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RESEARCH ARTICLE

Mechanically deboned poultry meat and brewer's processing by-product as promising ingredients for nutritionally valuable extruded snacks

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ABSTRACT

Functional food is evolving constantly, trying to satisfy everyday needs for macro and micronutrients. Protein-rich food is highly demanded, due to protein's structural role in tissue formation, cell reparation, and hormone and enzyme production. Extruded products prepared of cornmeal, mechanically deboned poultry meat (MDPM) and brewer's spent grain (BSG) were evaluated for their nutritional and physical properties. Addition of BSG and increase of MDPM share in the blend, resulted in significantly ($p<0.05$) better nutritional characteristics of obtained snacks, giving products with 14.4% and 12.0% protein content. BSG had significant ($p<0.05$) influence on extrudates' physical properties: lateral expansion has dropped, (89.17% vs. 51.79%), length has increased (12.4 mm vs. 18 mm),while lower values of hardness and firmness of extrudates were registered as well. Also, incorporation of this brewing industry by-product in combination with a higher share of MDPM resulted in significantly ($p<0.05$) darker products. The results of this study showed that BSG and MDPM are perspective ingredients for nutritionally valuable ready-to-eat extruded products, but additional investigation is needed in order to optimise processing parameters and quality of obtained meat snacks

Keywords: Brewer's spent grain; By-product utilization; Extrusion; Mechanically deboned poultry meat; Snacks

INTRODUCTION

Due to today's life habits and opportunities, such as: increased number of one-person households, more women working, increased working hours, highly mobile population, variable family eating time, convenience food trend has been in expansion . Snack food is one of the main representatives of convenience food, and usually illustrates energy-dense, nutrient-poor foods high in sodium, sugar, and/or fat, consumed between regular meals (Guy, 2001; Younginer et al., 2016). Furthermore, there is consistent increase in frequency of snacking by US children, with the largest increases in salty snacks and candies (Piernas and Popkin, 2010). Convenient food together with snacking has been recognized between the top 10 food trends for 2019 and 2020 by an Innova market research survey (Ridler, 2018; Wiley,2019). On the other hand, studies conducted last few decades point out that people are taking greater responsibility for their own health and are becoming aware of diet contribution to health. To overcome this problem food science and industry aim to develop a different kind of convenience functional food rich in macro and micronutrients that will fulfil diet needs. One possible form of convenience functional food could be extruded snack products since they are easy-to-handle, prepared and already often consumed. These circumstances are forcing snack industry to constantly develop and rise, what is confirmed by fact that its worldwide revenue accounts for roughly 4% of the global Food market and it is expected to increase significantly by 2023 (Food Report, 2019; Hess et al., 2016;).

Cereal flour and/or starches are the most utilized ingredients for commercial snack products. Therefore, most of snack product have are characterized by nutritional density and lack of some essential amino acids. Thus, improvement of

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extruded products and finding new alternative ingredients are critical for further progress of snack food industry. Due to increased popularity of the high-protein diets, snacks rich in protein are gaining in value on the market. Therefore, many researchers investigate possibilities to increase the nutritional value of snack products by adding either animal-based protein sources (Cunningham et al., 1993; Rhee et al., 1999; Lee et al., 2003; Cho and Rizvi, 2010; Verma et al., 2014; Cakmak et al., 2016) or plant-based protein sources (Ainsworth et al., 2007; Stojceska et al., 2008; Ktenioudaki et al., 2012; Paraman et al., 2012; Obradović et al., 2015; Jangchud et al., 2018). Furthermore, some researchers suggested that microalgae (Joshi et al., 2014; Lucas et al., 2018) and insects (Azzollini et al., 2018) could become promising high-protein starch substituent.

Most studies have relied on the addition of one functional ingredient, while in our research we examined the possibility of implementation of two protein-rich constituents. Brewer's spent grain (BSG) is a nutritionally valuable by-product of the brewing industry. Its disposal is a common environmental problem, hence it is important to investigate possibility to reuse it. It is considered as a lignocellulosic material rich in protein (20%) and fibre (70%), containing about 17% cellulose, 28% noncellulosic polysaccharides, chiefly arabinoxylans and 28% lignin. Due to its high content in proteins, vitamins and fibre, BSG is a promising ingredient to be used in human nutrition (Mussatto et al., 2006). Since plant-based proteins do not hold all essential amino acids (Lawrie and Ledward, 2006), it is important to incorporate animal proteins in snack products. Mechanically deboned poultry meat (MDPM) is a low-cost turkey and/or chicken product, rich in proteins and other nutrients, produced by mechanical separation of a bone and attached skeletal muscle (Froning and Mckee, 2001). MDPM is a preferable choice because of higher protein content and lower fat content, as well as lower price compared to beef and pork. Cunningham et al. (1993) recommend MDPM as a meat source in extruded products and Ray et al. (1996) concluded that the least energy was consumed for extrusion of dough containing MDPM, as a meat source.

Extrusion technology is a complex process consisting of continuous mixing, kneading, cooking, shearing, forming, and/or puffing of the material (Navale et al., 2015; Riaz, 2000). Due to a process short time, many heat-sensitive components, as vitamins and essential amino acids retain in the snack (Fellows, 2000; Riaz, 2000). Other advantages of extrusion are: low energy consumption, high productivity and automated operation. High temperatures and intensive pressure drop, developed during extrusion, reduce the number of microorganisms and inactivate lipases and lipoxidase. Hence, extrusion prevents microbial contamination and lipid oxidation, and thus it extends storage time of food (Navale et al., 2015).

The primary objective of this study was to investigate how the addition of BSG (20%) and increase of MDPM share influenced chemical, physical and textural properties of extruded meat snacks.

MATERIAL AND METHODS

Materials

BSG of 75% moisture content, 4.8% of proteins, 2.1% of fat and 16% of carbohydrates was kindly provided by Razbeerbriga brewery (Bukovac, Serbia). It was dried in convection dryer at 120°C for 4h to meet the target moisture level of 5.0%. Dried BSG was finely milled in a hammer mill (ABC Inženjering, Serbia) equipped with 1mm sieve, and final product had protein, fat and carbohydrates content of 17.45%, 4.65% and 67.60%, respectively. MDPM was courtesy of Perutina Ptuj - Topiko doo (Bačka Topola, Serbia). It consisted of 70.08% of moisture, 18.44% of proteins and 9.99% of fat. Cornmeal of 12.9% moisture, 6.11% protein and 1.24% fat content was obtained from Mirotin Tisa (Savino selo, Serbia). Salt and red paprika powder were purchased from the local store.

Sample preparation

The cornmeal, BSG, MDPM, salt and paprika were mixed in appropriate ratio, given in Table 1. All ingredients were weighed and mixed in bowl cutter SMZ 20/82 (Alexanderwerk, Germany) until a homogenous mixture was obtained. The samples were extruded immediately after mixing.

Extrusion processing

A Bühler co-rotating twin-screw extruder (model BTSK-30, Buhler, Uzwil, Switzerland) with L/D ratio of 28:1 and screw configuration as in the study of Kojić et al. (2018), specially designed for the production of directly expanded snack products, was used. Total length of the extruder barrel, consisting of 7 sections, was 880 mm. The extruder was equipped with two tempering tools, used to control barrel temperature. A die plate with one opening of 4 mm diameter and with cone inlet was utilized.

The extrusion was carried out at screw speed of 800 rpm with the feed rate of 35kg/h. Water temperature in heating/cooling jacket of extruder barrel's sections 2-4 and 6-7 was set at 100°C and 120°C, respectively. The starting moisture content of the material was determined using rapid moisture analyser (model HE53, Mettler Tolledo, USA). Targeted moisture content in the barrel was 25% w/w and it was achieved by water addition at the end of section 1 via pump. For achieving the final length

Table 1: Raw blends of samples

Sample	BSG (g/100g)	MDPM (g/100g)	Cornmeal (g/100g)	Salt (g/100g)	Paprika (g/100g)
0-0	0	0	98	1.5	0.5
0-10	0	10	88	1.5	0.5
0-20	0	20	78	1.5	0.5
0-30	0	30	68	1.5	0.5
20-0	20	0	78	1.5	0.5
20-10	20	10	68	1.5	0.5
20-20	20	20	58	1.5	0.5
20-30	20	30	48	1.5	0.5

of the product, the cutter was fitted at the outlet of the extruder with six knives rotating with a constant speed of 300 rpm. The output extrusion parameters temperature at the die, pressure at the die, torque and specific mechanical energy (SME) were directly read from the PLC screen of the extruder.

Physico-chemical and colour analysis

Protein (ISO 937, 1978), total fat (ISO 1443, 1973) and moisture (ISO 1442, 1997) contents of MDPM, blends and extrudates were determined according to methods recommended by International Organization for Standardization. Protein, total fat and moisture contents of BSG and cornmeal were acquired using appropriate AOAC (2019) methods.

The diameter and the length of the extrudates were measured using a calliper (MIB Messzeuge GmbH, Spangenberg, Germany). Lateral expansion (LE, %) was calculated using the equation below:

$$LE = \frac{d_e - d_d}{d_d} * 100(\%) \qquad \text{Eq.1}$$

where d_e was mean diameter of 15 replicates and d_d was the diameter of die hole.

Bulk density (BD) of extruded snacks was determined using bulk density tester (Tonindustrie, West und Goslar, Germany). All measurements were repeated three times.

Density of samples was measured by analytical balance MS204S (Zurich, Switzerland) equipped with a density kit ML-DNY-43 (Zurich, Switzerland), using ten random snack pieces. The sample was weighed in air and in distilled water, and the density was calculated using the equation below:

$$\rho = \frac{\mathrm{A}}{\mathrm{A}-\mathrm{B}} \cdot (\rho_{\mathrm{L}} - \rho_0) + \rho_0 \qquad \text{Eq.2}$$

where *A* and *B* are the weighs measured in air and distilled water, respectively; ϱ, ϱ_L, and ϱ_0 are densities of extrudate, air and distilled water, respectively. All measurements were carried out at the temperature of 23°C.

After gridding the samples to fine powder, the colour was measured using the MINOLTA Chroma Meter CR-400 (Minolta Co., Ltd., Osaka Japan) applying D-65 lighting, a 2° standard observer angle and an 8-mm aperture in the measuring head. Colour of the samples was measured five times, and it was denoted by three dimensions, CIE L^*, CIE a^* and CIE b^*. L^* values vary from zero (black) to 100 (white) indicating lightness, while positive values of a^* and b^* colour coordinates represent redness and yellowness, respectively.

Texture analysis was performed at room temperature by TA.XT2 Texture Analyser (Texture Technologies Corp., Scarsdale, NY/Stable MicroSystems, Godalming UK). Means of the measurement were discussed. Hardness of the sample was measured using the method of *Compression test* given in the work of Paula and Conti-Silva (2014). Firmness was measured using Warner-Bratzler V-shaped cutting blade having the same measurement conditions likewise in *Cut test* described by Paula and Conti-Silva (2014). The values of firmness were obtained as the highest pick value of curve obtained during Warner-Bratzler test. The measurements of each sample were done in 15 replicates.

Statistical analysis

The effect of BSG and MDPM addition on the variables were analysed by two-way ANOVA and the differences between the mean values were evaluated using Duncan's post hoc test with a significance level of 95% ($P<0.05$). The effect of fat in mixtures on the SME was evaluated using correlation test. The tests were performed by Statistica version 13 (TIBCO SoftwereInc, 2017).

RESULTS AND DISCUSSION

Process parameters

Table 2 presents extrusion process parameters. As it can be seen, the process conditions were adjusted to be the same for all the mixtures. However, the samples with added BSG had lower SME values. Since in this work screw speed and throughput were constant, torque was the main parameter influencing SME. Previous research suggested that the lubricating effect of fat during extrusion reduces the frictional torque and therefore the mechanical energy input (Ilo et al., 2000; Moraru and Kokini, 2003). Negative correlation between mixtures fat content and SME (r = -0.7) determined in this study confirmed previous findings. Mixtures containing BSG had higher fat content, which probably contributed to the lower SME values. Having in mind that SME represents the energy generated by friction caused by the move of dough in the extruder, extrusion process carried out with mixtures containing BSG is more economical.

Proximate analysis

The effects of BSG addition and share of MDPM on proximate composition of extrudates are presented in Table 3. Protein content varied from 5.90% for 0-0 sample to 14.44% for 20-30sample, while fat content ranged from 0.68% to 3.64%, respectively. Significant differences (p<0.05) were observed in fat and protein content between all formulations. Protein and fat content increased with the addition of BSG and MDPM. This leads to the statement that BSG and MDPM were main sources of proteins and fat in mixtures what could be anticipated based on their proximate analysis. Statistical analysis confirmed this suggestion showing that both, MDPM and BSG had a significant influence (p<0.05) on protein and fat content. The samples containing BSG showed significantly higher values (p<0.05) of protein and fat content than their counterparts without BSG.

However, snacks obtained during this research had higher protein content and lower fat content compared to popular snack products, such as: potato chips, crackers and other commercially available high-energy savoury snacks (Jumpretz et al., 2013). Jumpretz et al. (2013) have reported that most of these popular snacks have fat content around 28%, and protein content around 6-7%. Snack products produced during this research had the highest fat content of 3.64% (sample 20-30), being almost eightfold less than the fat content of commercial snack products. Fat contents of other samples were less than 3%, conforming EU criteria (EU, 2020) for nutrition claim "*low fat*".

Moreover, 13.65% of total energy value of sample 20-30 is gained by protein. Thus, this sample satisfies EU requirement considering the minimal part of the energy value provided by protein (12%) (EU 2020) and could contain nutrition claim "*source of protein*". Due to high protein content, reaching 14.44% these snacks could help in prevention of protein-energy malnutrition, which mostly affects the children (Institute of Medicine, 2006). Recommended Dietary Allowance of protein is 0.8g per kg body weight per day. Hence, the 50g portion of the 20-30 sample-snack can satisfy almost 50% protein requirement of children age 6, having an average bodyweight of 20kg (Disabled world, 2019).

Since produced extrudates are composed of cornmeal and do not contain wheat flour, these products could be declared as gluten-free snacks as well.

Lateral expansion, bulk density, density and length of extrudates

Consumer acceptability of snack products is highly influenced by their attractive appearance and texture

Table 2: Process conditions during extrusion

Sample	Screw speed (rpm)	Torque[a] (Nm)	Temperature[b] (°C)	Pressure (bar)	Moisture[c] (%)	Water capacity (kg/h)	Moisture[d] (%)	SME (kWh/kg)
0-0	800	72.6	129	0.6	11.7	6.2	25.0	109.8
0-10	800	55.0	135	0.8	14.8	4.7	24.9	88.8
0-20	800	52.8	127	0.8	19.8	2.3	24.8	87.5
0-30	800	52.8	131	0.7	25.6	0	25.6	94.0
20-0	800	63.8	134	0.6	10.4	6.5	24.4	100.9
20-10	800	46.2	129	0.8	13.3	5.3	24.7	72.9
20-20	800	39.6	124	0.8	19.3	2.6	24.9	66.9
20-30	800	39.6	126	0.9	24.7	0	24.7	71.8

[a]Motor load, 100% torque is 220 Nm. [b]Measured by sensors located at the die of extruder barrel. [c]Moisture content of mixture before extrusion determined by rapid moisture analyzer. [d]Total moisture content during extrusion calculated based on moisture content of the material, material throughput and water throughput in the extruder barrel.

Table 3: Proximate analysis of extrudates

		0% MDPM	10% MDPM	20% MDPM	30% MDPM	BSG	MDPM	BSG x MDPM
Protein content (%)	0% BSG	5.90±0.03[a]	8.20±0.03[b]	9.95±0.06[d]	11.09±0.08[f]	*	*	*
	20% BSG	9.41±0.09[c]	10.34±0.13[e]	12.00±0.02[g]	14.44 ±0.05[h]			
Fat content (%)	0% BSG	0.68±0.02[a]	1.12±0.01[b]	1.31±0.02[c]	1.93±0.03[e]	*	*	*
	20% BSG	1.16±0.02[b]	1.52±0.01[d]	2.16±0.02[f]	3.64±0.02[g]			

Values bearing the different superscript letters within the same characteristic raw are significantly different from each other, P< 0.05,ns - not significant ,*P<0.05

(Anton et al., 2008), which are directly related to physical properties of extrudates. Physical properties of produced extruded products are presented in Table 4. LE significantly ($p<0.05$) diminished with the addition of BSG. This is in line with previously published results demonstrating that BSG has a negative effect on LE (Ainsworth et al., 2007; Stojceska et al., 2008; Stojceska et al., 2009). One explanation could be that increased fat content reduced the expansion of extrudate due to insufficient pressure during extrusion (Navale et al., 2015). Furthermore, fat content could impede water adsorption of starch, and thus starch could not be properly gelatinized (De Pilli et al., 2008). Also, the addition of BSG led to an increase in protein content. This is notable since Philipp et al. (2017) previously showed that blends with higher protein share resulted in poorer expansion. Another limitation of expansion is fact that the addition of BSG resulted in less starch in mixture, which is the ingredient most responsible for puffing of the snack (Ainsworth et al., 2007). Statistical analysis demonstrated that the addition of MDPM also had a significant influence ($p<0.05$) on LE. However, results showing scattered data are not in compliance with literature which suggests that increase of meat level in flour snacks causes a decrease of expansion (Lee et al., 2003).

Length of extrudates was also influenced by the addition of both, BSG and MDPM. Incorporation of BSG had a significant positive effect ($p<0.05$) on length of extrudates, while MDPM contribution was opposite (Table 4), i.e. extrudates' length significantly ($p<0.05$) diminished with MDPM inclusion. The length of samples made with BSG was significantly ($p<0.05$) greater than the length of samples made without it, except for the sample 20-30. This exception could be explained with intensive LE of sample 20-30, and hence less intensive longitudinal expansion.

Bulk density and density of extrudates were also significantly ($P<0.05$) influenced by both ingredients. BD and density of extrudates have increased with the addition of MDPM in samples without BSG, which was in agreement with previously published results by Lee et al. (2003). However, the samples with BSG showed scattered data related to these parameters. On the other hand, opposite to results presented by Ainsworth et al. (2007), BD significantly diminished ($P<0.05$) with the addition of BSG, i.e. density of extrudates significantly ($P<0.05$) decrease.BD and expansion are reciprocal characteristics (Navale et al., 2015; Philipp et al., 2017). Therefore, these results are directly in line with extrudates' length measurements, confirming bigger longitudinal expansion. In other words, total expansion of extrudates (lateral and longitudinal) was more intensive in samples with BSG addition. For extrudates intended for human nutrition, it is recommended to have low bulk density since it suggests hardness of less scale, what was confirmed by further results (Table 5), and better crispness, referring to sensory attribute describing hard food emitting noise upon mastication (Paula and Conti-Silva, 2014). BD could be chosen as a parameter which most accurately describes the expansion of extrudates. Hence, based on BD, the enriched sample with the best physical properties was 20-30 sample. Its bulk density was 333.26 g/dm^3, while the lowest bulk density had 20-0 sample 320.17 g/dm^3.

Textural and colour measurements

Mean values of textural and colour measurements of extrudates are given in Table 5. Significantly ($p<0.05$) lower results of textural characteristics, i.e. hardness and firmness, were observed when BSG was included in the blend.

Contrary to the findings of Bhat et al. (2019), suggesting that hardness of extrudates increase with fibre addition, in presented research hardness and firmness of snack products decrease with the inclusion of BSG. Furthermore, the inclusion of BSG caused decrease of cornmeal share, i.e. corn starch in extrudates. According to Stojceska et al. (2008) greater share of corn starch in extrudates causes drop of hardness. Obviously, it was not the case in this investigation. However obtained results of hardness and firmness could be explained by greater expansion of extrudates containing BSG, since more expanded products are characterized by lower hardness (Ačkar et al., 2018). The samples with the lowest hardness values 20-0, 20-20 and 20-30 sample (13.55 kg, 10.30 kg, 9.04 kg, respectivly) were also characterized by the lowest bulk density values (320.17 g/dm^3, 369.05 g/dm^3, 333.26 g/dm^3, respectivly). Moreover, reported results are

Table 4: Mean values of physical characteristics of extrudates

		0% MDPM	10% MDPM	20% MDPM	30% MDPM	BSG	MDPM	BSG x MDPM
Lateral expansion (%)	0% BSG	62.17±10.89^a	89.17±7.60^b	87.5±8.40^b	85.17±13.87^b	*	*	*
	20% BSG	61.83±5.38^a	52.5±3.90^c	56.5±4.51^{a,c}	71.96±6.21^d			
Length of extrudates (mm)	0% BSG	12.13±1.75^a	12.29±0.85^a	12.14±0.95^a	11.38±0.65^b	*	*	*
	20% BSG	14.39±0.65^c	17.95±0.50^d	14.68±0.67^c	11.4±0.44^b			
Bulk density (g/dm^3)	0% BSG	410.37±6.38^d	445.5±3.71^e	489.87±0.64^f	517.85±1.51^g	*	*	*
	20% BSG	320.17±1.76^b	366.68±4.01^a	369.05±1.64^a	333.26±0.37^c			
Density of extrudates (g/cm^3)	0% BSG	0.91±0.02^b	0.83 ±0.05^e	0.89±0.07^b	0.95±0.03^f	*	*	*
	20% BSG	0.71± 0.02^a	0.77 ±0.03^d	0.73± 0.01^a	0.64±0.03^c			

Values bearing the different superscript letters within the same characteristic raw are significantly different from each other, $P<0.05$, ns - not significant,*$P<0.05$

Table 5: Mean values of textural characteristics and colour measurements

			0% MDPM	10% MDPM	20% MDPM	30% MDPM	BSG	MDPM	BSG x MDPM
Texture	Hardness (kg)	0% BSG	45.30±8.67^{d}	28.26±2.80^{b}	25.06±7.00^{b}	37.33±9.07^{c}	*	*	*
		20% BSG	13.55±2.04^{a}	13.72±1.89^{a}	10.30±1.52^{a}	9.04±1.56^{a}			
	Firmness (N)	0% BSG	176.85±42.3^{cd}	174.4±30.2^{cd}	162.44±47.95^{c}	186.5±24.22^{d}	*	*	*
		20% BSG	75.45±10.64^{b}	60.67±6.79^{ab}	52.55 ±11.62^{a}	69.20 ±7.08^{ab}			
Colour	*L**	0% BSG	80.97±0.36^{cd}	81.43±0.43^{d}	79.92±1.21^{b}	79.0±1.60^{bc}	*	*	*
		20% BSG	67.93±0.42^{a}	68.18±1.17^{a}	69.63±0.83^{f}	66.34±1.62^{e}			
	*a**	0% BSG	4.94±0.19^{b}	1.82±0.25^{c}	1.61±0.34^{c}	2.14±0.27^{d}	*	*	*
		20% BSG	4.81±0.22^{a}	4.78±0.24^{ab}	4.57±0.16^{a}	5.52±0.31^{e}			
	*b**	0% BSG	38.74±0.68^{d}	37.96±1.21^{cd}	37.28±0.16^{c}	37.35±1.24^{c}	*	*	*
		20% BSG	27.51±0.98^{ab}	27.49±0.89^{ab}	26.78±0.74^{a}	28.06±0.42^{b}			

Values bearing the different superscript letters within the same characteristic raw are significantly different from each other, p< 0.05, ns - not significant ,*P<0.05

in accordance with findings claiming thathigh level of lipids reduces the breaking forces of extrudates (Dextrumaux et al., 1999) and long fibre stands can promote breakage (Thomas et al., 1998). Share of MDPM was not related to these two parameters of snack samples since scattered data of hardness and firmness were obtained.Hardness could also be influenced by operation conditions, meaning that the increase of barrel temperature results in greater hardness, while the rise of screw speed and moisture results in a decrease of hardness. Since extrusion temperature, screw speed and moisture were the same for all samples in this research, it can be concluded that only BSG influenced hardness of the snack products. The 20-30 sample had a hardness of only 9.04 kg and firmness of 69.20 N. Both results were significantly lower than the analogue sample with only MDPM. High hardness and firmness values of extruded snacks for human nutrition are not desirable.

Incorporation of BSG resulted in a darker sample, i.e. the lightness of samples(*L** value)containing BSG decreased significantly (p<0.05). Redness of the sample (*a** value) significantly rose up with the addition of BSG. However, the highest *a** value (4.94) was determined for the sample containing only cornmeal. It can be explained by the influence of red colour of paprika powder, which was not covered by other ingredients in this sample. Even though statistical analysis showed that MDPM had a significant influence on redness of the sample, obtained data are dispersed and a clear relationship between redness and MDPM content could not be defined. The yellowness (*b** value) followed the same trend as lightness confirming reported data related to its decrease with BSG addition (Ačkar et al., 2018), which was the only parameter that had a significant influence on it. The obtained results of colour were in the accordance with the results reported by several authors (Ainsworth et al., 2007; Stojceska et al., 2008; Ktenioudaki et al., 2012), but not in accordance with results published by Lee et al. (2003), stating that increase in MDPM share results in higher *a** and *b** values. Importantly, obtained *L**, *a** and *b** values of samples with BSG are similar to values of whole-grain products reported by Oliveira et al. (2017),thus consumer could connect them with healthy nutritional food (Sandvik et al., 2018).

CONCLUSIONS

Ready-to-eat snacks containing MDPM and BSG, showed better nutritional quality, in terms of increased protein and fat content compared to their counterparts without BSG. Improved nutritional characteristics did not decrease physical and textural quality. On the contrary, the addition of BSG has improved bulk density, hardness, firmness and colour. Moreover, the production of meat snacks with BSG addition required less energy input. Based on the obtained results, one could conclude that snacks containing BSG showed better results considering chemical, physical and textural properties than snacks consisted of only MDPM and cornmeal. High-protein and low-fat content are the properties which make them eminently suited as nutritionally valuable snack products. Also, due to gluten-free nature, the circle of consumers could be expanded. Nutritionally valuable snack product developed during this research has a potential to significantly improve eating habits and change unhealthy concept of snack food.

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Author's contributions

Conceived and designed experiments: P. Ikonić, J. Delić, R. Čolović and T. Peulić. Performed extrusion process: R. Čolović, V. Banjac and P. Ikonić. Performed analysis of physical and chemical properties: S. Rakita and J. Delić. Performed texture and colour analysis: M. Jokanović, T. Peulić and J. Delić. Performed statistical analysis and interpretation of results: J. Delić, P. Ikonić, V. Banjac and M. Jokanović. Wrote the manuscript: J. Delić, P. Ikonić, M. Jokanović and V. Banjac.

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