (P≤0.05) reduced the values of all test parameters tested in this study more than the control treatment. Interestingly, other fibers gave comparable results compared to the control treatment with varying degrees. Generally, TPA parameters were not affected by the other three fibers (RS, FOS, GOS) except in a few cases. For instance, cohesiveness and resilience values reduced significantly (P<0.05) when the addition level was above 10%. Additionally, FOS significantly (P<0.05) reduced chewiness when the addition level was above 5%. It was not easy to compare our results with what has been published due to the differences in nugget formulas, type of fiber, fiber source, addition levels the target of addition and processing steps. It is worth mentioning again that fibers were added in this study to achieve two goals: increasing the fiber content in the final product and replacing chicken skin. The changes in the TPA parameters resulting from fiber addition to chicken nuggets were reported in several pieces of literature. Verma et al. (2015) reported a decrease in chicken nuggets' firmness values when the percentage of pea hall fiber increased from 8% to 12%. However, cohesiveness and chewiness increased when meat substitution with pea hall flour was greater than 8%. (Wan Rosli et al., 2011) found a decrease in hardness, cohesiveness and chewiness of chicken patty formulated with an oyster mushroom when the addition level of mushroom was 25% and 50%, to replace chicken meat. Alves et al. (2016) observed a decrease in hardness at 80% substitution of pork back fat by PSGBF gel, a decrease in cohesiveness at 100% substitution of pork back fat by PSGBF gel and a decrease in chewiness at 80% substitution of pork back fat by PSGBF gel when green banana flour was used as a fat replacer in bologna type sausage. Akesowan (2016) noticed that firmness was increased, with increasing the konjac flour/xanthan gum (KF/XG) mixture of the produced chicken nuggets, when the shiitake powder (SP) was maintained at 1–2 %.
This study performed two texture measuring tests: TPA (Table 4 and 5, and Figures 5 and 6) discussed above, and the shear force test (Table 6 and 7). Both tests measure firmness using different probes and test conditions. Comparing the results of both tests, it can be concluded that the shear test was more sensitive to change in the type and level of dietary fiber. According to the shear test, RS and GOS addition up to 15% did not significantly (P≥0.05) affect the firmness values compared to the control treatment. Whereas, for POD and FOS, the change in firmness value became significant (P<0.05) above the 5% addition level. The decrease in shear force was reported in previous studies involving the addition of fiber to chicken nuggets.

A more tender texture was found when dietary fiber was incorporated in the core portion of the chicken nuggets (Verma et al., 2010). A slight decrease in shear force value, with an increase in dietary fiber incorporation, was also reported by Das et al. (2006) and Atughonu et al. (1998). Soher et al. (2013) found that the shear force value increased in a chicken burger formulated with carrot pomace.

4.4 Yield

Many studies reported different yield types such as batter pickup%, par-fry yield%, cook loss%, freeze loss%, and total yield% (Fang, 2015). In this study, the yield was measured using two methods: After the breading step (Batter Pickup) and after the final cooking step (Yield). After the breading step, POD, FOS and GOS significantly ($P<0.05$) increased the yield compared to the control by 7.46%, 9.55% and 10.31%, respectively (Table 8), Whereas RS treatments did not differ significantly ($P>0.05$) from the control. Little work was found in literature about the effect of adding fiber to nuggets on batter pickup. For instance, Fang (2015) calculated the percentage of batter pickup of soya chicken nuggets treated by functional fibers (70% isomalto-oligosaccharide (IMO) and 30% hydroxypropyl methylcellulose (HPMC)), and it was found that the percentage of batter pickup did not significantly differ from the control, in contrast to our results. It is unknown how fiber addition to chicken nuggets affects batter pickup, but it seems that fiber affects the chicken nuggets' adhesive properties (Fang, 2015).
After cooking yield, POD significantly ($P\leq 0.05$) increased the yield by 5.45%, 5.19%, 3.47% and 1.87% as compared to the control, FOS, GOS and RS, respectively (Table 8). To the best of our knowledge, the fibers used in this study to formulate chicken nuggets were not previously investigated. Several studies reported an increase in yield but the fibers used in this study increased the yield to higher values. Ammar (2017) found that chicken nuggets which incorporated the natural fiber sources, orange albedo and eggplant pulp, significantly enhanced the yield% by 3.73% and 3.53%, respectively. Adding bajra flour to chicken nuggets at two levels, 10% and 20%, increased the yield by 1.27% and 2.17%, respectively (Para & Ganguly, 2015). Sathu et al. (2017) also observed a significant increase in cooking yield (1.78% - 2.89%) in chicken nuggets with added oats. In contrast, Polizer et al. (2015) reported no differences in chicken nuggets' cooking yield formulated with added pea fiber.

4.5 pH

The quality attributes such as texture and color are correlated with pH value (Sharima-Abdullah et al., 2018). The pH values in this study were measured after the chicken nuggets' formulation step. The results indicated that the pH value was not affected by the type of fiber and addition level compared to the control treatment (Figure 7 and Table 8).
No previous studies were conducted to investigate addition of the dietary fibers used in this study on chicken nuggets' pH values after the formulation step. Reviewing the previous scientific works performed on dietary fiber from different plant sources in chicken nuggets indicated no agreement among these studies about the effect of adding these fibers on chicken nuggets' pH after the formulation step. Some previous works, involving the addition of banana flour and soybean skin (Kumar et al., 2017) and citrus fibers (Gedikoglu, 2015), agreed with our results. On the contrary, studies involving the addition of pea fibers (Polizer et al., 2015), flaxseed flour (Bilek and Turhan, 2009) and whey powder (Serdaroğlu, 2006) reported pH changes compared to the control. The changes in pH values were attributed to the pH of the dietary fiber plant source (Mehta et al., 2015; Verma et al., 2016) and to the addition level (Verma et al., 2016). It should be mentioned that the absence of pH changes in chicken nuggets after the formulation step in our study does not mean that the final product from different treatments will have the same pH value. Ammar (2017) reported that the finished product's pH value was higher than raw meat, and this increase in pH value might be due to the release of alkali compounds from amino acids upon cooking (Choe et al., 2013; Gedikoglu, 2015; Kim et al., 2010).

4.6 Sensory Evaluation

Sensory evaluation was carried out to study consumers' acceptability and satisfaction with the 15% RS and 15% GOS (were selected for their minor effects on nuggets' physical properties) chicken nugget treatments compared to the control (Table 10). The results showed no significant ($P \leq 0.05$) difference between the dietary fiber used (RS and GOS) compared to the control, although there were significant differences between treatments regarding instrumental texture and color measurements. This result agrees with the work of Polizer et al. (2015) who reported that partial replacement of meat (10%) or fat (10%) with pea fiber (2%) and water did not change product acceptance by consumers. Additionally, it has been found that incorporating bajra flour into chicken nuggets at the addition level of 10-20% did not impact the final product's sensory properties despite differences in instrumental texture measurements (Para & Ganguly, 2015). In contrast, Sathu et al. (2017) found that lupin flour at a 4.0 % level adversely affected chicken nuggets' appearance, color, flavor and overall acceptability. Akesowan (2016) observed that shiitake powder (SP) affected chicken nuggets' sensory properties where an increase in the addition level from 1 to 2.5% affected the color score. Simultaneously, the taste score was affected by the mixture of SP and the konjac flour/xanthan gum (KF/XG) mixture.

4.7 Proximate Composition

Nuggets formulated with 15% GOS was selected from other types of dietary fibers to compare their composition with the control nuggets. GOS was selected due to its minor effects on the nuggets' physical properties. The results of this study demonstrated that moisture, ash, fat and protein content of chicken nuggets formulated with GOS were significantly ($P < 0.05$) lower than the control treatment (Table 9). One of this study's objectives was to decrease chicken nuggets' fat content by replacing chicken skin with dietary fiber. Complete replacement of chicken skin with GOS reduced the fat content from 14.84 to 10.21% (31.24% fat reduction). Several studies investigated changes in the proximate composition resulting from the addition of dietary fiber to replace fat in the processing of chicken nuggets. Akesowan (2016) reported a 17.6% reduction of fat in chicken nuggets which initially contained 3.5% using konjac flour/xanthan gum (KF/XG) mixture (0.2–1.5 %) and shiitake powder (SP) (1–4 %). Verma et al. (2015) observed that moisture, ash and protein content were statistically reduced in chicken nuggets which incorporated 8-12% pea hall flour. Kim et al. (2015) observed that the protein, fat and ash content were significantly reduced in chicken nuggets which contained mixtures of chicken skin and fiber at four levels (2.5, 5.0, 7.5 and 10%) of addition. The fat content was 11.61% in the control and was reduced by 44.87% in the chicken nugget treatment at 10% addition level. Sharima-Abdullah et al. (2018) reported that chicken nuggets with added chickpea flour and textured vegetable protein had no differences in % ash content, an increased % protein content and a reduced-fat content from 7.50% to 3.83% (48.39% reduction) compared to the control. Polizer et al. (2015) reported no significant differences in the % ash content, while the % moisture content was increased and the % fat content decreased from 14.32% to 10.66% (25.55% reduction). These changes resulted from adding fiber to create a reduced fat treatment. The variation in % fat reduction in previous studies may be related to the initial fat content and fat replacement levels in the formulations.

5 Conclusions

Total replacement of chicken skin with dietary fibers (RS or FOS or GOS) affects the final product's texture, color, yield and proximate composition. However, sensory acceptability was not affected. All fibers used (RS, POD, FOS and GOS) did not affect the color values L^*, a^*, b^* significantly compared to the control treatment regardless of the addition level used except RS fiber, which reduced the a^* and b^* values significantly compared to control.

POD significantly reduced the values of all test parameters used to study texture in this study compared to the control treatment. Generally, TPA parameters were not affected by the other three fibers (RS, FOS and GOS) except in a few cases. For instance, cohesiveness and resilience values reduced significantly when the addition level was above 10%. Additionally, FOS significantly reduced chewiness when the addition level was above 5%. Moisture, ash, fat and protein content of chicken nuggets formulated with GOS were significantly lower than the control treatment.

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