PAPER

EFFECTS OF INNOVATIVE GLUTEN-FREE COATINGS ON QUALITY, SENSORY AND MICROBIAL PROPERTIES OF CHICKEN NUGGETS

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ABSTRACT

In parallel to the increased incidences of celiac diseases, the demand to produce a significant array of gluten-free products is rapidly growing. A total of 28 dry and liquid coatings of chicken nuggets were formulated using seven blend ratios of rice-to-corn flours (0:100, 100:0, 50:50, 60:40, 70:30, 40:60 and 30:70), two levels of corn starch (5 and 15%), 0.3% methyl cellulose (MC), and/or 0.5% carboxy methyl cellulose (CMC), and other ingredients such as 2% xanthan gum, 2% sucrose, 2.5% salt and 1% spice. Based on visual evaluations 16 groups were eliminated at first stage. After sensory analyses, six groups out of remaining 12 were selected and gluten analyses were performed. Although all had the gluten level below the legal limit of 20 mg/kg, three formulations (30:70, 40:60 and 60:40) with the lowest amounts of gluten out of six were selected, and the rest of the experiments were continued with these final three formulas. The CMC-containing formulations had higher sensory scores than the MC-containing ones. The addition of more than 40% rice flour adversely affected sensory and textural properties. The use of 15% cornstarch, instead of 5%, enhanced the textural parameters.

Keywords: celiac disease, poultry products, gluten-free batter; functional foods

1. INTRODUCTION

Celiac disease – a genetically based autoimmune condition – is characterized by human intolerance to gluten, a component of wheat, barley, and rye (LOEWE, 1993). The incidence of celiac disease has increased dramatically in recent years, with the projection that over 1% of Americans and 0.3% of Europeans are estimated to suffer from it (FASANA *et al*., 2003). The global incidences of food allergies were estimated at 8% for children and 2% for adults (JACKSON *et al*., 2006). Globally, there is a very narrow range of commercially-available gluten-free products such as biscuit, cakes, breads, and confectionary products, with a rapidly growing need for gluten-free poultry products.

Chicken nuggets are commercially produced using a coating of wheat flour, deep-frying, and quick-freezing (OWENS, 2001). Since wheat flour is rich in gluten (over 60%) (GALLAGHER *et al*., 2004), different replacements for wheat flour are being sought actively for chicken nuggets. One of such replacements is rice flour, that has been utilized in batters for frying owing to its high availability and nutritious and low-calorie nature (SHIH and DAIGLE 1999, 2006 MUKPRASIRT *et al*., 2000). The use of amaranth flour in batter, chicken paste, and chicken nuggets was also explored using different blends (TAMSEN *et al*., 2018). TASBAS *et al*. (2016) studied the effects of gluten-free chicken nuggets formulated using cellulose, egg powder, whey powder, pectin, and gluten-free wheat flour on physicochemical characteristics such as color, texture, and shelf-life.

Given the limited number of studies in available in literature, there is an urgent need to develop alternatives to wheat flour in the coating of chicken nuggets as well as to test them in terms of food quality, safety and stability. The objectives of this study were to (1) develop gluten-free coatings for chicken nuggets using corn and rice flours at seven blend levels, and (2) test their quality, safety and sensory properties.

2. MATERIALS AND METHODS

2.1. Preparation of ingredients

To be used in gluten-free coating formulations, chicken steaks, and skins of chicken breasts and legs were obtained from a local poultry firm (Erpiliç, Bolu, Turkey). AF V2 gluten-free binding agent (a mixture of green bean, bamboo, potato, and rice fiber), gluten-free spice mix tasty AG (a mixture of onion, garlic, and cumin powders), liquid casing used to cover nuggets (rice flour, corn flour, corn starch, methyl cellulose (MC), carboxy methyl cellulose (CMC), xhanthan gum, sucrose, and salt), and powder forms of sauces (rice flour, corn flour, yeast, sugar, salt, sunflower oil, emulsifier, and coloring agent) were acquired from DPS (Dutch Protein and Services Ingredients for the Food Industry, Holland).

2.2. Preparation of chicken nuggets

Chicken steaks were stored for 6 h at 1 to 4°C after slaughtering. Meat samples were grinded with a grinding machine (Hachoir 1500 watt) using a 5-mm blade to obtain minced meat. The meat temperature was kept under 4°C during the grinding process. Similarly, chicken skins were also grinded with the same machine under the same conditions but with a 1.3-mm blade. Minced meat samples were mixed with spice, binding agent, and water, kneaded to yield a typical nugget texture, shaped using a nugget-specific mold and rested for 6 h at a refrigeration temperature. The ingredients and preparation of chicken nuggets for the experiments are presented in Table 1 and Fig. 1.

Table 1. Ingredients of gluten-free chicken nuggets.

Ingredients	Percentage (%)
Chicken steak	74.5
Chicken skin	6.2
Water	12.4
Spice mix	1.6
Binding	5.3

Figure 1. (a) Chicken breast steak, (b) minced chicken breast, (c) chicken skin, (d) mixture of minced meat and skin, (e) minced meat, skin, and spice mix, (f) mixture of minced meat, skin, binging agent, and spice, (g) gluten-free nugget blend, (h) shaping, and (i) gluten-free nuggets before coating.

2.3. Formulations of liquid and dry coatings

Dry and liquid sauce formulations were based on the following seven blend ratios of rice to corn flours in percentages: 100% rice flour, 100% corn flour, 40:60, 30:70, 50:50, 60:40, and 70:30. Two levels of corn starch (5 and 15%), 0.3% MC, and/or 0.5% CMC, 2% xanthan gum, 2% sucrose, 2.5% salt, and 1% spice were also mixed in. All the mixture ingredients were in the powder form and used to yield a total of 28 liquid coating formulations whose codes are provided in Fig. 2

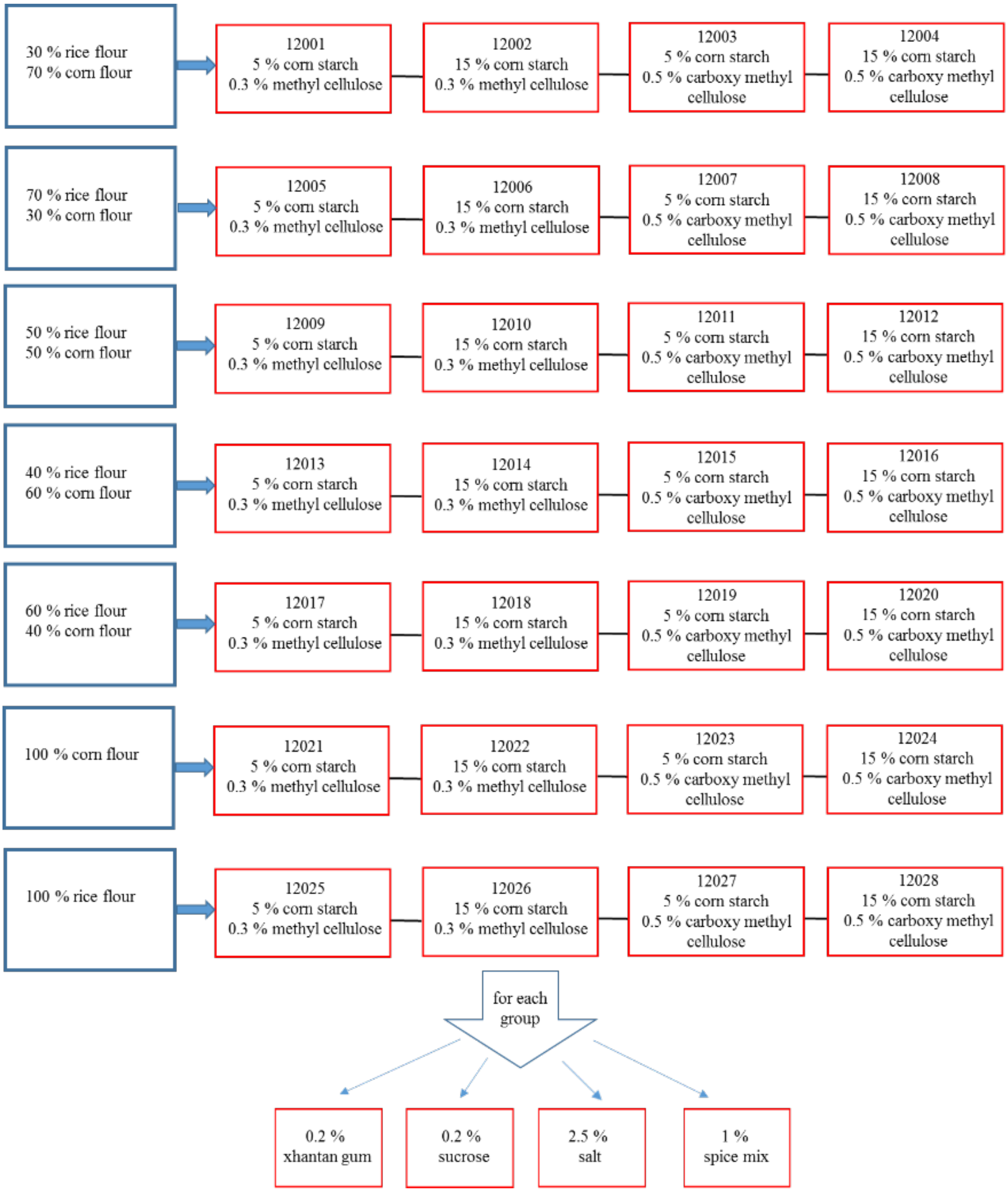

Figure 2. Formulations and codes of coatings used in this study.

Figure 3. Coating of gluten-free chicken nuggets with (a) batter, (b) batter preparation and mixing, (c) manual coating with batter, (d) manual coating with breader, and (e) coated gluten-free nuggets.

Once coated with the 28 liquid coating formulations (Fig. 3), the nuggets were manually coated with a dry sauce (Table 2) made up of the rice-to-corn flour blend of 50:50. After each formula was prepared and shaped, the liquid coating (batter) at the liquid coating-to-water ratio of 1:2, and then the dry coating (breader) were applied (Fig. 3).

Table 2. Formulations of gluten-free dry coatings.

Ingredients	Dry coating (%)
Rice flour	40
Corn flour	40
Yeast	3-5
Sugar	5-10
Salt	2-5
Sunflower oil	2-5
Emulsifier	< 2
Coloring agent	< 2

2.4. Frying, cooking, freezing and packaging of coated gluten-free chicken nuggets

Once coated, gluten-free chicken nuggets were fried (Bosch TFB3201 model fryer, Germany) at 180°C for 30 s using sunflower oil. Then, they were cooked in a steamed oven (CPS Cook Star, Holland) under the processing conditions of 4 min conveyor speed, 70% steam, 150°C oven temperature in order to reach 74°C at their coldest point. They were frozen inside a spiral freezer (CPS Tempo Frost, Holland) at -40°C and then packaged with 10 nuggets per package using Styrofoam plates and stretch films (Fig. 4).

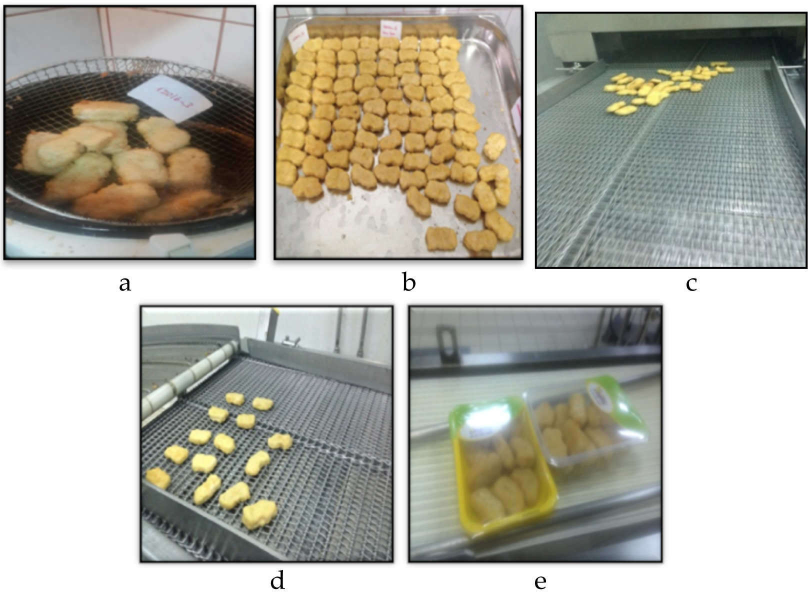

Figure 4. (a) Frying of gluten-free nuggets, (b) fried gluten-free nuggets, (c) feeding gluten-free nuggets to a steam oven, (d) feeding gluten free nuggets to a spiral freezer, and (e) packaging.

2.5. Selection of best coatings

Once produced, the coated gluten-free chicken nuggets were rested for a week to observe the integrity and homogeneity of the coatings. They were heated to detect whether or not nuggets retained their shape as well as there existed breakages for the coating layer. Based on the visual evaluations, 16 groups were eliminated, while the experiments were continued with the remaining 12 groups. Upon their sensory analyses, six groups out of 12 were selected. After the re-production of the six groups, the gluten analyses were performed. Although all had the gluten level below the legal limit of 20 mg/kg, three formulations with the lowest amounts of gluten out of six were selected.

2.6. Analyses of chemical composition and food quality

pH was measured after the homogenization of the mixture of 10 g samples with 100 mL distilled water by ultra turrax for 1 min (VURAL and OZTAN, 1996). Five g of the homogenous samples were taken into uniform containers and dried at 105°C until constant levels of weight and moisture (%) were reached. Their protein content was determined using the Kjeldahl method as a result of which N content (%) determined was multiplied by 6.25 to estimate protein fraction in % (AOAC, 2005).

The amount of fat in % was determined using the Soxhelet extraction by a gravimetric method. Three g of the homogenous samples were taken into a crucible, dried at 105°C for 4 h and then taken into an ash oven at 550°C until completely turning into grey-white ash. Ash (%) content was based on differences in weight before and after burning (AOAC, 2005). Gluten-free chicken nuggets were weighed before and after cooking to estimate product yield (%) (VERMA *et al*., 2012).

After the nuggets were cut into two pieces, the three color values of L^*, a^*, and b^* were measured from both their surface and inside. The measurements were performed using a colorimeter (CR 300, Minolta, Japan) with calibrated standards (reference no: 1353123, $Y = 92.7$, $x = 0.3133$, $y = 0.3193$). Gluten-free chicken nuggets were weighed before and after coating to estimate surface coating (%) (ALTUNAKAR, 2003).

Both raw and cooked gluten-free chicken nuggets were dried at 105ºC for 24 h, and their moisture retention (%) was estimated according to HUANG *et al.* (1999). Dried nugget samples at 105ºC for 24 h were taken to determine oil retention (%). First, the fat content of the nuggets was determined, and their oil retention was calculated according to HUANG *et al.* (1999).

Thiobarbituric acid reactive substances (TBARS) were determined after the centrifugation (Hermle Z326K, Germany) at 10000 rpm for 5 min of the homogenized mixture of 10 g samples and 30 mL tricloracetic acid (7.5%). The centrifuged samples were filtered, and 5 mL filtrated samples were mixed with 5 mL 0.02 mol/L TBA solution prepared with 0.1 N HCl. After being subjected to vortexing, the samples were placed into a water bath at 100 ◦C for 35 min. The tubes were cooled down immediately and read at 538 nm (Perkin Elmer UV/VIS Spectrophotometer Lambda 35, USA) against blank. Results were calculated using a tetraethoxypropane (TEP) standard curve expressed in malonaldehyde/kg (MIELNIK *et al*., 2006).

The amount of hexanal was determined using a gas chromatography mass spectroscopy (GC-MS), with the samples being transferred into headspace vials and held at 40°C for 10 min. After the insertion of carboxen/polidimetilsiloxano (CARB-PDMS) fiber of 85 μm in thickness as an adsorbent into vials for 40 min to adsorb volatile compounds, the fiber was injected into GC-MS (Hewlett Packard 7890 GC with HP 5975 MS detector) equipped with FID detector and kept waiting for 10 min to desorb all its compounds to GC-MS column (DB- 624, 30 m in length; 0.25 mm in internal diameter, and 1.4 μm in internal thickness). The GC-MS conditions consisted of 250°C injection block and detector temperature, 1 mL/min flow rate, 230°C MS source temperature, and 150°C MS quadrupole temperature. Helium was used as the carrier gas at a flow rate of 1 mL/min.

Oven temperature program was set initially at 40 ◦C for 5 min with the increases from 40 to 110°C, 110 to 150°C, and 150 to 210°C at rates of 3°C/min, 4°C/min, and 10°C/min, respectively, and held for 12 min at 210°C. The mass spectrum ranged from 41 to 400 m/z with 70 eV electron energy. Similarity of the compounds was determined using the Wiley and NIST libraries (KIRALAN, 2010).

The amount of gluten was determined using the ELISA method. After five g of the samples were grinded, 0.25 g were mixed with cocktail solution and incubated for 40 min at 50°C water bath. After cooling, 7.5 mL of 80% ethanol was added and mixed thoroughly. After a 10-min centrifugation, the samples were diluted at the ratio of 1:12.5 with the dilution solution and transferred into vials. After the addition of washing solution three times, 100 μL of conjugate were added. The samples were incubated for 30 min at room temperature, and after the addition of washing solution again, 50 mL of substrate and chromogen were added. Upon the subsequent incubation at room temperature for 30 min, 100 μL of stop solution were added, and results were read at 450 nm (AOAC, 2010).

The apparent viscosity of the liquid coating was measured under a constant shear rate of 120/s at 25°C using a CP4/40 SCO 111 SS probe (diameter: 40 mm; slit: 0.15 mm) (Malvern Instruments, Kinexus Pro). The temperature of the batter samples was maintained during measurements using a circulating water bath. The texture of the gluten-free chicken nuggets was measured using a conical 45° probe with a 50-kg loading cell (TA plus, LLOYD Instruments, A trademark of Ametek Inc). Speed was adjusted to 100 mm/min to press 50% of the 15-mm sample thickness. Hardness (N), cohesiveness, springiness (mm), gumminess (N mm), chewiness (N mm), stickiness (g), and force of shear (N) were measured. Using a Craft knife adaptor (50 mm x 0.6 mm) at 1.5 mm/s, the speed of cutting force was controlled (ULU, 2006).

2.7. Microbial analyses

Ten g of the samples were diluted with 0.1% peptone (Merck, Germany) water to prepare serial dilutions. 0.1 mL of appropriate dilutions were surface-plated onto plate count agar (PCA, Merck, Germany) to count both total mesophilic aerobic bacteria (TMAB) and total psychrotroph aerobic bacteria (TPAB). TMAB and TPAB plates were incubated at 37°C for 24 h and at ±2°C for 10 days, respectively (HALKMAN and SAGDAS, 2011).

One mL of the appropriate three consecutive dilutions was transferred into Fluorocult-Lauryl Sulfate Tryptose (FLST) broth test tubes (Merck, Germany) containing Durham tubes. The tubes were incubated at 37°C for 24 to 48 h for the count of coliform. Cloudy and gas-formed tubes were evaluated as coliform positive. Positive tubes were inspected at dark under the UV lamb at 366 nm and 1 mL of Kovac's reagent (Merck, Germany) was added to the tubes emitting fluorescence light. The tubes whose color turned dark red were evaluated as *Escherichia coli* positive. By using the MPN tables, the numbers of both coliform and *E. coli* were expressed in MPN/g (HALKMAN and SAGDAS, 2011).

Twenty-five g of samples were diluted with 225 mL of *Listeria* enrichment broth (Merck, Germany). After their incubation at 33°C for 4 h, a selective enrichment (Merck, Germany) was added, and their incubation was continued for an additional 44 h. The enriched culture was streaked onto Oxford agar plates (Merck, Germany) incubated at 37°C for 24 to 48 h. Suspected colonies were transferred to Tryptone Soya Yeast Extract (TSYE) agar (Merck, Germany). After their incubation at 37°C for 24 h, developed colonies were transferred to 1% rhamnose containing Phenol Red Broth Base (PRBB) agar (Merck, Germany) and blood agar (Merck, Germany) for the further identification of *Listeria* spp. (HALKMAN and SAGDAS, 2011).

For the determination of *Salmonella* spp, 25 g of the samples were mixed with 225 mL peptone water (1% w/v) and incubated at 37ºC for 24 h. After their incubation, 0.1 mL of the pre-enriched culture was transferred to Rappaport Vassiliadis Soya (RVS) broth (Merck, Germany) and incubated at 41.5ºC for 24 h. The selective enriched culture grown was streaked onto Xylose Lysine Deoxycholate (XLD) agar plates (Merck, Germany) incubated at 37ºC for 24 h. Typical colonies were identified on Triple Sugar Iron (TSI) agar (Merck, Germany).

2.8. Sensory analyses

Sensory analyses of the frozen gluten-free chicken nuggets coated were conducted in the Sensory Analyses Lab of the Department of Food Engineering of Ankara University, Turkey. Sensory panel was formed using eight panelists professionally trained from the faculties and graduate students of the Department of Food Engineering. The samples were assigned to 3-digit numbers randomly and served to panelists. Each sample was evaluated for appearance, color, taste, aroma, texture, and overall acceptability on a 9-point hedonic scale with 1 being extremely bad and 9 extremely good (JACKSON *et al*., 2006).

2.9. Statistical data analyses

Significant differences among group means were determined using Tukey's multiple comparison tests following one-way analysis of variance (ANOVA) at $p < 0.05$. Data analyses were performed using MINITAB 17 (Minitab Inc. State College, PA, USA).

3. RESULTS AND DISCUSSION

3.1. Selection of the best batch of coatings

The selection of the best coating formulations for the gluten-free chicken nuggets was based on appearance and sensory properties, since some coatings lacked good adhesion properties after freezing, and reheating in microwave oven. In particular, the coatings with 100% rice or corn flour exhibited big cracks as well as uncovered or unevenly covered surfaces. The microwave heating resulted in burns and dissimilar color developments on some surfaces. Shrinkage and hardening were also observed for some coatings (Figs. 5a-d).

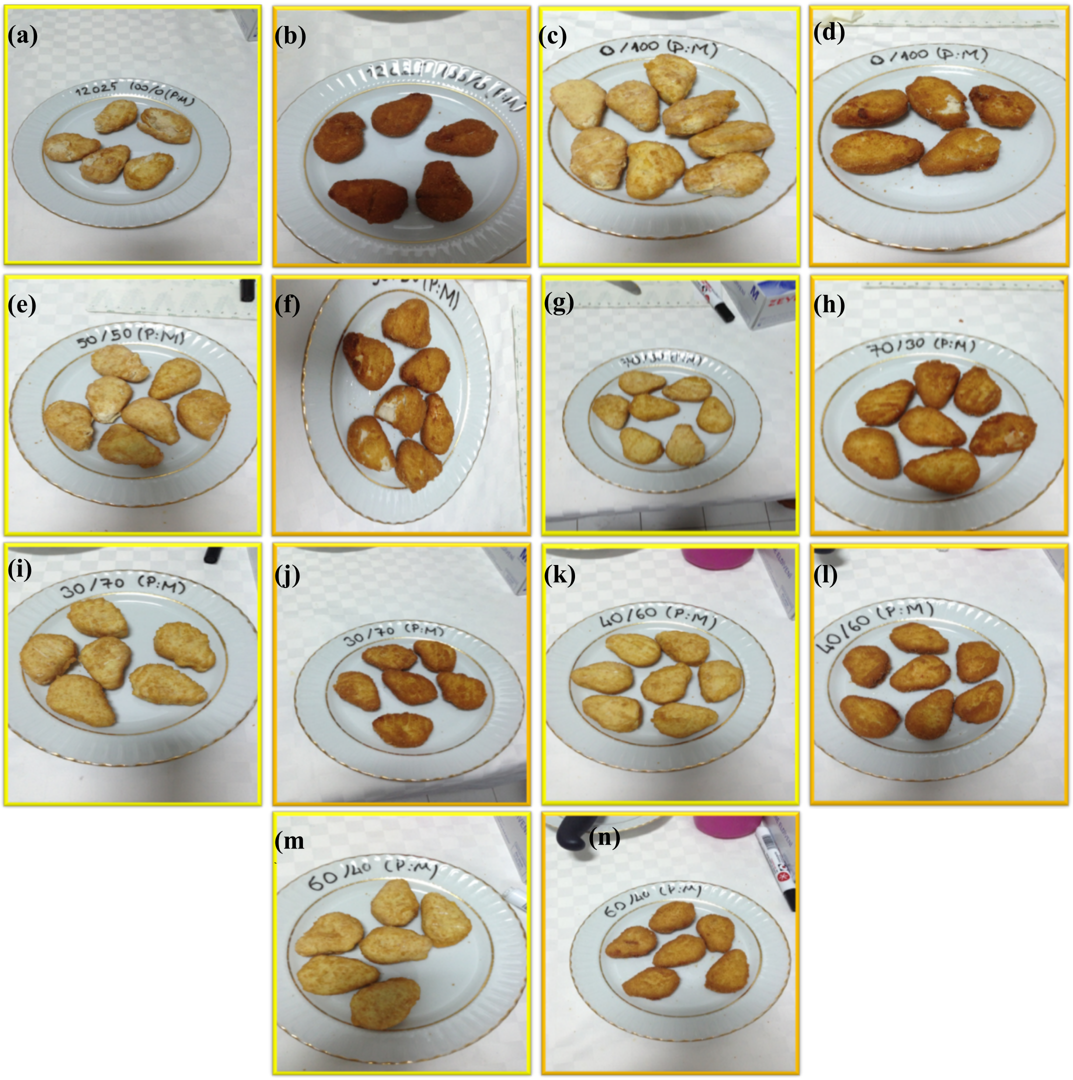

Figure 5. Frozen and fried gluten-free chicken nuggets coated with (a and b) 100% rice flour (R), (c and d) 100% corn flour (C), and R-to-C blend ratios (%) of (e and f) 50:50, (g and h) 70:30, (i and j) 30:70, (k and l) 40:60, and (m and n) 60:40.

The 50:50 blend ratio suffered, to a lesser extent, from non-homogenous coatings, cracking, the disintegration of coating, outpouring, and local burning due to heating (Figs. 5e-f). The 70:30 blend ratio led to a more homogenous coating, but the nuggets became very hard in terms of their texture and lost their elasticity (Figs. 5g-h). The other three rice-corn blend ratios (30:70, 40:60, and 60:40) induced a more homogenous coating after freezing, with no disintegration and outpouring (Figs. 5i-n). These blend ratios were used in the remaining experiments with the 12 groups.

3.2. Microbial properties

Prior to the sensory analyses on a 9-point hedonic scale, the 12 coating formulations of the gluten-free chicken nuggets (coded as 12001 to 12004, and 12013 to 12020) were tested for the presence of TMAB, TPAB, and the three pathogen bacteria (coliform, *E. coli*, *L. monocytogenes* and *Samonellae* spp). The numbers of TMAB and TPAB were all below < 1 cfu/g, with no detection of the pathogen bacteria.

3.3. Sensory properties

Based on the sensory analyses, the scores ranged from 5.80 to 7.80 for appearance, 5.40 to 7.80 for color, 5.80 to 7.80 for taste, 5.8 to 7.6 for aroma, 4.40 to 7.20 for texture, and 5.60 to 7.40 for overall acceptability. The CMC-containing formulations (12004, 12015, 12016, 12019 and 12020) were rated higher than the MC-containing groups in terms of the sensory scores, in particular, for the textural properties (Fig. 6). Therefore, the MC-containing formulations were further eliminated after the sensory analyses.

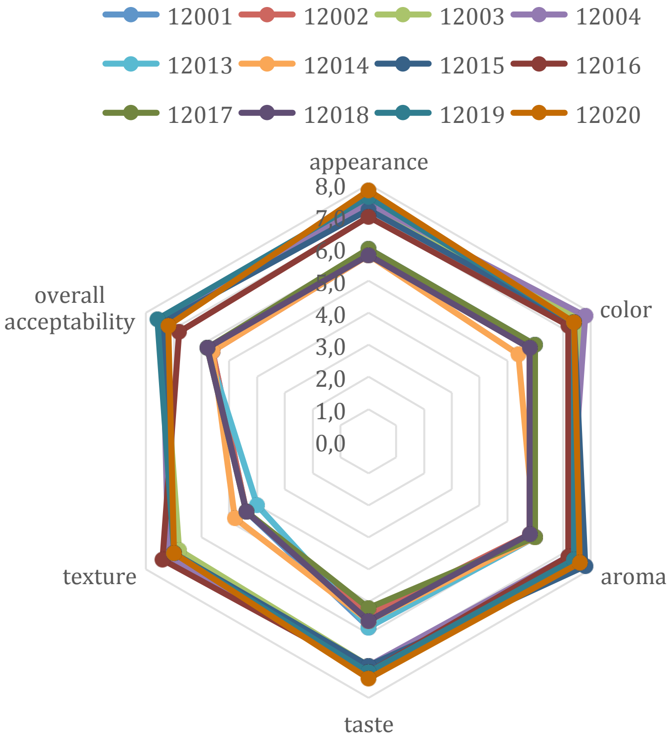

Figure 6. Sensory analyses of gluten-free chicken nuggets coated with three blend ratios of rice (R) to corn (C) flour (12001 = 30:70, 5% CS, 0.3% MC; 12002 = 30:70, 15% CS, 0.3% MC; 12003 = 30:70, 5% CS, 0.5% CMC; 12004 = 30:70, 15% CS, 0.5% CMC; 12013 = 40:60, 5% CS, 0.3% MC; 12014 = 40:60, 15% CS, 0.3% MC; 12015 = 40:60, 5% CS, 0.5% CMC; 12016 = 40:60, 15% CS, 0.5% CMC; 12017 = 60:40, 5% CS, 0.3% MC; 12018 = 60:40, 15% CS, 0.3% MC; 12019 = 60:40, 5% CS, 0.5% CMC; and 12020 = 60:40, 15% CS, 0.5% CMC).

3.4. Quality properties

The gluten contents of the six CMC-containing groups varied between < 3 and 27.78 mg/kg (Table 3). According to The Commission of the European Communities Regulation No 41/2009 issued on January 20, 2009, the final food products labeled with "very low gluten content" should have the gluten level of below 100 mg/kg, while foods labeled "gluten-free" should contain no more than 20 mg/kg (THOMPSON, 2018). Thus, the three formulas (12004, 12015 and 12016 with 0.5% CMC) with the lowest amounts of gluten out of six were selected for the further studies.

Table 3. Gluten contents of six coatings with carboxy methyl cellulose (CMC) for chicken nuggets.

Sample codes	Gluten (mg/kg)
12003	16.18
12004	< 3
12015	7.9
12016	< 3
12019	27.78
12020	18.33

12003 = 30:70 R/C flour, 5% CS; 12004 = 30:70 R/C flour, 15% CS; 12015 = 40:60 R/C flour, 5% CS; 12016 = 40:60 R/C flour, 15% CS; 12019 = 60:40 R/C flour, 5% CS; and 12020 = 60:40 R/C flour, 15% CS.

The chemical composition analyses of the final three products revealed similar values of pH, moisture, fat, ash, protein, and viscosity ($p > 0.05$) (Table 4). DEMIROK (2014) estimated the ranges of the moisture, fat, ash and protein contents, and pH of the commercially-available chicken nuggets in the Turkish market at 38.37 to 57.79%, 13.16 to 22.60%, 2.01 to 2.59%, 14.94 to 18.75%, and 6.03 to 6.17, respectively. The gluten-free chicken nugget formulations in the present study had lower fat and ash contents than the commercial products. The lower fat content may be attributed to less oil absorbance by the corn-and-rice-based gluten-free coating than the wheat-based coating during frying. The lower ash content may be the result of differences between our and commercial formulations.

Table 4. Chemical compositions of coated gluten-free chicken nuggets ($n = 3$).

Sample codes	Moisture (%)	Fat (%)	Ash (%)	Protein (%)	pH	Viscosity (Pa.s)
12004	59.75±1.45	9.07±0.03	1.37±0.01	14.76±0.32	6.21±0.02	3.13±0.02
12015	60.70±0.83	9.20±0.06	1.38±0.01	14.80±0.68	6.19±0.01	2.73±0.03
12016	60.73±1.22	9.16±0.05	1.37±0.01	14.85±0.55	6.21±0.03	3.36±0.04

12004 = 30:70 R/C flour, 15 % CS; 12015 = 40:60 R/C flour, 5 % CS; and 12016 = 40:60 R/C flour, 15 % CS.

XUE and NGADI (2007) estimated the viscosity of liquid coating formulated with 100% wheat, corn and rice flours at 5.44, 3.25 and 3.49 Pa.s, respectively. The viscosity values of liquid coatings formulated with soy and rice flours were reported as 4.43 and 3.52 Pa.s, respectively (DOGAN *et al.*, 2005). The viscosity values of the final three formulations

(12004, 12015, and 12016) in the present study were similar to those of the corn and rice flour-based formulations but lower than those of the wheat flour-based formulations by DOGAN *et al.* (2005), and XUE and NGADI (2007).

The surface coatings (%) of the final three formulations were between 26.29±2.46 and 25.17±3.30% ($p > 0.05$). The coating ingredients are directly related to viscosity, adhesion, and oil absorption during frying (ERGEZER *et al.*, 2008; CHEN *et al.*, 2008). The surface coating of the commercially-available formulations changed from 25.27 to 36.13% similar to that of our gluten-free formulations. The surface coatings based on the wheat, corn, rye and soy flours were found to range from 11.53 to 14.28%, with the rye flour with the highest value (GOKCE *et al.*, 2016). DOGAN *et al.* (2005) found that the 5% soy flour led to the highest surface coating when compared to the wheat and 5% rice flours.

Gums were observed to enhance the surface coatings of the fish nuggets with the wheat and corn flours (Chen *et al.*, 2009). According to Albert *et al.* (2009), the use of oxidized starch, xanthan gum, and hydroxyl methyl cellulose instead of flour did not increase the coating ability of the fish nuggets. The gluten-free coatings developed in the present study appeared to have a better surface coating ability than the other formulas reported in the related literature. Also, the addition of both CMC and xanthan gum in this study increased the coating ability and viscosity.

The product yield is a good indicator of the coating ability and rises with the increased economic value of a given product (ALTUNAR *et al.*, 2004). The product yields of the final three formulations (12004, 12015, and 12016) were determined as 97.83±3.44, 96.78±4.12, and 98.82±3.26%, respectively ($p > 0.05$). ALTUNAR *et al.* (2004) stated that pre-jelatinized tapioca starch relative to amylo corn and waxy ones had the highest product yield for deep-fat fried chicken nuggets. DEVATKAL *et al.* (2011) pointed out that the risen amount of sorghum flour elevated the product yield (94.99%) of the gluten-free chicken nuggets. JEN *et al.* (1999) found that the sorghum flour enabled the formation of a three dimensional structure between starch and plant-based protein, thus boosting the emulsion stability and product yield.

The 5 and 10% oat flours significantly grew the product yields of the low-fat chicken nuggets (SANTHI and KALAIKANNAN, 2014). The product yield of the gluten-free chicken nuggets in the present study was higher than that of the sorghum-added ones and close to that of the oat-added ones. GOKCE *et al.* (2016) found that the corn and soy flours had the highest and lowest product yields of the chicken nuggets (82.64 and 78.10%), respectively, among the wheat, corn, rye and soy flours. These findings were attributed to the formation of a film layer on the coated surface by the high content of gelatinized starch without which the soy flour had the low product yield (GOKCE *et al.*, 2016).

The moisture and oil retentions are the important quality parameters of plant-based flours as affecting the sensory and textural properties (KUMAR and SHARMA 2004). Depending on the rise of temperature inside a given product during frying, water that fills the pores is evaporated whose places are replaced by oil. The moisture retentions of the final coatings (12004, 12015, and 12016) were estimated at 69.22±4.22%, 67.25±3.12%, and 71.28±5.47%, while their oil retentions were 59.57±3.06%, 57.21±4.01%, and 59.12±4.46%, respectively ($p > 0.05$). The higher moisture than oil retention values appeared to stem from hydrocolloids and xanthan gum immersing less oil than did the wheat flour, as SANZ *et al.* (2004) also indicated. The oil retention of meat balls was estimated at 53.69, 52.39 and 50.21% when produced with the 2, 4 and 6% sorghum flours, respectively (Huang *et al.*, 1999). DEMIROK (2014) estimated the fat contents of chicken nuggets at 11.62, 16.35 and 16.71% in response to cooking in steam-assisted oven, frying, and frying after microwave-assisted defrosting, respectively. Similarly, SHIH and DAIGLE (1999) reported that the rice-based coatings absorbed less oil during frying due to its chemical structure.

The high concentrations of TBARS indicate the presence of lipid oxidation compounds such as aldehyde, carbonyl, and hydrocarbones responsible for the spoilage of meat and meat products (AL-KUTBY, 2012; CAGDAS and KUMCUOGLU, 2015). In general, the products with below 3 mg MDA/kg TBARS are considered to be in good quality in terms of lipid oxidation (CADUN *et al.*, 2008). The TBARS values in the present study were 0.17±0.07, 0.17±0.06, and 0.08±0.02 mg MDA/kg for 12004, 12015, and 12016, respectively ($p < 0.05$).

The hexanal concentration can be used as a quality indicator, in particular, for the stored products (MIELNIK *et al.*, 2006). PIGNOLI *et al.* (2009) reported that the hexanal concentration changed during storage due to its reduced volatility as a result of its reactions with proteins. The hexanal concentrations were estimated at 161±23, 330±49, and 213±38 (x 10^6 AU) for 12004, 12015, and 12016, respectively ($p < 0.05$).

Although no significant difference among the three formulas was found in the inner or outer color values, the L^*, a^* and b^* values of the inner surface were significantly higher those of the outer surface ($p < 0.05$). The gluten-free chicken nuggets in the present study had slightly high L^* but similar a^* and b^* values than did the commercial chicken nuggets (64.38 to 68.41, 1.41 to 3.51, and 16.46 to 19.35, respectively) (LUKMAN *et al.*, 2009). Turkey nuggets coated with corn flour had higher L^* (56.6) and b^* (42.3) values due to their carotenoid coloring pigments, while those coated with rice flour had lower L^* (38.5) and b^* (31.0) values than did those coated with wheat or soy flour (JUKIC *et al.*, 2011). The deep-fat frying of the chicken nuggets with the wheat, corn, rye and soy flours was reported to generate the L^* values in the range of 28.79 to 39.16 with the lightest and darkest values from wheat and soy flours, respectively (GOKCE *et al.*, 2016). JACKSON *et al.* (2009) revealed that the L^* value of nuggets were not affected by the wheat versus rice flour but by the cooking type. The lower L^* value of the fried nuggets in the present study was consistent with the finding by JACKSON *et al.* (2006) that the color of the fried nuggets grew darker. SOSA *et al.* (2006) also observed a darker color with the deep-fat frying of nuggets, tofus, and doughnuts. The L^* and a^* values of chicken nuggets with 5% and 10% sorghum flours were reported to decrease (DEVATKAL *et al.*, 2011). DYKES and ROONEY (2006) found that the sorghum flour-based coatings resulted in darker nuggets than did the wheat flour ones due to their anthocyanin and tannin contents. The a^* value of the sorghum flour coating was lower than that of the regular coating for beef meatballs (VAN ZYL and SETSER, 2001).

3.5. Textural properties

No significant difference in the textural properties was found among the best three gluten-free coatings of the chicken nuggets (Table 5).

Table 5. Textural properties of the best three gluten-free coatings of chicken nuggets.

Textural properties	12004	12015	12016
Hardness (N)	51.23±6.50	43.00±12.10	53.24±6.45
Cohesiveness	0.55±0.06	0.65±0.00	0.61±0.01
Springiness (mm)	0.74±0.02	0.67±0.12	0.76±0,02
Gumminess (N mm)	27.17±6.99	26.54±9.37	33.09±4.45
Chewiness (N mm)	20.57±5.93	20.87±8.04	21.54±4.11
Stickiness (g)	-0.004±0.002	-0.009±0.005	-0.005±0.001
Force of shear (N)	12.42±0.77	11.01±1.37	13.18±0.42

The textural properties in this study were similar to those of the commercial chicken nuggets (LUKMAN *et al.*, 2009). DEMIROK (2014) quantified the hardness, springiness, gumminess, chewiness, and stickiness values of the commercial chicken nuggets in the ranges of 2.59 to 5.05 N, 4.59 to 6.14 mm, 0.91 to 2.46 N mm, 5.56 to 11.53 N mm, and 0.01 to 0.08 g respectively.

The substitution of the wheat flour with the corn, soy, rice, soy/corn or rice/corn flours in coating turkey nuggets showed that the corn/soy flour had the highest hardness value (JUKIC *et al.*, 2011). The reformulated nuggets had the higher hardness value with the rice than wheat flour (JACKSON *et al.*, 2006). The chicken nuggets coated with the wheat and 5% and 10% sorghum flours did not differ in terms of hardness, with higher chewiness and gumminess for the 10% sorghum than wheat and 5% sorghum flours, and lower springiness for the 10% sorghum flour (DEVATKAL *et al.*, 2011). The rye flour-coated chicken nuggets were found to be softest, while the soy and corn flour-coated ones had a similar hardness value (GOKCE *et al.*, 2016).

4. CONCLUSIONS

The development of the gluten-free coatings for the chicken nuggets is of great importance to people with gluten intolerance. The replacement of the wheat flour by the gluten-free coatings developed in this study for the chicken nuggets enhanced their physical, sensory and textural properties. Given the similarity between the reformulated and commercial products, the gluten-free chicken nuggets performed well even after freezing and thawing. Further studies are needed to compare their shelf-life stability to the commercial products' one

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