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Physical properties and texture of gluten-free snacks supplemented with selected fruit additions

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A b s t r a c t. Extrusion-cooking is used to produce directly expanded gluten-free snacks, especially for consumers with celiac disease. The aim of the study was to evaluate the effect of various fruits type supplementation as well as the processing screw speed on the physical properties and texture of ready-to-eat corn-based gluten-free snacks. Black elderberry, chokeberry and strawberry were dried and used in the amount of 5 to 20% as a corn grit replacement. The directly expanded snacks were processed with a single-screw extruder at various screw speeds (80 and 120 rpm) and tested to measure their expansion ratio, bulk density, colour profile as well as their texture profile. The results showed the various effects of adding different types and amounts of fruit on the physical properties and texture of supplemented gluten-free snacks. A higher amount of fruit resulted in a significant decrease in the expansion ratio and an increase in the bulk density of the snacks. Reduced lightness and a more pronounced red tint were observed when red fruits were added. The desired hardness of the snacks suggested that the addition of fruit should be retained below 15% of the recipe content. The screw speeds applied showed a significant effect on the expansion, bulk density and texture of the tested snacks.

K e y w o r d s: corn snacks, chokeberry, elderberry, strawberries, texture

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INTRODUCTION

In recent years, the consumption of snack foods has been growing rapidly due to the development of new processing methods and the use of new raw materials. Some of them fall within the category of functional foods as they contain health promoting ingredients with proven nutritional benefits. One of the technologies used in the manufacture of new types of functional snacks is extrusion-cooking. The HTST (high temperature-short time) extrusion-cooking method allows for the manufacture of modern snacks with an improved nutritional value and specific quality characteristics that meet the needs of contemporary consumers, especially gluten-free products for celiac disease patients (Bouasla *et al*., 2016, 2017; Mitrus and Moscicki, 2014; Oniszczuk *et al*., 2015). Extruded snacks can be produced without salt or sugar and with a very low fat content, therefore they may be a preferred choice for the diets of children (Potter *et al*., 2013; Wójtowicz *et al*., 2017). In the extrusion-cooking process ready-to-eat snacks are manufactured. The basic ingredients for directly expanded products are usually corn or rice grits. However, sometimes corn grit is replaced by other raw materials (Ačkar *et al*., 2018). This is mainly due to the fact that starch – the main component of corn snacks – is energy-rich but has a very low nutritional value. Therefore, in order to improve the nutritional and functional characteristics of gluten-free snacks, it is advisable to add some ingredients with specific functional properties (Dehghan-Shoar *et al*., 2010). Such enriching additives can, however, have a varied influence on the appearance and texture of snack products (Anton *et al*., 2009).

The beneficial effects of fruit and vegetables are attributed to their fibre content and antioxidant properties (Hidalgo and Almajano, 2017; Potter *et al*., 2013). One of the most promising additives are berries. Fruits require processing in order to extend their relatively short shelf life, they are dried, lyophilized, frozen or cooked with sugar to make jams or other preserves. Strawberries are primarily valued for their taste and intensive bright-red colour. Their consumption is widely promoted because they contain many antioxidants, including vitamin C. They also contain anthocyanins, fibre, and phenolic components (Bao *et al*., 2018). The most popular fruit in Poland is the strawberry (Gajdoš Kljusurić *et al.,* 2016). Also, chokeberry and elderberry are becoming more and more popular due to their antioxidant properties (Michalczyk *et al*., 2009). The chokeberry in particular exhibits such potential (Lipińska *et al*., 2017). It contains many healthy compounds such as polyphenols or anthocyanins. However, the fruit is not particularly popular among consumers as it is bitter and tart in taste (Lachowicz *et al*., 2018a). Another valuable fruit is elderberry which grows under natural conditions both in Europe and in South Africa or Western Asia. The fruit contains such compounds as anthocyanins, flavanols, or phenolic acids. Cyanidin glycosides are among its predominant anthocyanins (Pliszka, 2017). Several reports have cited the possibility of the application of berry fruits in food products such as juices (Lachowicz *et al*., 2018b; Ricci *et al*., 2019; Tundis *et al*., 2018; Wang *et al*., 2019), smoothies (Guazi *et al*., 2019), snacks (Gramza-Michałowska and Człapka-Matyasik, 2011; Kowalska *et al*., 2018a,b), jams (Banaś *et al*., 2018), pie fillings (Threlfall *et al*., 2007), flour confectionery (Osipenko *et al*., 2019), cookies, natural colourants (Wathon *et al*., 2019) in the form of dried/lyophilized and powdered fruits (Gagneten *et al*., 2019; Oniszczuk *et al*., 2016), extracts (Cilek *et al*., 2019) or residues (Drożdż *et al*., 2019).

The aim of this study was to process ready-to-eat corn-based gluten-free snacks supplemented with selected fruits (chokeberry, elderberry, strawberry) and to assess the physical properties and texture of the obtained crisps depending on the type and amount of additive and the screw speed applied during extrusion-cooking.

MATERIALS AND METHODS

Corn grits (purchased from Lubella Sp. z o.o. Sp. K., Lublin, Poland) were used as the basic raw material for the preparation of gluten-free snacks. Three types of fresh fruit were collected at the peak harvest time from local farmers. The black elderberries and black chokeberries were rinsed with tap water and dried using an air dryer at 40°C overnight. The fresh strawberry fruits were frozen in a laboratory freezer overnight and freeze-dried using an ALPHA 2-4 LD plus lyophilizer (Martin Christ GmbH, Germany) with a condenser temperature of -54°C and a heated shelf temperature of 40°C. Dry fruits with a moisture content below 5% were ground using a laboratory grinder TESTCHEM LMN10C (Radlin, Poland) to the size of particles with dimensions lower than 1 mm. Powdered fruits were used in the amounts of 5, 10, 15 and 20% (w/w) as a replacement for corn grits and mixed. The moisture content of the blends was set at 14% by the addition of distilled water.

Extruded corn snacks with fruit addition were made using a single screw extruder-cooker TS-45 (Z.M.Ch. Metalchem, Gliwice, Poland). They were shaped with a 3-mm circular forming die and cut just after they left the die. The ratio of the screw length to its diameter was L/D = 12. The temperature of processing used during the extrusion-cooking process was set at: 132 and 142ºC in section I and II, respectively and 135ºC at the forming die. The snacks were extruded at a screw speed of 80 and 120 rpm. They were then collected, cooled down to ambient temperature and stored in sealed plastic bags at room temperature prior to testing.

The obtained ready-to-eat snacks were tested to assess their expansion ratio, bulk density, and colour profile at the CIE-Lab scale and texture under different processing conditions and for the different types and quantity of additives used.

The expansion ratio was calculated as the ratio of snack diameter to the diameter of the forming die. The calculation was replicated 10 times for each type of snack (Bisharat *et al*., 2013).

The bulk density of the snacks was determined as the weight of a specific volume of the extrudates. The test was performed in triplicate (Wójtowicz *et al*., 2018).

The colour profile of the supplemented snacks was measured using the Color and Appearance Measurements System Lovibond CAM-System 500 (The Tintometer Ltd., Amesbury, UK) at the CIE-Lab scale. The results were presented as the means of 10 replications of the coordinate $L*$, $a*$ and $b*$. Parameter $L*$ described the balance between white (100) and black (0). The coordinate $a*$ indicates the balance between redness(+) and greenness(-), and $b*$ is defined as the balance between yellowness(+) and blueness(-). The total colour change was calculated as ΔE according to Wójtowicz *et al*. (2017) and Pęksa *et al*. (2016).

The texture profile was evaluated by using a Zwick/Roell BDO-FB0.5TH texture apparatus (Zwick GmbH & Co., Ulm, Germany) equipped with an Ottawa cell. A double compression test of up to 50% of the sample height was used to evaluate firmness (F), crispness (CR) fracturability

(F), springiness (S), cohesiveness (C), and chewiness (CH) with a working head test speed of 100 mm min^{-1}. Firmness was represented by the top peak force at the first compression cycle. Crispness was described as the first force peak needed to destroy the cellular structure of the extrudates. Springiness is the physical property of the snack describing its tendency to restore its original shape upon the termination of the first penetration cycle. Cohesiveness may be understood as the tendency of a product to cohere or stick together, and was determined as the work needed at the second deformation relative to the resistance under the first deformation. Chewiness, typical of solid foods, was determined as the hardness and cohesiveness ratio and showed how the extrudates behave during biting (Shah *et al*., 2017).

A statistical analysis ANOVA (at $\alpha = 0.05$) was performed using Statistica 13.3 software (StatSoft, USA) with an F-test and p values to evaluate the effect of the level of fruit addition and the screw speed applied during the experiment. A post hoc Tukey test was used to compare the mean values of the test results and homogenous groups identified the significance of differences.

RESULTS AND DISCUSSION

The high quality of the extruded snacks is usually determined by the high expansion index (Wójtowicz *et al*., 2018). Moreover, the intensity of treatment in the extrusion-cooking process depends on such properties as the expansion ratio and porosity (Jakubczyk *et al*., 2017; Lucas *et al*., 2018). During extrusion-cooking, several components undergo transformations. One of the most important of them is gelatinization which occurs in the melted dough inside the barrel, the dough cooks at a high temperature in the presence of water. Water bonded inside the treated material is turned into steam and evaporates immediately after the pressure drops outside the forming die. The expansion of the extruded snacks is the effect of a porous structure forming in melted starch and the protein matrix becoming rigid after cooling down. Generally, additives may disturb the gelatinization and melting processes and cause less expansion (Bisharat *et al*., 2013; Makowska *et al*., 2015). The expansion ratio of the extruded snacks decreased along with higher supplementation levels of chokeberry, elderberry and strawberry in relation to the control corn sample with high regression coefficients ranging from 0.889 to 0.998 (Fig. 1). The maximum value of the expansion ratio was observed for corn snacks (5.88) processed at 120 rpm. For almost all the tested snacks, higher screw speeds during processing caused the snacks to expand to a greater extent, regardless of the type of fruit used. As reported by Yanniotis *et al.* (2007) and Drożdż *et al.* (2019), the addition of fruits or its residues may lower the expansion ratio due to the high content of fibrous fractions, especially pectins, this occurs because fibre components limit starch gelatinization and thus lower the tendency for the formation of the honey-comb like structure of the extrudates.

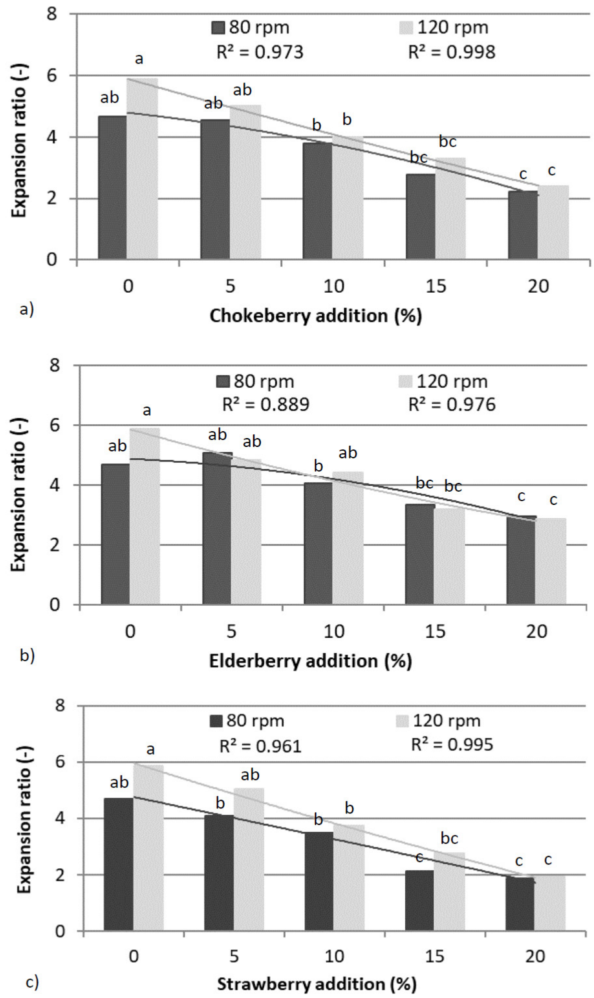

Fig. 1. Results of the expansion ratio of snacks supplemented with fruits processed under various screw speeds: a – chokeberry, b – elderberry, c – strawberry.

However, when analysing the results for snacks with the addition of elderberry, it was observed that the highest value of the expansion ratio (5.08) was achieved in extrudates with a 5% content of fruit processed at a screw speed of 80 rpm. Moreover, almost all of the samples which had elderberry fruits added to them were characterized by higher expansion values compared with snacks supplemented with chokeberry and strawberry. Minimum values of the expansion ratio were reported for corn snacks supplemented with 20% fruit additives with values of 1.88, 2.21 and 2.87 for strawberry (80 rpm), chokeberry (80 rpm), and elderberry (120 rpm), respectively. A statistical analysis (Table 1) showed that the addition of chokeberry, elderberry, and strawberry significantly affected the expansion ratio. When adding dried tomatoes to corn crisps, a decrease in expansion was also noted, which was attributed to the decreasing amount of starch in the recipe, and thus a lower amount of starch undergoing gelatinization and expansion, which made it impossible to form the intensely porous structure characteristic of extruded snacks (Wójtowicz *et al.*, 2018). An increase in the level of dried vegetables, like broccoli or olive paste, in the composition of corn crisps also caused a reduction in the expansion ratio. This phenomenon is related to the interaction that occurs between starch and protein (Bisharat *et al.*, 2013). Also, during the addition of bran to the corn snacks, it was noted that the expansion ratio index decreased with the increase in the bran level. Therefore, a high content of dietary fibre (mainly insoluble fractions) and a decreasing quantity of starch are thought to cause a lower expansion of corn snacks (Makowska *et al.*, 2015). Similar observations have been made if dried herbs were added to snacks (Oniszczuk *et al.*, 2015; Wójtowicz *et al.*, 2017).

Table 1. Results of a statistical analysis of selected physical properties of supplemented snacks depending on the fruit type and screw speed used during production

Variable	Additive type	Screw speed (rpm)	F-Test	p value
ER	Chokeberry	80	284.237	0.000
		120	44.037	0.000
	Elderberry	80	180.642	0.000
		120	27.273	0.000
	Strawberry	80	342.164	0.000
		120	61.009	0.000
BD	Chokeberry	80	6798.267	0.000
		120	1353.136	0.000
	Elderberry	80	669.178	0.000
		120	382.959	0.000
	Strawberry	80	13921.884	0.000
		120	4148.703	0.000
L^*	Chokeberry	80	4314.552	0.000
		120	6140.248	0.000
	Elderberry	80	5455.841	0.000
		120	4954.555	0.000
	Strawberry	80	2412.585	0.000
		120	2088.278	0.000
a^*	Chokeberry	80	106.427	0.000
		120	462.724	0.000
	Elderberry	80	78.385	0.000
		120	104.678	0.000
	Strawberry	80	174.708	0.000
		120	453.948	0.000
b^*	Chokeberry	80	447.987	0.000
		120	3941.308	0.000
	Elderberry	80	916.066	0.000
		120	1577.693	0.000
	Strawberry	80	331.914	0.000
		120	461.423	0.000

ER – expansion ratio; BD –bulk density; L^* – lightness; a^* – red-green balance; b^* – yellow-blue balance.

The literature on the subject points out that very often the reduction in expansion is inversely proportional to the measurement of bulk density (Lucas *et al.*, 2018). Similar trends were also observed in our study. The bulk density of ready-to-eat snacks should be as low as possible and tailored to suit the level of consumers' acceptance of expanded crisps. The bulk density of the tested gluten-free corn snacks supplemented with dried fruits increased with increasing amounts of additives (Fig. 2) and high regression coefficients, ranging from 0.887 to 0.999, were found. A similar relationship was noted during the addition of spirulina, bean flour or lyophilized tomato powder to snacks (Lucas *et al.*, 2018; Wójtowicz *et al.*, 2018). Furthermore, a statistical analysis (Table 1) showed that the addition of chokeberry, elderberry and strawberry fruits had a significant impact on bulk density. The lowest bulk density (38.26 kg m^{-3}) was observed in corn snacks with a 5% elderberry addition when processed at 120 rpm, followed by corn crisps extruded at 120 rpm (41.55 kg m^{-3}). This additive had a positive impact on the formation of the porous structure of crisps. The bulk density results showed that corn snacks containing the highest levels of fruits and processed at 80 rpm were the densest in each group. The highest density was measured for extrudates with a 20% of strawberry addition (215.35 kg m^{-3}) made at a screw speed of 80 rpm.

Colour is one of the crucial quality indicators for food. This parameter determines how attractive a product is for consumers (Lucas *et al.*, 2018). An analysis of colour (Table 2) showed L^* values ranging from 30.91 to 83.75, a^* values from 3.98 to 15.61 and b^* values from 0.40 to 22.23. The L^* values of the extruded snacks decreased as the supplementation levels of the chokeberry, elderberry and strawberry increased. The highest lightness value (82.06 and 83.75) as well as the maximum b^* value (19.36 and 22.30) were observed for the corn snacks without any additives made at screw speeds of 80 and 120 rpm, respectively, because of high lightness values and the intensive yellow colour of corn grits. Due to the higher amount of dried fruits, the lowering of the lightness values was correlated with reduced yellowness (Table 2). The lowest L^* value (30.91) was observed in corn snacks enriched with 20% chokeberry processed at a screw speed of 120 rpm. Also, the lowest value of the a^* coordinate (0.40) was observed for the same sample. This kind of berry has a black-navy

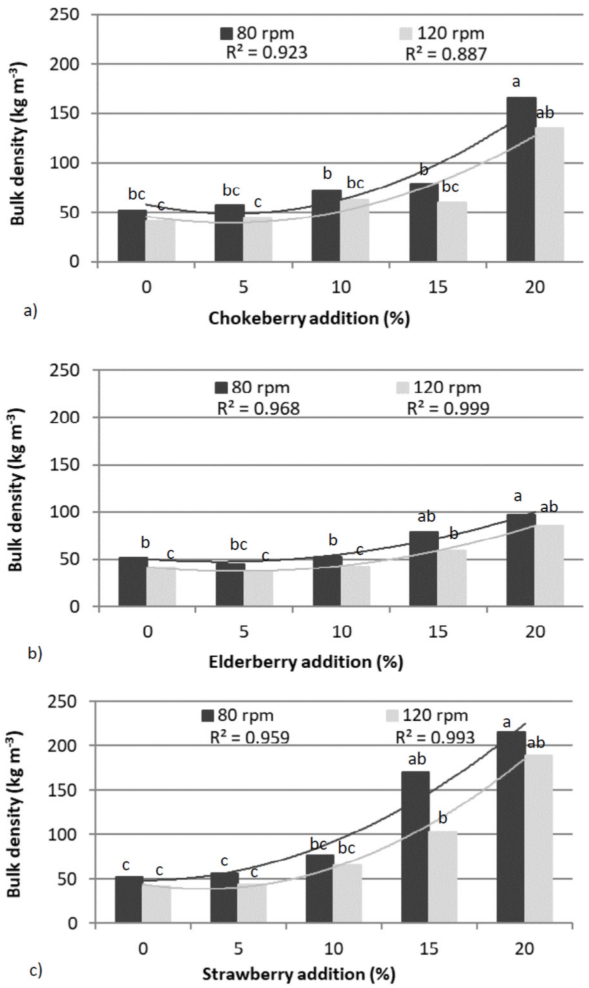

Fig. 2. Results of the bulk density of snacks supplemented with fruits processed under various screw speeds: a) chokeberry, b) elderberry, c) strawberry.

blue shade and was the darkest fruit among all the tested additives. In the case of the b^* value of the supplemented snacks, the most intensive yellowness (16.39) was found in snacks with a 20% strawberry addition processed at 120 rpm. Also, the negative correlation was observed between the a^* and b^* coordinates; an increase in the prominence of the red tint decreased the yellowness intensity of the supplemented snacks. Fewer correlations were noted for the L^* and a^* coordinates. A statistical analysis (Table 1) showed that the addition of chokeberry, elderberry and strawberry fruits significantly affected the L^*, a^* and b^* values. The production of extruded food is associated with changes in colour. This fact has been reported by other researchers (Ondo *et al*., 2013; Pęksa *et al*., 2016). These changes are attributed mainly to the raw materials used as well as to the reactions occurring during the process, *i.e.* the browning reactions, Maillard reactions or pigment degradation under extended thermal treatment (Athmaselvi *et al*., 2012; Han *et al*., 2018; Shah *et al*., 2017; Pasławska *et al*., 2010). ΔE values varied from 21.36 to 57.55 indicating the significant effect of fruit addition to the total colour change index (Table 2).

Texture is defined as a set of mechanical, structural and acoustic features that consumers perceive as the physical characteristics of food products. Texture testing is important because it covers the range of properties that determine the final product quality (Jakubczyk *et al*., 2017). Table 3 shows the mean values of the texture profile of corn snacks enriched with chokeberry, elderberry and strawberry made at 80 and 120 rpm.

The results of the texture profile of the extruded snacks are presented in Table 3. In compression testing firmness is usually evaluated as the maximum force under the first compression cycle. Maximum firmness (111.59 N) was found in corn snacks supplemented with a 20% chokeberry fruit addition followed by (105.14 N) corn snacks with a 20% strawberry fruit addition processed at 120 rpm. The lowest value of firmness (34.88 N) was noted in tested corn snacks with a 10% elderberry fruit addition extruded at 80 rpm. Moreover, almost all of the snacks enriched with up to 15% of dried fruits showed a low firmness, irrespective of the screw speed during processing. This may be attributed to the low bulk density and a high expansion of the snacks if a limited amount of dried fruits was added, and disintegration of the internal structure of the extruded material takes place. A statistical analysis (Table 4) showed that the addition of chokeberry, elderberry and strawberry significantly affected the firmness values. Firmness is related to the expansion ratio because harder products tend to have less expansion and increased density, as shown in Table 2. A similar relationship was reported during the evaluation of the influence of wheat fibre or almond flour on the hardness of extruded corn starch (Yanniotis *et al*., 2007; Hashemi *et al*., 2017).

Crispness is an important quality attribute which refers to the texture of brittle snacks. High-pitched sounds during biting and the specific structure (fragile and well-expanded) are typical for crispy extruded snacks (Philipp *et al*., 2017). A low crispness value is identified through brittleness and ease of breakdown. It is also associated with particular sound effects as a result of small and numerous peaks in the expanded and porous structure (Nascimento *et al*., 2012). As the force in the compression test is high, crispness is low. In our study, the minimum force (0.01 N), indicating favourable crispness levels, was observed for corn snacks with a 20% strawberry fruit addition processed at 120 rpm. The highest values of the first peak force (4.17 N) were observed for corn extrudates with a 15% addition of chokeberry extruded at 120 rpm. Furthermore, a statistical analysis (Table 4) showed that the addition of chokeberry and elderberry fruits to snacks processed at 120 rpm as well as strawberry fruit to products extruded at 80 rpm had a negligible effect on the value of crispness.

Table 2. Mean values of colour coordinates L^*, a^* and b^* of corn snacks enriched with fruit addition processed at various screw speed

Fruit type	Additive amount (%)	Screw speed (rpm)	Colour			
			L^*	a^*	b^*	ΔE
Control	0	80	82.06^{a}	3.98^{c}	19.36^{a}	Ref.
		120	83.75^{a}	4.14^{c}	22.23^{a}	Ref.
Chokeberry	5	80	46.46^{b}	8.22^{b}	7.77^{b}	37.68
		120	46.72^{b}	7.41^{b}	7.85^{b}	39.86
	10	80	40.20^{bc}	10.68^{ab}	4.37^{bc}	44.96
		120	36.91^{bc}	12.31^{a}	1.24^{c}	51.97
	15	80	33.43^{c}	10.36^{ab}	0.88^{c}	52.41
		120	34.02^{c}	11.08^{ab}	1.20^{c}	54.44
	20	80	32.76^{c}	9.72^{ab}	1.20^{c}	52.85
		120	30.91^{c}	10.76^{ab}	0.40^{c}	57.55
Elderberry	5	80	50.28^{b}	5.82^{bc}	11.96^{b}	32.68
		120	50.92^{b}	4.62^{c}	10.12^{b}	35.00
	10	80	44.58^{b}	6.54^{bc}	9.01^{b}	38.97
		120	45.18^{b}	6.70^{bc}	9.56^{b}	40.68
	15	80	37.49^{bc}	10.36^{ab}	0.88^{c}	48.67
		120	34.02^{c}	11.08^{ab}	2.04^{bc}	54.12
	20	80	35.33^{bc}	8.16^{b}	3.42^{bc}	49.55
		120	33.94^{c}	8.54^{b}	1.20^{c}	54.25
Strawberry	5	80	59.24^{ab}	7.55^{b}	15.22^{ab}	23.47
		120	63.24^{ab}	5.34^{bc}	16.39^{ab}	21.36
	10	80	55.42^{ab}	10.92^{ab}	13.86^{ab}	28.07
		120	56.36^{ab}	9.32^{ab}	13.40^{ab}	29.24
	15	80	37.49^{bc}	12.32^{a}	11.16^{b}	46.08
		120	49.24^{b}	8.31^{b}	9.17^{b}	37.13
	20	80	44.73^{b}	14.83^{a}	8.22^{b}	40.44
		120	45.30^{b}	15.61^{a}	8.30^{b}	42.47

L^* – lightness; a^* – red-green balance; b^* – yellow-blue balance; ΔE – total colour chance index, $^{a\text{-}c}$ – means indicated with similar letters in columns do not differ significantly at $\alpha = 0.05$.

Only the addition of elderberry and strawberry fruits has a significant effect on crispness when processed at 80 and 120 rpm, respectively.

The maximum value of fracturability (105.14 N) was noted in the corn snacks supplemented with a 20% addition of strawberry fruit processed at 120 rpm, while the minimum value (8.35 N) was reported for snacks enriched with a 5% addition of chokeberry fruit extruded at 120 rpm. The fracturability of the supplemented snacks was positively correlated with an increasing amount of dried fruits. Moreover, a statistical analysis (Table 4) showed that the addition of elderberry and strawberry fruits to corn snacks extruded at 80 rpm had no significant effect on the fracturability of the snacks. Only the addition of dried chokeberry and strawberry fruit significantly affected the fracturability value when the snacks were processed at 120 rpm.

Springiness is a physical property which may be defined as the rate at which a deformed material goes back to its undeformed condition after the deforming force is removed, it measures elastic recovery. Snacks should not be elastic, so a lower value indicates a favourable brittleness property of the extrudates. The maximum value of springiness (2.17) was observed in corn snacks processed at 120 rpm and supplemented with a 10% addition of strawberry fruit. The minimum value of springiness (1.10) was noted in snacks supplemented with a 5% addition of

Table 3. Mean values of the texture profile of corn snacks enriched with fruit addition processed at various screw speeds

Fruit type	Additive amount (%)	Screw speed (rpm)	F	CR	FR	S (-)	C	CH
				(N)			(N)	
Control	0	80	52.04[b]	1.54[b]	14.55[c]	1.65[ab]	0.05[ab]	2.39[bc]
		120	70.40[ab]	1.69[b]	19.20[bc]	1.82[ab]	0.05[ab]	3.81[b]
Chokeberry	5	80	45.89[b]	2.23[ab]	13.33[c]	1.10	0.03[b]	2.34[bc]
		120	51.41[b]	1.62[b]	8.35[d]	1.94[ab]	0.03[b]	1.33[bc]
	10	80	46.90[b]	3.53[a]	25.11[bc]	1.96[ab]	0.04[b]	1.95[bc]
		120	52.58[b]	1.94[b]	15.37[c]	1.92[ab]	0.04[b]	2.21[bc]
	15	80	53.84[b]	2.71[ab]	41.58[b]	1.46[b]	0.02[b]	1.34[bc]
		120	62.81[ab]	4.17[a]	38.55[b]	1.68[ab]	0.02[b]	0.99[c]
	20	80	76.32[ab]	2.14[ab]	36.14[b]	1.42[b]	0.06[ab]	4.45[b]
		120	111.59[a]	2.14[ab]	36.14[b]	1.42[b]	0.03[b]	3.78[b]
Elderberry	5	80	43.18[bc]	1.66[b]	16.44[c]	1.50[b]	0.03[b]	1.21[bc]
		120	44.77[b]	2.73[ab]	20.80[bc]	1.67[ab]	0.03[b]	1.25[bc]
	10	80	34.88[c]	3.15[a]	24.47[bc]	1.83[ab]	0.02[b]	0.83[c]
		120	40.18[bc]	2.12[ab]	24.76[bc]	1.85[ab]	0.02[b]	0.97[c]
	15	80	44.04[b]	1.87[b]	24.95[bc]	1.48[b]	0.01[b]	0.52[c]
		120	42.74[bc]	1.78[b]	20.41[bc]	1.41[b]	0.02[b]	0.95[c]
	20	80	69.41[ab]	2.66[ab]	22.05[bc]	1.47[b]	0.04[b]	2.76[bc]
		120	66.79[ab]	3.65[a]	27.16[bc]	1.58[b]	0.03[b]	1.91[bc]
Strawberry	5	80	44.92[b]	3.57[a]	31.53[b]	1.86[ab]	0.03[b]	1.34[bc]
		120	56.26[ab]	2.13[ab]	18.89[bc]	1.91[ab]	0.01[b]	0.65[c]
	10	80	61.74[ab]	2.86[ab]	25.10[bc]	1.70[ab]	0.02[b]	1.00[c]
		120	63.14[ab]	1.69[b]	37.20[b]	2.17[a]	0.02[b]	1.26[bc]
	15	80	80.95[a]	3.48[a]	42.61[b]	1.29[bc]	0.03[b]	2.14[bc]
		120	98.04[a]	2.40[ab]	58.20[ab]	1.65[b]	0.02[b]	1.78[bc]
	20	80	63.12[ab]	2.64[ab]	41.33[b]	1.19[c]	0.12[a]	7.87[ab]
		120	105.14[a]	0.01[c]	105.14[a]	1.54[b]	0.12[a]	12.39[a]

F – firmness, CR – crispness, FR – fracturability S – springiness, C – cohesiveness, CH – chewiness, [a-d] – means indicated with similar letters in columns do not differ significantly at $\alpha = 0.05$.

chokeberry fruit extruded at a low screw speed. Similar homogenous groups (Table 3) as well as the statistical analysis (Table 4) indicated that the addition of chokeberry, elderberry and strawberry fruits did not affect the springiness values to any significant extent, especially when extruded at 120 rpm. Only the addition of chokeberry fruit to snacks processed at 80 rpm had a noticeable impact on the springiness value.

Cohesiveness determines the intermolecular attraction of mass in the material, this property holds the snack together. It is related to the internal stickiness of a product and is usually determined by the amount of force required to remove an item from the product mass. The cohesiveness of corn snacks was very limited due to its porous structure and ranged from 0.01 to 0.12 N, but a statistical analysis indicated that the addition of chokeberry, elderberry and strawberry fruits significantly affected the cohesiveness value (Table 4). The maximum chewiness of the snacks (12.39 N) was found for corn crisps supplemented with a 20% addition of strawberry fruit processed at 120 rpm, nevertheless all of the tested samples enriched with a 20% addition of dried fruits exhibited a higher degree of chewiness due to the low expansion and high density of the products. The lower values for chewiness were noted for corn snacks with a maximum addition of 15% dried fruits and varied from 0.65 to 2.34 N. Slightly higher chewiness

Table 4. Results of an ANOVA statistical analysis of corn snacks texture parameters depending on the type of fruit used and screw speed during processing

Variable	Additive type	Screw speed (rpm)	F-Test	p value
F	Chokeberry	80	17.107	0.000
		120	129.162	0.000
	Elderberry	80	64.581	0.000
		120	24.331	0.000
	Strawberry	80	17.031	0.000
		120	82.686	0.000
CR	Chokeberry	80	2.332	0.091
		120	3.084	0.049
	Elderberry	80	3.530	0.025
		120	2.328	0.091
	Strawberry	80	2.216	0.104
		120	6.714	0.001
FR	Chokeberry	80	3.158	0.036
		120	7.771	0.0006
	Elderberry	80	2.118	0.116
		120	0.576	0.683
	Strawberry	80	1.712	0.189
		120	25.516	0.000
S	Chokeberry	80	3.469	0.026
		120	0.427	0.787
	Elderberry	80	0.358	0.835
		120	0.755	0.566
	Strawberry	80	1.745	0.179
		120	2.470	0.078
C	Chokeberry	80	7.119	0.001
		120	38.000	0.000
	Elderberry	80	10.000	0.0001
		120	19.227	0.000
	Strawberry	80	30.299	0.000
		120	58.417	0.000
CH	Chokeberry	80	13.601	0.00002
		120	55.939	0.000
	Elderberry	80	20.580	0.000
		120	26.337	0.000
	Strawberry	80	21.593	0.000
		120	66.835	0.000

Explanations as in Table 3.

levels were reported for the control corn snacks with values of 2.39 and 3.81 N if 80 and 120 rpm was applied during processing, respectively. A statistical analysis (Table 4) showed that the addition of chokeberry, elderberry and strawberry fruit has a significant impact on the chewiness of the extruded snacks.

CONCLUSIONS

1. Gluten-free corn snacks supplemented with dried fruits in the amount of 5-20% were made by using the extrusion-cooking technique. The results showed various effects of the addition of different fruit types on the physical properties and texture of the supplemented gluten-free snacks.

2. A higher content of black elderberry, black chokeberry and strawberry fruits had a significant impact on the reduction of the expansion index as well as increasing the bulk density of the snacks.

3. The addition of dried fruits caused a decrease in the lightness values $L*$ of the snacks and a more pronounced red tint $a*$ depending on the colour (red) of the fruits used. Some differences were observed depending on the fruit type and amount applied.

4. For all of the tested snacks, a significant increase in firmness was noted with higher amounts of fruits used in the recipe. Snack texture suggests that the dried fruit content of the recipe should not exceed 15% as higher fruit levels increase snack hardness to an unacceptable level.

5. The various screw speeds applied during the experiment showed significant effects on the expansion, bulk density and texture of the tested snacks. The addition of chokeberry and strawberry fruits to snacks processed at 120 rpm had a significant impact on the fracturability values.

6. Appropriate quality features were obtained when a 120 rpm screw speed was applied for processing the ready-to-eat expanded corn-snacks supplemented with dried fruits.

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