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Selected properties of snacks extruded at various screw speeds supplemented with Moldavian dragonhead seed addition

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A b s t r a c t. The main aim of the study was to determine selected characteristics of extruded snacks supplemented with *Dracocephalum moldavica* L. seeds added to the recipe in amounts ranging from 5 to 20% of the basic raw material composition. The effect of the screw speed on the selected corn-based snacks characteristics has also been been studied. A single-screw extruder was employed to obtain the snacks in the form of ready-to-eat extrudates. Several properties were evaluated, among them: the expansion ratio, the water absorption and solubility indices as well as pasting properties, depending on the level of the additive and the screw speeds applied. Extruded snacks supplemented with *Dracocephalum moldavica* L. seeds exhibited an enhanced nutritional value compared with corn snacks due to the high content of fibre, protein and ash. The addition of the seeds decreased the expansion ratio significantly. The water absorption index of the snacks decreased as the level of seed addition in the processed blends was raised, while the water solubility index was significantly affected by the variable screw speed during the processing of the supplemented snacks. The recommended level of *Dracocephalum moldavica* seeds in corn-based snacks should not exceed 15% due to the high nutritional value as well as the high expansion and efficient treatment intensity of the components resulting in the ready-to-eat characteristic of the supplemented snacks.

K e y w o r d s: snacks, extrusion-cooking, Moldavian dragonhead seeds, physical properties

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INTRODUCTION

Extrusion-cooking is a popular food processing technique, classified as a high temperature-short time process (HTST), used in the production of a wide range of food and feed products (Mościcki, 2011; Wójtowicz *et al*., 2017). As regards short-time treatment, extrusion-cooking is one of the most effective methods as it only slightly reduces the nutritional value of processed components. The limited destruction of the nutritional components and biologically active compounds (*e.g.* antioxidants) coupled with the improvement in starch and protein digestibility are just a few advantages of this process (Oniszczuk *et al*., 2015, 2019; Wójtowicz *et al*., 2018). These advantages make the extrusion-cooking technique a preferred processing method in the manufacture of many food and feed products, *e.g.* crisps, pasta, breakfast cereals, instant products, flat bread, confectionery, and many others (Bouasla *et al*., 2016; Kręcisz and Wójtowicz, 2017; Wójtowicz *et al*., 2015).

An improved diet may help to prevent and ease the treatment of a range of conditions collectively known as conditions of affluence, such as diabetes, being overweight, and obesity. According to dietary guidelines, a healthy balanced diet must be based on more vegetables, fruit, whole grain food, vegetable oils containing monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), fat-free and low-fat dairy products and seafood. Moreover, the consumption of food products high in sodium, saturated and trans-fats, or simple sugars should be reduced. Current scientific research is attempting to examine the impact of consuming such products on a variety of aspects associated with the risk of developing the conditions named above (Day and Swanson, 2013).

Modern and functional food should combine a pleasant taste with a beneficial effect on the natural resistance of the body, thereby enhancing the prevention of diseases associated with poor diet or supporting chronic disease therapies, they should possess certain physical features and have a favourable influence on the mental condition of the consumer. The literature on the subject draws attention to the application of plant extracts as a source of natural antioxidants in food products. However, not only extracts but also whole plants, leaves or flowers are nutritionally valuable and may be used for food supplementation, especially as a source of flavonoids and phenolic acids (Oniszczuk *et al*., 2015, 2019).

The Moldavian dragonhead (*Dracocephalum moldavica* L., *Lamiaceae*) is a well-known herbal plant with specific properties: it contains phenolic compounds, especially flavonoids (Yang *et al*., 2014). Primarily, the main raw material that can be used for medicinal purposes is the *Dracocephalum moldavica* leaves and flowers. They work well as infusions to treat stomach and liver disorders, headaches and congestion, coronary heart disorders and hypertension (Yang *et al*., 2014). Some recent reports have described the fitness of dragonhead extracts for such therapeutic applications as: cardioprotective, antiplatelet, neuroprotective, sedative, and anti-aging applications. Dragonhead seeds are a good source of protein, lipids, and fibre (Dziki *et al*., 2013). Dragonhead seeds have also been confirmed to be useful for the extraction of valuable essential oils (Horn *et al.*, 2014) and bioavailable total flavonoids with health-promotive effects on rats (Zeng *et al*., 2016). They contain a high amount of fat (around 30%), of which 90% are unsaturated fatty acids, mainly omega-3 fatty acids. The plant is also known as a good source of linolenic acid (59.4% in seeds after processing to obtain volatile oils). After obtaining the oil by cold pressing, there are some residues left containing protein with an unchanged nutritional value when compared with the original material (Hanczakowski *et al*., 2009). Taking these positive nutritional features of dragonhead seeds into consideration, the residues of cold oil pressing could be a valuable source of protein and unsaturated fatty acids in high quality snacks (Oniszczuk *et al*., 2017a).

The aim of this study was to add various amounts of dragonhead (*Dracocephalum moldavica* L.) seeds to snacks and to evaluate the selected physical characteristics and pasting properties of the snacks extruded at various screw speeds.

MATERIALS AND METHODS

Corn grits (purchased from PZZ Lubella GMW Sp. z o.o. Sp. K., Lublin, Poland) were used as the basic raw material to prepare the extruded snacks. *Dracocephalum moldavica* L. seeds were harvested in 2017 in our own field. They were dried (45°C, 1 h), ground to obtain flour with a particle size of 500 µm using the TESTCHEM LMN10C grinder (Radlin, Poland) and stored at room temperature in sealed bags prior to the experiments. The amount of Moldavian dragonhead seeds was 5, 10, 15 and 20% w/w as a replacement of the corn grits.

The chemical composition of the raw materials and prepared snacks was assessed using the AACC methods: the protein content by the Kjeldahl method (AACC 46-13.01), fat content by the AACC 30-25.01 method, fibre content by the AACC 32-21.01 method and ash content by the AACC 08-03.01 method (AACC, 2011).

The snacks were processed using the single screw extruder-cooker TS-45 (Z.M.Ch. Metalchem, Gliwice, Poland). The samples were shaped on a 3 mm circular forming die and cut just after passing the die (the length of the snacks was 25 mm). The ratio of the screw length to its diameter was L/D=12, and the processing temperature was set at 133/145/140°C in the dosing section, plasticizing section, and forming die, respectively. The snacks were extruded at various screw speeds: 60, 80, 100 and 120 rpm. Then, the samples were collected, cooled down to room temperature and stored in sealed bags at the same temperature prior to the tests.

The ready-to-eat snacks were tested for their expansion ratio, bulk density, water absorption and water solubility indices as well as for pasting properties under different processing conditions and levels of additive. The ratio of the snack diameter to the diameter of the forming die was expressed as the mean value of the radial expansion ratio (ER) from 10 replications (Wójtowicz *et al.*, 2017). The Bulk density (BD) of the snacks was measured in triplicate as the weight of the specific volume of the extrudates (Wójtowicz *et al.*, 2018). An empty plastic container with a volume of 1 l was filled with the tested snacks and the mass of the snacks was evaluated. The water absorption index (WAI) and the water solubility index (WSI) were tested as proposed by Bouasla *et al*. (2017) and Kręcisz *et al*. (2017). The WAI was calculated as the weight of gel obtained after centrifugation compared to the amount of dry sample. The WSI was calculated as the percentage of residues from the supernatant compared to the dry sample mass. The tests were performed in triplicate.

The pasting properties of the processed snacks were measured with the Brabender Micro Visco-Amylo-Graph (Brabender, Germany). A 10 g sample of ground extrudate was dispersed in 100 mL of distilled water. The pasting properties were evaluated at a constant testing bowl speed (250 rpm) and sensitivity (235 cmg). The measurements were performed twice following the method described by Wójtowicz *et al*. (2017) and Mitrus *et al*. (2017) and the following temperature profile: heating from 30 up to 93°C with a temperature gradient of 7.5°C min^{-1}, holding at 93°C for 5 min, cooling from 93 to 50°C with a temperature gradient of 7.5°C min^{-1}, holding at 50°C for 1 min. Brabender Viscograph software (version 4.1.1) was used to determine the parameters of the pasting properties. The following parameters were evaluated: peak viscosity (PV) – maximum viscosity recorded during the heating stage, hot paste viscosity (HPV) – paste viscosity after being held for 5 min at 93°C, cold paste viscosity (CPV) – viscosity obtained as the cooked paste was cooled down to 50°C, breakdown (BD) – the difference between PV and HPV, setback (SB) – the difference between CPV and HPV.

A statistical analysis was performed using Statistica software, version 13.3 (StatSoft, USA). The results were evaluated using an ANOVA analysis of variance with one-dimensional significance tests for each variable separately and its interactions with sigma-restrictions parameterization and the decomposition of effective hypotheses. The significance of differences was assigned through the identification of homogenous groups. Response surface methodology (RSM) with square adjustment was used to evaluate the integrated effect of the additive level and screw speed on selected properties of the snacks. All the analyses were performed at a confidence level of 95%.

RESULTS AND DISCUSSION

The chemical composition of the corn grits used in the experiment was as follows (in d.m.): protein 9.24%, fibre 4.42%, fat 1.66%, ash 0.50%; while the chemical composition of *Dracocephalum moldavica* seeds was as follows: protein 19.99%, fibre 71.84%, fat 22.04%, ash 4.94%. The approximate chemical composition of the corn snacks supplemented with *Dracocephalum moldavica* seeds extruded at 100 rpm is presented in Table 1. The addition of Moldavian dragonhead seeds was reported to increase the level of all the tested chemical components, in other words, it enhanced the nutritional value of the supplemented snacks. The highest increase was observed in the level of total dietary fibre ($r = 0.975$). This is due to the high level of fibre in dragonhead seeds in general. Additionally, the ash content almost tripled when the highest amount of the additive was used, which suggests a high content of macro- and microcomponents in the tested snacks when the additive was present at a level of 20% ($r = 0.985$). It was found that the screw speed did not significantly affect the chemical composition of the enriched snacks (data not shown). A significant increase was reported for both insoluble and soluble dietary fibre ($r = 0.879$ and 0.877, respectively), which may be connected with the presence of polysaccharides in the outer layer of the whole grain seeds in the ground material used in the experiment. The low level of fat in the supplemented snacks ($r = 0.987$) may arise from the formation of starch-fat or protein-fat complexes during the extrusion-cooking process due to a significant increase in the protein content ($r = 0.997$), which was described previously (Bouasla *et al*., 2016; De Pilli *et al*., 2012). In every aspect the tested snacks are much healthier than fried snacks or chips that contain at least 16-30% fat in the final product (Oniszczuk *et al*., 2017b; Wójtowicz *et al*., 2017, 2018).

The results of the surface response of the expansion ratio of the snacks as a function of the percentage of Moldavian dragonhead seeds added with various screw speeds of processing are presented in Fig. 1. The highest expansion value was noted for the control snacks processed at 120 rpm (5.54), while the lowest one was for snacks supplemented with dragonhead seeds at a level of 20% and processed at the lowest screw speed (3.45). The opposite relationship in terms of the amount of functional additive used in the raw mixture was obtained by Mir *et al.* (2019) during the addition of chestnut flour. The most significant effect, as shown by the high F-test values, was observed with increasing levels of additive applied. The higher the dragonhead seed level, the lower the expansion ratio observed due to the increased content of fat and fibre in the extruded snacks. A smaller, but still significant, effect on the radial expansion ratio was observed for the screw speed:

Table 1. Proximate chemical composition of corn snacks supplemented with the addition of *Dracocephalum moldavica* seeds extruded at 100 rpm

Additive level	Protein	Fat	Ash	Crude fibre	IDF	SDF	TDF
(%)							
0	9.692^{a}	0.24^{a}	0.57^{a}	6.05^{a}	2.72^{a}	1.18^{ab}	3.90^{a}
5	10.168^{ab}	0.73^{b}	0.84^{ab}	9.12^{b}	9.85^{b}	0.39^{a}	10.24^{b}
10	10.839^{b}	1.66^{c}	0.90^{b}	9.30^{b}	6.58^{ab}	3.82^{b}	10.40^{b}
15	11.491^{bc}	1.87^{c}	1.24^{bc}	10.93^{bc}	11.26^{bc}	5.22^{c}	16.48^{c}
20	11.911^{c}	2.79^{d}	1.47^{c}	11.81^{c}	14.84^{c}	4.80^{bc}	19.64^{d}
r	0.997	0.987	0.985	0.956	0.879	0.877	0.975

IDF – insoluble dietary fibre, SDF – soluble dietary fibre, TDF – total dietary fibber, $^{a\text{-}d}$ – means indicated with similar letters in columns do not differ significantly at $\alpha = 0.05$, r – correlation coefficient.

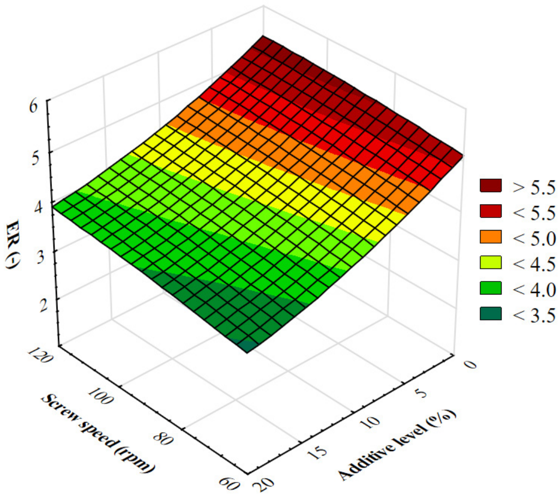

Fig. 1. RSM results of the expansion ratio of corn snacks with various concentrations of Moldavian dragonhead seeds processed at various screw speeds at a confidence level of 95%.

increasing the processing speed meant a higher expansion ratio (Table 2), probably due to higher pressure inside the extruder barrel as a result of the shearing of the processed material (Day and Swanson, 2013). Also, the effect of interactions between the level of additive and the screw speed applied during processing was still significant. A higher expansion ratio occurring along with a higher screw speed during the extrusion-cooking process has been reported by many researchers for various raw materials (Mitrus and Wójtowicz, 2011; Wójtowicz *et al*., 2015). The presented tendencies are also in line with the effect of a falling expansion ratio with a growing level of fibre-rich components processed with extrusion-cooking, both for expanded products as well as pasta, fish feed or biopolymers (Bouasla *et al*., 2017; Oniszczuk *et al*., 2016, 2019; Pęksa *et al*., 2016). The reduction in expansion is mainly related to the reduction in the amount of starch, which is replaced by a vegetable additive, preventing the formation of a porous structure which is characteristic of extrudates (Mościcki,

Table 2. Analysis of variance results demonstrate the influence of extrusion parameters on the pasting properties of corn snacks with different additions of Moldavian dragonhead seeds

Pasting properties	Effect of extrusion parameters	Sum of squares	Degrees of freedom	Mean square	F-test	p
	SS	2.0	3	0.7	15.1	<0.0001
ER	A	29.6	4	7.4	166.7	<0.0001
	SS x A	1.2	12	0.1	2.3	0.0152
	SS	0.3	3	0.1	2.5	0.0764
WAI	A	2.9	4	0.7	16.8	<0.0001
	SS x A	1.6	12	0.1	2.9	0.0046
	SS	40.3	4	10.1	10.6	<0.0001
WSI	A	8.7	3	2.9	3.0	0.0403
	SS x A	7.8	12	0.7	0.7	0.7549
	SS	387.3	3	129.1	81.0	<0.0001
PV	A	8457.8	4	2819.3	1769.0	<0.0001
	SS x A	334.8	12	37.2	23.3	<0.0001
	SS	283.6	3	94.5	137.5	<0.0001
HPV	A	2275.4	4	758.5	1103.2	<0.0001
	SS x A	104.9	12	11.6	16.9	<0.0001
	SS	466.1	3	155.4	105.8	<0.0001
CPV	A	2235.3	4	745.1	507.3	<0.0001
	SS x A	89.0	12	9.9	6.7	0.0005
	SS	1155.3	3	385.1	160.0	<0.0001
BD	A	18744.3	4	6248.1	2596.6	<0.0001
	SS x A	487.8	12	54.2	22.5	<0.0001
	SS	33.1	3	11.0	10.7	0.0004
SB	A	33.1	4	11.0	10.7	0.0004
	SS x A	17.5	12	1.9	1.9	0.1280

SS – screws speed, A – additive level, ER – expansion ratio, WAI – water absorption index, WSI – water solubility index, PV – peak viscosity, HPV – hot paste viscosity, CPV – cold paste viscosity, BD – breakdown, SB – setback.

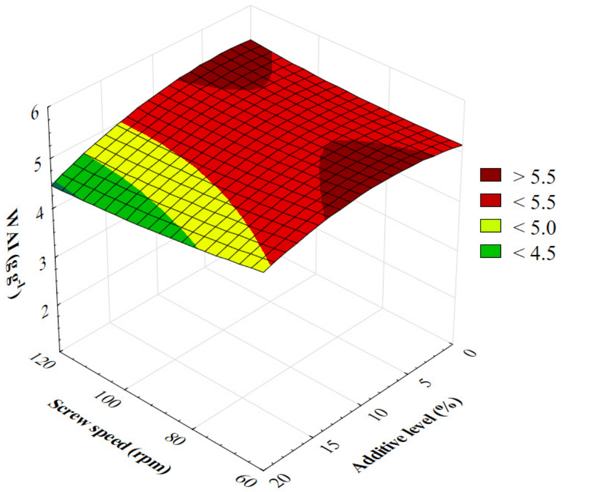

Fig. 2. RSM results of WAI of the corn snacks with various concentrations of Moldavian dragonhead seeds processed at various screw speeds at a confidence level of 95%.

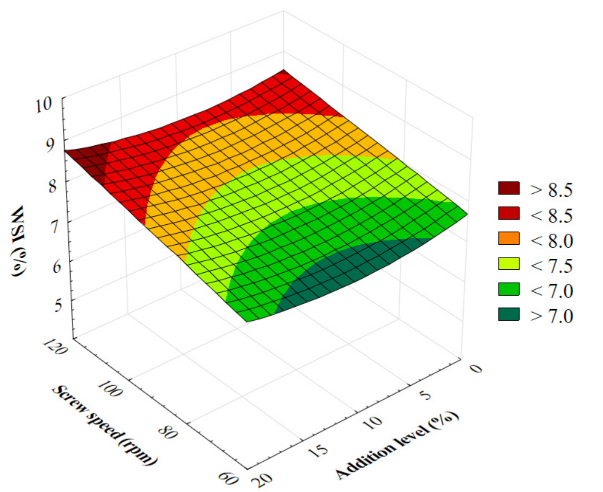

Fig. 3. RSM results of WSI of corn snacks with various concentrations of Moldavian dragonhead seeds processed at various screw speeds at a confidence level of 95%.

2011). The fibrous fractions derived from the additive can also lead to the destruction of cellular structures, which consequently prevents the formation of air bubbles inside the structure of the extrudates. This phenomenon may be attributed to the interactions between the decreasing amount of starch in the mixture and the increasing amount of fibre, protein or fat from plant additives (Day and Swanson, 2013; De Pilli *et al*., 2012; Lucas *et al*., 2018; Mir *et al*., 2019; Wójtowicz *et al*., 2017, 2018).

Figure 2 shows the surface response of the effect of the additive level and extrusion screw speed on the water absorption index of the tested snacks. The WAI varied from 4.46 to 5.58 g g^{-1} of absorbed water per one gram of sample depending on the composition of the tested snacks. The values obtained were lower than those recorded by Lucas *et al.* (2018) for extruded snacks enriched with spirulina. The effect of screw speed on the WAI was negligible (Pęksa *et al*., 2016; Suksomboon *et al*., 2011), however, both the effect of the level of the additive and the interactions between the tested variables were significant. The decreasing WAI in snacks enriched with a high level of *Dracocephalum moldavica* seeds may be attributed to the high fibre quantity caused by a high level of the additive and obstacles to the processing of blends with a high fibre content, which is responsible for a lower content of starch and, consequently, lower gelatinization intensity. The gelatinization of starch is the main factor affecting water absorption. The higher the intensity of gelatinization in materials undergoing a thermo-mechanical treatment during extrusion-cooking, the higher the level of water absorption observed (Pardhi *et al.,* 2019). In this case, the effect of the screw speed on the WAI was insignificant, probably due to the high volume of fibre-rich additive disturbing the processing flow. The screw speed was also less effective in treating material blends.

The surface response of the water solubility index of the tested snacks is presented in Fig. 3. In this case, the most significant effect was observed for various screw speeds applied during processing (Table 2). The addition of dragonhead seeds had little effect on the WSI values. They ranged from 8.97 to 6.89% as the screw speed decreased from 120 to 60 rpm, respectively. The values obtained in this study were close to those reported by Pardhi *et al.* (2019). A higher WSI was observed for snacks processed with corn grits as well as with 15 and 20% of the additive at the highest screw speed. Such a high water solubility may be the result of the destruction of compounds exposed to treatment under high shearing forces and starch decomposition (Lucas *et al.,* 2018*;* Wójtowicz *et al*., 2017). The effect of interactions between the level of the additive and the screw speed was insignificant (Table 2). The higher WSI reported for the snacks is closely related to the limited water absorption ability, which is typical of extruded products and shows reduced integration of components during processing. The high content of fibre and fat in the processed blends may be a factor influencing the above-mentioned behaviour (Bouasla *et al*., 2017).

The measurement of pasting properties may help to assess the intensity of the extrusion-cooking treatment of starchy products. Extruded cereals exhibit much more stable viscosity characteristics than unprocessed ones. Their pasting viscograms often lack the characteristic peak viscosity. Peak viscosity is influenced by many factors, such as: starch type, the degree of starch gelatinization, starch granule swelling, amylose content and leaching, as well as the influence of other components, including proteins, lipids, and fibre (Natabirwa *et al*., 2018). Corn snacks with a 5% content of Moldavian dragonhead seeds added and those without it did not produce the characteristic peak viscosity because the starch was significantly gelatinized during the extrusion-cooking process as confirmed by the high WAI in these snacks. The addition of the dragonhead seeds had a negative effect on the value of the peak viscosity (Fig. 4). The highest peak viscosity (103 mPa s) was observed for snacks with the addition of 5 % dragonhead seeds processed at the highest screw speed (Table 3). The presence of protein and fat components from dragonhead seeds may hinder water absorption by starch granules (Lopes *et al*., 2012). A higher screw speed applied during processing resulted in a small increase in the peak viscosity values in almost all of the tested samples (decrease from 3.09 to 29.63%, except for samples with 20% of the additive), however the most important effect was observed for the additive level as the highest value of F-test was found

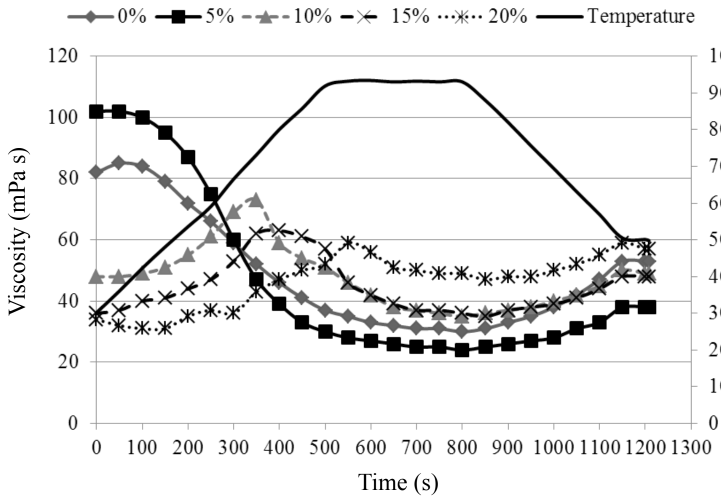

Fig. 4. Example of the viscograms of corn snacks with various concentrations of Moldavian dragonhead seeds processed at 100 rpm.

Table 3. Pasting properties of corn snacks with different additions of Moldavian dragonhead seeds

Additive level (%)	Screw speed (rpm)	PV (mPa s)	HPV (mPa s)	CPV (mPa s)	BD (mPa s)	SB (mPa s)
0	60	82c	27a	53bc	51c	23c
	80	84c	29ab	52bc	54c	22c
	100	87cd	30ab	50b	58c	20bc
	120	90cd	31ab	48	59c	19bc
5	60	97d	26a	39a	71cd	13ab
	80	98d	24a	38a	74cd	14b
	100	103d	24a	37a	79d	13ab
	120	100d	24a	35a	76cd	11a
10	60	58a	37b	52bc	21ab	15b
	80	65ab	40bc	55bc	25ab	15b
	100	75bc	35b	49b	40b	14b
	120	70b	31ab	45ab	39b	14b
15	60	54a	41bc	53bc	13a	12a
	80	61ab	44c	58c	17a	14b
	100	64ab	36b	47b	28ab	11a
	120	70b	31ab	44ab	39b	13ab
20	60	59a	50d	61cd	9a	11a
	80	60ab	49d	64d	10a	10a
	100	59a	49d	59c	10a	10a
	120	57a	42bc	54bc	15a	12a

PV – peak viscosity; HPV – hot paste viscosity; CPV – cold paste viscosity; BD – breakdown; SB – setback. [a-d] – means indicated with similar letters in columns did not differ significantly at α = 0.05.

(Table 2). The efficiency of extrusion-cooking treatment with the addition of up to 15% of dragonhead seeds was confirmed by the high viscosity of the first heating stage which is characteristic of gelatinized products. The hot paste viscosity (HPV) indicates the fragility of the swollen starch granules towards shearing forces. The addition of dragonhead seeds and the extruder screw speed showed a significant effect on the hot paste viscosity of the processed snacks (Table 2). The results show that the higher addition of dragonhead seeds to the processed blends resulted in higher HPV values. However, the higher extruder screw speed had a negative effect on the HPV value. Cold paste viscosity (CPV) indicates the retrograding tendency of soluble amylose after cooling or the ability of starch paste to form a gel (Lopes *et al*., 2012). During the research, it was found that the CPV values for extruded corn snacks with added dragonhead seeds ranged between 35-64 mPa s.

Research has demonstrated that higher extruder screw speeds cause a reduced cold paste viscosity value. A higher concentration of dragonhead seeds during the processing of corn snacks had a positive effect on CPV. This may suggest that a higher protein, fat and fibre content prevents excessive starch degradation during the extrusion-cooking process (Mitrus *et al*., 2017). However, its gel formation ability is much lower than that of the starchy extrudates (Mitrus *et al*., 2017) due to a high protein and fibre content and the interaction between starch and other components (Marquezi *et al*., 2016). Similar reports have been presented by other researchers (Siddiq *et al*., 2013; Nkundabombi *et al*., 2016).

Breakdown (BD) is used to measure the stability of the paste during thermal treatment. A higher addition of dragonhead seeds during extrusion-cooking resulted in a negative influence on the value of breakdown in corn snacks. On the other hand, higher extruder screw speeds had a slight but significantly positive influence on the same value. Setback (SB) indicates a retrograding behaviour in starch gels. The higher the setback value, the greater the degree of retrogradation (Nkundabombi *et al*., 2016). During the research, it was found that higher screw speeds during extrusion-cooking decreased the setback values in corn snacks. This may suggest reduced starch retrogradation due to the formation of starch-protein or starch-fat complexes during extrusion-cooking (Mitrus *et al*., 2017). The addition of Moldavian dragonhead seeds also had a significant effect on the observed SB values, but the relationships between the level of the additive and the screw speed applied in the experiment was insignificant (Table 2).

CONCLUSIONS

1. *Dracocephalum moldavica* seeds have the potential to become an interesting food additive because of the unique nutritional composition of the seeds. Extruded snacks supplemented with *Dracocephalum moldavica* L. seeds exhibited an enhanced nutritional value compared with corn snacks due to the high content of fibre, protein and ash. The most significant increase was observed in the protein content and the total dietary fibre level, which is a positive effect of supplementation with dragonhead seeds.

2. A higher level of Moldavian dragonhead seed addition coupled with a lower screw speed during processing significantly reduced the expansion ratio of the tested snacks.

3. The water absorption index of the snacks decreased as the level of dragonhead seed addition in the processed blends was raised, while the water solubility index was significantly affected by the variable screw speed during the processing of the supplemented corn-based snacks.

4. The pasting properties of the tested snacks changed both with the level of the additive and the screw speed applied during the extrusion-cooking process. The most significant decrease in peak viscosity was observed due to increasing the dragonhead seed level and this in turn was due to the decreased starch content. However, the application of a higher screw speed during snack processing resulted in a higher peak viscosity, except for samples with a 20% addition of dragonhead seeds, where the effect was insignificant. It has been found that the higher addition of dragonhead seeds resulted in higher hot paste viscosity values but that increased screw speed had a negative effect on the hot paste viscosity values.

5. The recommended level of *Dracocephalum moldavica* seeds in corn-based snacks should not exceed 15% because the high nutritional value, high expansion and efficient treatment intensity of the ingredients resulted in the desirable ready-to-eat characteristic of the supplemented snacks.

Conflict of interest: The Authors do not declare conflict of interest.

REFERENCES

AACC International, **2011.** Approved Methods of Analysis, 11th Ed., AACC International, St. Paul, MN, U.S.A.

Bouasla A., Wójtowicz A., and Zidoune M.N., 2017. Gluten-free precooked rice pasta enriched with legumes flours: physical properties, texture, sensory attributes and microstructure. LWT-Food Sci. Technol., 75, 569-577. https://doi.org/10.1016/j.lwt.2016.10.005

Bouasla A., Wójtowicz A., Zidoune M.N., Olech M., Nowak R., Mitrus M., and Oniszczuk A., 2016. Gluten-free precooked rice-yellow pea pasta: effect of extrusion-cooking conditions on phenolic acids composition, selected properties and microstructure. J. Food Sci., 81, C1070-C1079. https://doi.org/10.1111/1750-3841.13287

Day L. and Swanson B.G., 2013. Functionality of protein-fortified extrudates. Compr. Rev. Food Sci. Food Saf., 12, 546-564. https://doi.org/10.1111/1541-4337.12023

De Pilli T., Derossi A., Talja R.A., Jouppila K., and Severini C., 2012. Starch-lipid complex formation during extrusion-cooking of model system (rice starch and oleic acid) and real food (rice starch and pistachio nut flour). Eur. Food Res. Technol., 234, 517-525. https://doi.org/10.1007/s00217-012-1662-6

Dziki D., Miś A., Gładyszewska B., Laskowski J., Kwiatkowski S., and Gawlik-Dziki U., 2013. Physicochemical and grinding characteristics of dragonhead seeds. Int. Agrophys., 27, 403-408. https://doi.org/10.2478/intag-2013-0010

Hanczakowski P., Szymczyk B., Kwiatkowski S., and Wolski T., 2009. Composition and nutritive value of protein of Moldavian balm seeds (*Dracocephalum moldavica* L.) (in Polish). Rocz. Nauk. Zoot., 36(1), 55-61.

Horn T., Völker J., Rühle M., Häser A., Jürges G., and Nick P., 2014. Genetic authentication by RFLP versus ARMS? The case of Moldavian dragonhead (*Dracocephalum moldavica* L.). Eur. Food Res. Technol., 238, 93-104. https://doi.org/10.1007/s00217-013-2089-4

Kręcisz M. and Wójtowicz A., 2017. Evaluation of selected properties of gluten-free instant gruels processed under various extrusion-cooking conditions. Acta Sci. Pol. Technol. Aliment., 16(2), 135-147. https://doi.org/10.17306/j.afs.2017.0459

Lopes L.C.M., Batista K.A., Fernandes K.F., and Santiago R.A.C., 2012. Functional, biochemical and pasting properties of extruded bean (*Phaseolus vulgaris* L.) cotyledons. Int. J. Food Sci. Technol., 47, 1859-1865. https://doi.org/10.1111/j.1365-2621.2012.03042.x

Lucas B.F., De Morais M.G., Santos T.D., and Costa J.A.V., 2018. Spirulina for snack enrichment: Nutritional, physical and sensory evaluations. LWT-Food Sci. Technol., 90, 270-276. https://doi.org/10.1016/j.lwt.2017.12.032

Marquezi M., Gervin V.M., Watanabe L.B., Bassinello P.Z., and Amante E.R., 2016. Physical and chemical properties of starch and flour from different common bean (*Phaseolus vulgaris* L.) cultivars. Braz. J. Food Technol., 19, https://doi.org/10.1590/1981-6723.0516

Mir S.A., Don Bosco S.J., and Shah M.A., 2019. Technological and nutritional properties of gluten-free snacks based on brown rice and chestnut flour. J. Saudi Soc. Agric. Sci., 18(1), 89-94, https://doi.org/10.1016/j.jssas.2017.02.002

Mitrus M. and Wójtowicz A., 2011. Selected quality characteristics of extruded snacks with modified starch addition (in Polish). Acta Agrophys., 18(2), 335-345.

Mitrus M., Wójtowicz A., Oniszczuk T., Gondek E., and Mościcki L., 2017. Effect of processing conditions on microstructure and pasting properties of extrusion-cooked starches. Int. J. Food Eng., 13(6). https://doi.org/10.1515/ijfe-2016-0287

Mościcki L. (Ed.), 2011. Extrusion-Cooking Techniques. Application, Theory and Sustainability. Wiley-VCH, Weinheim, Germany.

Natabirwa H., Muyonga J.H., Nakimbugwa D., and Lungaho M., 2018. Physico-chemical properties and extrusion behaviour of selected common bean varieties. J. Sci. Food Agric., 98, 1492-1501. https://doi.org/10.1002/jsfa.8618

Nkundabombi M.G., Nakimbugwa D., and Muyonga J.H., 2016. Effect of processing methods on nutritional, sensory, and physicochemical characteristics of biofortified bean flour. Food Sci. Nutr., 4, 384-397. https://doi.org/10.1002/fsn3.301

Oniszczuk T., Wójtowicz A., Kocira S., Żelizko K., Oniszczuk A., Dib A., 2017a. The use of Moldavian dragonhead bagasse waste in extruded products. Proc. IX Int. Scientific Symp. “Farm Machinery and Processes Management in Sustainable Agriculture” (Eds E. Lorencowicz, J. Uziak, B. Huyghebaert), November 22-24, Lublin, Poland, 278-283, https://doi.org/10.24326/fmpmsa.2017.50

Oniszczuk A., Olech M., Oniszczuk T., Wojtunik-Kulesza K., and Wójtowicz A., 2017b. Extraction methods, LC-ESI-MS/MS analysis of phenolic compounds and antiradical properties of functional food enriched with elderberry flowers or fruits. Arab. J. Chem., 1-12 (in press), https://doi.org/10.1016/j.arabjc.2016.09.003

Oniszczuk T., Oniszczuk A., Gondek E., Guz L., Puk K., Kocira A., Kusz A., Kasprzak K., and Wójtowicz A., 2019. Active polyphenolic compounds, nutrients contents and antioxidant capacity of extruded fish feed containing purple coneflower (*Echinacea purpurea*). Saudi J. Biol. Sci., 26(1), 24-30, https://doi.org/10.1016/j.sjbs.2016.11.013

Oniszczuk A., Wojtunik K., Oniszczuk T., Wójtowicz A., Mościcki L., and Waksmundzka-Hajnos M., 2015. Radical scavenging activity of instant grits with addition of chamomile flowers determined by TLC-DPPH test and by spectrophotometric method. J. Liquid Chromatography and Related Technologies, 38, 1142-1146. https://doi.org/10.1080/10826076.2015.1028294

Pardhi S.D., Singh B., and Nayik G.A., 2019. Evaluation of functional properties of extruded snacks developed from brown rice grits by using response surface methodology. J. Saudi Soc. Agric. Sci., 18(1), 7-16, https://doi.org/10.1016/j.jssas.2016.11.006

Pęksa A., Kita A., Carbonell-Barrachina A.A., Miedzianka A., Kolniak-Ostek J., Tajner-Czopek A., Rytel E., Siwek A., Miarka D., and Drożdż W., 2016. Sensory attributes and physicochemical features of corn snacks as affected by different flour types and extrusion conditions. LWT-Food Sci. Technol., 72, 26-36. https://doi.org/10.1016/j.lwt.2016.04.034

Siddiq M., Kelkar S., Harte J.B., Dolan K.D., and Nyombaire G., 2013. Functional properties of flour from low-temperature extruded navy and pinto beans (*Phaseolus vulgaris* L.). LWT-Food Sci. Technol., 50, 215-219. https://doi.org/10.1016/j.lwt.2012.05.024

Suksomboon A., Limroongreungrat K., Sangnark A., Thititumjariya K., and Noomhorm A., 2011. Effect of extrusion conditions on the physicochemical properties of a snack made from purple rice (Hom Nil) and soybean flour blend. Int. J. Food Sci. Technol., 46(1), 201-208. https://doi.org/10.1111/j.1365-2621.2010.02471.x

Wójtowicz A., Oniszczuk A., Oniszczuk T., Kocira S., Wojtunik K., Mitrus M., Kocira A., Widelski J., and Skalicka-Woźniak K., 2017. Application of Moldavian dragonhead (*Dracocephalum moldavica* L.) leaves addition as a functional component of nutritionally valuable corn snacks. J. Food Sci. Technol., 54, 3218-3229. https://doi.org/10.1007/s13197-017-2765-7

Wójtowicz A., Mitrus M., Oniszczuk T., Mościcki L., Kręcisz M., and Oniszczuk A., 2015. Selected physical properties, texture and sensory characteristics of extruded breakfast cereals based on wholegrain wheat flour. Agric. Agric. Sci. Procedia, 7, 301-308. https://doi.org/10.1016/j.aaspro.2015.12.051

Wójtowicz A., Zalewska-Korona M., Jabłońska-Ryś E., Skalicka-Woźniak K., and Oniszczuk A., 2018. Chemical characteristics and physical properties of functional snacks enriched with powdered tomato. Polish J. Food Nutr. Sci., 68(3), 251-261. https://doi.org/10.1515/pjfns-2017-0028

Yang L.N., Xing J.G., He C.H., and Wu T., 2014. The phenolic compounds from *Dracocephalum moldavica* L. Biochem. Syst. Ecol., 54, 19-22. https://doi.org/10.1016/j.bse.2013.12.009

Zeng C., Jiang W., Tan M., Xing J., and He C., 2016. Improved oral bioavailability of total flavonoids of *Dracocephalum moldavica via* composite phospholipid liposomes: Preparation, *in-vitro* drug release and pharmacokinetics in rats. Pharmacogn. Mag., 12(48), 313-318.