

The influence of freeze-dried red and purple potatoes on content of bioactive polyphenolic compounds and quality properties of extruded maize snacks

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Abstract

Taking into account, that freeze-dried red and purple potatoes are a rich source of polyphenols, mostly anthocyanins, it seems reasonable to utilise such raw material, free of gluten, to produce gluten-free snacks based on maize, by means of extrusion. The aim of the study was to analyse the content of bioactive polyphenols in extruded maize snacks with varying share of freeze-dried red and purple potatoes of the varieties Magenta Love and Blue Star, and to evaluate their antioxidant potential. Additionally the analysis of consumer acceptance of such products was performed. It was observed, that maize extrudates with a share of freeze-dried red and purple potatoes are an innovative, valuable pro-health product which could be used by healthy consumers, but also by the people with certain dietary disorders, such as celiac disease. Application of 25% share of freeze-dried red potatoes Magenta Love variety to extrudates proved to be the best in terms of content of bioactive compounds and antioxidant activity. Also the colour, high sensory scores and improved texture properties suggest that such a product could be well accepted on the market.

Keywords: antioxidant activity, antioxidant, extrusion, lyophilisation

1. Introduction

Red and purple potatoes have recently gained much interest of food producers, as they are a source of many bioactive polyphenols, including anthocyanins (Brown *et al.*, 2003; Lachman *et al.*, 2009). Bioactive compounds of potatoes included in a group of polyphenols involve phenolic acids (chlorogenic acid, gallic acid, ferulic acid, protocatechuic and caffeic acids), flavonoids (catechin, epicatechin, quercetin, rutin, myricetin and kaempferol) and the above mentioned anthocyanins acylated with phenolic acids. Purple-fleshed potatoes contain petunidin- and malvidin-3-rutinoside-5-glucosides acylated with p-coumaric and ferulic acid while red-fleshed potatoes are rich in pelargonidin- and peonidin-3-rutinoside-5-glycosides acylated with p-coumaric and ferulic acid (Brown *et al.*, 2003; Lachman *et al.*, 2009; Nara *et al.*, 2006; Reyes *et al.*, 2005). Phenolic compounds have multi-directional

biological activity. The research on polyphenols, mostly phenolic acids and flavonoids, proved that they have a broad spectrum of bacteriostatic and pharmacologic activities, positively impact blood vessels and heart, and protect against various types of radiation, burns and frostbites. They exert anti-inflammatory, anti-allergic, anti-carcinogenic, anti-viral and anti-thrombotic effects (Benavente-Garcia *et al.*, 1997; Krystyjan *et al.*, 2015; Middleton *et al.*, 2000; Silva *et al.*, 2000).

Taking into account, that freeze-dried red and purple potatoes are a rich source of polyphenols, mostly anthocyanins, it seems reasonable to utilise such raw material, free of gluten, to produce gluten-free snacks based on maize, by means of extrusion. Extrusion is a versatile industrial technique commonly utilised in the food industry, which could be used to obtain products with pro-health attributes (Riaz, 2002). The application

of extrusion guarantees that the products are free from microbiological contaminations and contain negligible levels of acrylamide, and have a prolonged shelf life (Riaz, 2002; Riaz and Rokey, 2012). It could be expected that application of freeze-dried red and purple potatoes in the production of snacks would be a better option than fruit-based additives (Camire *et al.*, 2007; Gumul *et al.*, 2011), because of a high content of anthocyanins, which have a strong anti-mutagenic, anti-cancer and anti-hypertensive activity (Ahmed *et al.*, 2010). Additionally the anthocyanins present in red and purple potatoes are more stable (upon thermal processing – extrusion) and bioavailable than those from coloured fruits, because they exist in an acylated form (Lachman *et al.*, 2009). Therefore it could be expected that red and purple potatoes would enrich snacks in pro-health constituents more effectively than coloured fruits. It could be suggested that maize based snacks with a share of freeze-dried red and purple potatoes could become an innovative and valuable pro-health product not only for ordinary consumers, but also for people with gluten intolerance. Such an addition would be especially important for celiacs, who have to adhere to a strict diet, usually deprived of many nutritive and dietary components (McGough and Cummings, 2005; Rodrigo, 2006). The trial to produce and evaluate maize snacks with a share of freeze-dried red and purple potatoes seems to be justified.

The aim of the study was to analyse the content of bioactive polyphenols in extruded maize snacks with varying share of freeze-dried red and purple potatoes of the varieties Magenta Love and Blue Star, and to evaluate their antioxidant potential. Additionally, the parameters which influence the consumer acceptance of such products were determined, including their colour, texture and other sensory parameters. The final objective was to choose variety of potatoes and supplementation level, which could have the best impact on content of bioactive compounds, texture, colour and sensory evaluation of the products.

2. Materials and methods

Materials

Potatoes of varieties Magenta Love (red potato), Blue Star (purple potato) were grown in year 2015 in a field nursery at the Department of Environmental Protection and Organic Farming in Spišská Belá (Slovakia). The potatoes were freeze-dried for 40 h in a lyophilizer Gamma 1-16 LSC (Christ, Germany) – applying temperature of the shelves 20 °C and pressure 0.1 mbar. The freeze-dried red potatoes were grinded in a laboratory grinder Grindomix GM200 (Retsch GmbH & Co, Haan, Germany) and used for the production of maize extrudates, which were further analysed.

Extrusion was performed in a single screw laboratory extruder 20DN (Brabender, Duisburg, Germany), applying the following parameters: screw speed=190 rpm, dye diameter=3 mm, compression ratio=1:2, and temperature profile 150/165/180 °C. Moisture level in all the premixes used for extrusion was equilibrated to 13%.

Extrudates used in the study were prepared on the base of maize meal (100% – control), which was in 5, 15 and 25% replaced by freeze-dried red and purple potatoes.

In this publication (in the Tables and Figure) the following abbreviations were used:

- BS; ML =freeze-dried potatoes variety: Blue Star, Magenta Love, respectively;
- Control=control extrudate (100% maize meal);
- EML5; EML15; EML25=extrudate with a share of 5% of freeze-dried red potato variety Magenta Love; extrudate with a share of 15% of freeze-dried red potato variety Magenta Love; extrudate with a share of 25% of freeze-dried red potato variety Magenta Love; respectively;
- EBS5; EBS15; EBS25=extrudate with a share of 5% of freeze-dried purple potato variety Blue Star; extrudate with a share of 15% of freeze-dried purple potato variety Blue Star; extrudate with a share of 25% of freeze-dried purple potato variety Blue Star, respectively.

Methods

The following analyses were performed on each sample of freeze-dried potatoes, and obtained extrudates:

antioxidant constituents, antiradical and antioxidant activity were determined in the ethanol extracts. 0.6 g of the sample was dissolved in 30 cm³ 80% ethanol, shaken in a darkness for 120 min. (electric shaker: type WB22, Memmert, Schwabach, Germany), and centrifuged (15 min. 4,000 rpm.) in centrifuge (type MPW-350, MPW MED. Instruments, Warsaw, Poland). The supernatant was decanted and stored at -20 °C for further analyses.

Determination of total polyphenols content (TPC) was done by two spectrophotometric methods (1) using Folin-Ciocalteu reagent (with F-C reagent), according to Singleton *et al.* (1999); and (2) without using Folin-Ciocalteu reagent (without F-C reagent), according to Mazza *et al.* (1999), with the modification of Oomah *et al.* (2005). The content of phenolic acids was measured using a spectrophotometrical method, according to Mazza *et al.* (1999), with the modification of Oomah *et al.* (2005). The content of flavonols was measured spectrophotometrically, according to Mazza *et al.* (1999), with the modification of Oomah *et al.* (2005). Determination of the content of anthocyanins was done spectrophotometrically, according to Mazza *et al.* (1999), with the modification of Oomah *et al.* (2005). The content of flavonoids was evaluated using

a spectrophotometrical method, according to El Hariri *et al.* (1991)

Additionally antiradical and antioxidant activity was assessed using different analytical methods, namely DPPH (2,2-diphenyl-1-picrylhydrazyl) and FOMO (using of a phosphomolybdenum complex). Antiradical activity was measured by spectrophotometric method, using DPPH (according to Brand-Williams *et al.*, 1995). Antioxidant activity was measured spectrophotometrically using of a phosphomolybdenum complex (i.e. FOMO methods, according to Prieto *et al.*, 1999). Results of antiradical and antioxidant activity were expressed as trolox equivalent antioxidant capacity (TEAC) – mg Trolox per g dry mass of sample).

Analysis of colour

Colour of sample was analysed by instrumental method in Commission internationale de l'éclairage (CIE; <http://www.cie.co.at>) L*a*b* system. Determination of reflectance in CIE system (International Commission on Illumination, 2004) was done using spectrophotometer (Konica MINOLTA CM-3500d, Tokyo, Japan) at an angle 10°, with a slit width 30 mm. Samples were put in Petri's dishes with a diameter 55 mm. The measurement allowed determination of the following parameters: L*=luminance (L*=0 black, L*=100 white); a*=the intensity of green (a*<0) or red (a*>0); b*=the intensity of blue (b*<0) or yellow (b*>0). Each sample was analysed in 4 replicates. Colour differences (ΔE^*_{ab}) between individual samples were calculated as follows: $\Delta E^*_{ab} = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2}$ (International Commission on Illumination, 2004).

Texture analysis

Texture analysis was performed using texture analyser TA-Xt+ (Stable Micro Systems, Ltd., Surrey, UK), equipped with HDP/KS5 (Kramer shear cell 5 blade). The sample (of the length 35 mm) was torn by two adjacent blades moving at speed 5 mm/s, and the following parameters were measured – jaggedness as the linear distance of the resulting curve, breaking strength as the maximum force, shear work as the area under the obtained curve. All measurements were done in ten replicates.

Sensory analysis

Sensory analysis was performed according to PN-EN-ISO 6658 (PKN, 1998). Seven samples: control, EML5, EML15; EML25; EBS5; EBS15; EBS25 were assessed by a group twelve panellists with established sensory sensitivity. Analyses were done in a laboratory designed and equipped with respect to PN-ISO 8589 (PKN, 1998). Quality attributes: shape and appearance (coefficient of importance: 0.2), consistency (0.25), structure (0.15), smell and taste (0.4)

were measured on the 5-point scale. Consumer acceptability was rated as follows: 1 point=unacceptable; 2 points=poor; 3 points=satisfactory; 4 points=desirable; 5 points=very desirable.

Statistical analysis

The results were statistically compared basing on the Duncan's test, at the significance level 0.05, with the use of computer programme Statistica 8.0PL (Statsoft, Inc., Tulsa, OK, USA). All the measurements were done at least in duplicate. Correlation coefficient was measured with the use of computer programme Statistica 8.0PL.

3. Results and discussion

Characteristics of freeze-dried red and purple potatoes used in the production of extruded maize snacks

Anthocyanins are one of the major groups of polyphenolic compounds in red and purple potatoes, so the intensity of colour of red and purple potatoes allows to roughly estimate their antioxidant properties. It was observed that the analysed samples differ highly in colour parameters. Freeze-dried potatoes variety Blue Star, exhibiting purple colour, were characterised by much higher values of L* parameters, and were significantly lighter than red potatoes of red variety – Magenta Love (Table 1). Visible differences could be observed also in two other parameters a* and b*. Freeze-dried red potato variety Magenta Love displayed significantly (two times) higher values of a* and significantly (twice) smaller values of b* in comparison to purple potato variety Blue Star (Table 1).

The characteristics of freeze-dried red and purple potato preparations included also the content of bioactive polyphenol compounds and antioxidant activity. It could be noticed, that freeze-dried red potatoes variety Magenta Love had higher content of polyphenols in comparison to purple potato variety Blue Star, in both applied measurement methods, with F-C reagent (Singleton *et al.*, 1999) and without the reagent, according to Mazza *et al.* (1999) with the modification of Oomah *et al.* (2005). Similar tendency could be seen for polyphenol fractions, namely phenolic acids, flavonols, anthocyanins and flavonoids in analysed freeze-dried preparations (Table 1).

In the studies performed by Lachman *et al.* (2009) concerning the content of total polyphenols in red and purple potatoes, their content ranged from 455 to 481 mg of gallic acid/100 g of dry mass, while according to Kita *et al.* (2015) the content of total polyphenols is in the range 250–526 mg of gallic acid/100 g of dry mass. The studies of Andre *et al.* (2007) resulted in 285 mg/100 g. In order to compare the results presented here with those of other authors, they were also expressed in gallic acid. The content

of polyphenols in potato variety Magenta Love and Blue Star was respectively 837 and 415 mg of gallic acid/100 g of dry mass.

The content of flavonoids according to Lewis *et al.* (1998) ranged from 500 to 900 mg/100 g of fresh red and purple potatoes. The content of anthocyanins results reported by other authors were 0.160-0.571 mg of cyanidin-3-glucoside/g of dry mass (Kita *et al.*, 2015), 0.440-6.962 (Reyes *et al.*, 2005), 0.028-2.970 (Lachman *et al.*, 2009). While there is no available data concerning the levels of antioxidant compounds in freeze-dried preparations, so the comparison could be done only with the values reported for raw potatoes, recalculating their levels on dry mass. The obtained values were in general agreement with our data.

Some discrepancies could occur due to varying methods of determination of these compounds, extraction, and other factors (Reyes *et al.*, 2005).

Freeze-dried red potatoes, variety Magenta Love exhibited higher antioxidant activity than the preparation acquired from purple potatoes, variety Blue Star, in parallel to the contents of the above mentioned polyphenolic compounds (Table 1).

The influence of freeze-dried potatoes on physical properties of extruded maize snacks and its sensory evaluation

An application of freeze-dried red and purple potatoes caused significant differences in colour parameters of extrudates (Table 2) both in comparison to control sample

and between samples which contained different share (5, 15 and 25%) of red and purple potatoes. The control sample was the brightest (highest L*), because the increasing share of potatoes, caused product darkening. The changes were not excessive, however statistically significant. In terms of a* parameter only the extrudates with 5 and 15% share of freeze-dried potatoes variety Blue Star did not differ statistically from each other, and all samples varied significantly from control. The application of freeze-dried purple potatoes variety Blue Star, caused a statistically significant decrease of redness in comparison to control. The extrudates containing freeze-dried red potatoes, variety Magenta Love were more red than control. The extrudates obtained with the lowest share of potatoes did not differ from each other in b* parameter. On the other hand all extrudates were less yellow than the control sample, and the extent of the observed changes was -8 to -20% (in the case of freeze-dried red potatoes) or -23% (in the case of freeze-dried purple potatoes). The changes were increasing with rising share of potatoes. In general, potato varieties, applied in each level, caused a significant change of extrudate's colour in comparison to snacks based on pure maize (ΔE^*). Even the smallest amounts of freeze-dried purple potatoes caused changes visible even for an untrained observer, and the effects of the same level of red potato were even more evident. The colour of all other snacks was so different from control, that two distinct colours could be defined for them (Table 2).

Jaggedness, defined as the linear distance of the curve registered during snack breaking (force versus time), reflects the complexity of inner structure (Gumul *et al.*, 2011), which was the highest in the case of samples with

Table 1. Characteristics of freeze-dried red and purple potatoes.^{1,2}

	Blue Star	Magenta Love
L*	64.21±0.40 ^b	59.61±0.10 ^a
a*	10.43±0.20 ^a	21.76±0.00 ^b
b*	-8.87±0.00 ^a	-5.13±0.11 ^b
Total phenolic content (mg catechin/g d.m.) without F-C reagent	6.912±0.130 ^a	14.891±0.010 ^b
Content of phenolic acid (mg ferulic acid/g d.m.)	1.123±0.08 ^a	3.105±0.01 ^b
Content of flavonoids (mg rutin/g d.m.)	3.991±0.045 ^a	8.725±0.056 ^b
Content of flavonols (mg quercetin/g d.m.)	0.468±0.011 ^a	1.174±0.031 ^b
Content of anthocyanins (mg cyanidin-3-glucoside/g d.m.)	1.007±0.013 ^a	2.637±0.089 ^b
Total phenolic content (mg catechin/g d.m.) with F-C reagent	8.21±0.01 ^a	16.55±0.07 ^b
DPPH (TEAC; mg Trolox/g d.m.)	2.42±0.05 ^a	2.97±0.03 ^b
FOMO (TEAC; mg Trolox/g d.m.)	25.11±1.78 ^a	62.72±0.83 ^b

¹ Presented data are mean values ± standard deviation (values followed by the same superscript letters in a particular row are not significant at 0.05 level of confidence).

² L* = luminance (L*=0 black, L*=100 white); a* = intensity of green (a*<0) or red (a*>0); b* = the intensity of blue (b*<0) or yellow (b*>0); F-C reagent = Folin-Ciocalteu reagent; TPC = total polyphenols content; DPPH = 2,2-diphenyl-1-picrylhydrazyl; FOMO = phosphomolybdenum complex; TEAC = trolox equivalent antioxidant capacity.

freeze-dried potatoes variety Blue Star, while all other samples did not differ statistically from each other. More pronounced changes could be observed in the case of shear work, which tended to increase after the application of Blue Star preparation (in the case of 15% the change was statistically significant), and decrease after Magenta Love preparation was applied (statistically significant changes could be observed for 15 and 25% share) (Table 3).

Also in the case of breaking strength a decreasing trend could be observed, when Magenta Love preparation was used, but no statistically significant changes could be found after application of Blue Star. In general it could be observed that the application of freeze-dried potatoes had only limited effect on texture of the snacks. A decrease in breaking strength and shear work, observed after application of freeze-dried potatoes, variety Magenta Love, could be regarded as beneficial (Table 3), because low hardness is generally desirable in puffed snacks (Mesquita *et al.*, 2013).

The above mentioned quality indices are important in sensory assessment, which was performed by a panel of 12 experts. It has been observed that among all analysed maize extrudates with freeze-dried red and purple potatoes, the best quality scores were displayed by extrudate with 25% share of red potatoes, variety Magenta Love. High sensory quality of the extrudate was caused mainly by its smell and taste, structure and consistency (Figure 1).

Good sensory scores of the extrudates containing 25% share of freeze-dried red potatoes, variety Magenta Love are not surprising, taking into account the results of texture

parameters (Table 3), which are important factors in the sensory assessment and influence consumer acceptance. In the studies of Gumul *et al.* (2011) concerning the extrudates with defatted blackcurrant seeds it was shown that their 30 and 50% share significantly deteriorated sensory assessment. The best results were obtained with 10% share of this component, because of their smell, taste, consistency and shape. Similarly an improvement of structure, shape and appearance was caused by 10% share of residual oat flour in extruded maize snacks (Gumul *et al.*, 2015), while in the studies of Stojceska *et al.* (2008) concerning extrudates with 5-20% cauliflower by-products it was observed that

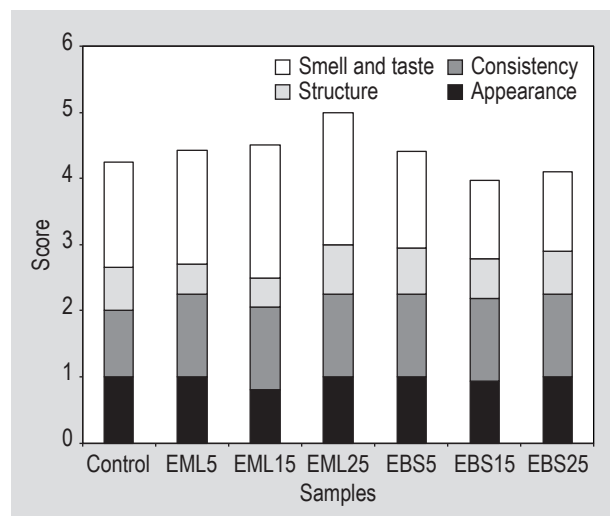


Figure 1. Sensory assessment of extrudates with a share of freeze-dried red and purple potatoes.

Table 2. Colour of extrudates with a share of freeze-dried red and purple potatoes.^{1,2}

Samples	L*	a*	b*	ΔE
Control	77.39±0.21 ^g	4.55±0.10 ^b	36.66±0.23 ^e	–
EML5	74.58±0.25 ^e (-4%)	6.70±0.08 ^c (+47%)	33.53±0.29 ^d (-8%)	4.73±0.29 ^b
EML15	71.09±0.42 ^b (-8%)	8.61±0.15 ^d (+89%)	30.88±0.68 ^c (-16%)	9.47±0.68 ^d
EML25	67.86±0.02 ^a (-12%)	9.45±0.24 ^e (+107%)	29.12±0.56 ^b (-20%)	13.11±0.56 ^f
EBS5	76.53±0.03 ^f (-1%)	3.95±0.02 ^a (-14%)	33.60±0.28 ^d (-8%)	3.24±0.28 ^a
EBS15	72.63±0.17 ^d (-6%)	4.07±0.11 ^a (-10%)	29.81±0.61 ^b (-19%)	8.35±0.61 ^c
EBS25	71.63±0.09 ^c (-7%)	4.32±0.17 ^b (-5%)	28.18±0.73 ^a (-23%)	10.26±0.73 ^e

¹ Presented data are mean values ± standard deviation (values followed by the same superscript letters in a particular column are not significant at 0.05 level of confidence). Values between parentheses indicate changes (%) in comparison to control.

² L* = luminance (L*=0 black, L*=100 white); a* = intensity of green (a*<0) or red (a*>0); b* = the intensity of blue (b*<0) or yellow (b*>0); ΔE = colour differences.

Table 3. Texture of extrudates with a share of freeze-dried red and purple potatoes.¹

Sample	Jaggedness (N·s)	Shear work (J)	Breaking strength (N)
Control	859±55 ^a	0.501±0.031 ^{bc}	46.9±3.1 ^c
EML5	910±83 ^{ab} (+6%)	0.459±0.035 ^b (-8%)	39.9±5.4 ^{ab} (-15%)
EML15	862±64 ^a (0%)	0.359±0.045 ^a (-28%)	36.1±4.1 ^a (-23%)
EML25	897±37 ^{ab} (+4%)	0.345±0.017 ^a (-31%)	39.3±6.9 ^a (-16%)
EBS5	952±41 ^{bc} (+11%)	0.544±0.036 ^{cd} (+8%)	49.6±3.3 ^c (+6%)
EBS15	1,075±67 ^d (+23%)	0.570±0.079 ^d (+14%)	51.5±7.3 ^c (+10%)
EBS25	1,003±47 ^{cd} (+17%)	0.496±0.035 ^{bc} (-1%)	46.2±3.0 ^{bc} (-1.5%)

¹ Presented data are mean values ± standard deviation (values signed the same letters in particular columns are not significant at 0.05 level of confidence). Values between parentheses indicate changes (%) in comparison to control.

their share up to 10% is acceptable, while higher amounts of such components result in a decrease of sensory scores due to smell and taste.

The influence of freeze-dried potatoes on content of bioactive polyphenolic compounds and antioxidant activity of extruded maize snacks

The extrudates with a share of freeze-dried red and purple potatoes were characterised by elevated TPC as compared to the product obtained from pure maize meal (control). The increase was parallel to the applied level of freeze-dried coloured potatoes. It could also be found that the application of red potato variety Magenta Love as an additive caused much stronger effects than the use of purple potatoes, variety Blue Star. Although the content of total polyphenols determined with the use of F-C reagent is useful for calculations of correlation between TPC and antioxidant activity, the results may not be precise according to many authors (Shahidi and Naczki, 1995), because the reagent could react not only with polyphenols but also with other food components, such as vitamin C, some alkaloids, amino acids, proteins, polysaccharides and organic acids. This is why the content of total polyphenols was also determined spectrophotometrically without the use of F-C reagent by the method of Mazza *et al.* (1999) with modification of Oomah *et al.* (2005). The snacks with a share of freeze-dried coloured potatoes were characterised by higher amounts of polyphenols than control sample (Table 4).

Moreover similarly as in the method with F-C reagent, the content of polyphenols in snacks increased in parallel to

a percentage of applied potato component (Tables 4 and 5). Among all analysed snacks, those with 25% share of freeze-dried potatoes variety Magenta Love were the richest in polyphenols. In the case of phenolic acids, it could be observed that the application of freeze-dried red potatoes caused their increase by approximately 105%, while the rise after using purple potatoes, variety Blue Star was about 38% in comparison to control. Also in this case the successive increase in phenolic acids could be seen, accompanying the applied share, and the values measured in the case of Blue Star variety were smaller. The largest level of phenolic acids could be found in snacks with 25% share of freeze-dried potatoes, variety Magenta Love (Table 4).

Taking into account the content of flavonoids, two-fold or even six-fold increase in their content could be observed after the application of freeze-dried coloured potatoes, and much stronger effects were seen after applying red potatoes, variety Magenta Love. Similarly as in the case of polyphenols and phenolic acids, a stepwise increase in their content could be seen with their growing share (Table 4). In the case of flavonoid fractions, namely flavonols and anthocyanins, no such dependence could be found. In the case of flavonols, it could be observed, that the share of 5% freeze-dried red and purple potatoes, did not have a significant effect in comparison to control. Larger share (15 and 25%) resulted in increase of flavonols in extrudates with freeze-dried potatoes. The content of anthocyanins in extrudates containing 15 and 25% of freeze-dried red potatoes, variety Magenta Love increased by 24 and 64% in comparison to control, respectively, while their level in extrudate prepared with 5% share was virtually unaffected. In the extrudates prepared with freeze-dried potatoes,

Table 4. Content of phenolic compounds in extrudates with a share of freeze-dried red and purple potatoes.^{1,2}

Samples	Total phenolic content (mg catechin/ g d.m.) without F-C reagent	Content of phenolic acid (mg ferulic acid/ g d.m.)	Content of flavonoids (mg rutin/ g d.m.)	Content of flavonols (mg quercetin/ g d.m.)	Content of anthocyanins (mg cyanidin-3-glucoside/ g d.m.)
Control	1.319±0.043 ^a	0.241±0.003 ^a	0.353±0.027 ^a	0.167±0.000 ^a	0.291±0.010 ^a
EML5	1.567±0.131 ^b (+19%)	0.292±0.018 ^c (+21%)	0.848±0.027 ^d (+140%)	0.166±0.010 ^a (0%)	0.295±0.000 ^a (0%)
EML15	2.476±0.064 ^d (+88%)	0.474±0.014 ^d (+96%)	1.722±0.064 ^f (+387%)	0.252±0.005 ^b (+51%)	0.361±0.024 ^b (+24%)
EML25	4.175±0.074 ^e (+216%)	0.725±0.009 ^e (+200%)	2.061±0.033 ^g (+484%)	0.327±0.014 ^c (+96%)	0.479±0.000 ^c (+64%)
EBS5	1.553±0.268 ^b (+18%)	0.249±0.000 ^b (+3%)	0.472±0.014 ^b (+34%)	0.181±0.007 ^a (0%)	0.296±0.000 ^a (0%)
EBS15	1.883±0.052 ^c (+43%)	0.301±0.032 ^c (+25%)	0.769±0.030 ^c (+118%)	0.208±0.013 ^b (+25%)	0.295±0.024 ^a (0%)
EBS25	2.585±0.231 ^d (+96%)	0.447±0.030 ^d (+85%)	0.988±0.079 ^e (+180%)	0.235±0.014 ^b (+41%)	0.295±0.000 ^a (0%)

¹ Presented data are mean values ± standard deviation (values signed the same letters in particular columns are not significant at 0.05 level of confidence). Values between parentheses indicate changes (%) in comparison to control.

² F-C reagent = Folin-Ciocalteu reagent.

variety Blue Star the level of anthocyanins did not depend on their share and was the same as in control (Table 4). Lack of direct correspondence between the results of flavonols and anthocyanins on one hand and flavonoids on the other can be explained by the presence of other flavonoid substances not determined as separate fraction, such as flavans or isoflavons.

Taking into account a decrease of phenolic substances during extrusion, which could be caused by their depolymerisation, decarboxylation (in the case of phenolic acids) or polymerisation of phenolic compounds and tannins due to high temperature and moisture, reduce extractability and antioxidant activity (Dlamini *et al.*, 2007; Repo-Carrasco-Valencia *et al.*, 2009), an addition of plant materials which is rich in phenolic compounds could be important for pro-health quality of the obtained snacks. In fact the use of freeze-dried red and purple potatoes resulted in a significant increase of those pro-health phenolic compounds in the final product. A significant rise of total polyphenols, phenolic acids, flavonols, anthocyanins and flavonoids was especially visible when red potato variety Magenta Love was used.

Although the enrichment of extruded snacks with pro-health or nutritive components was studied by many authors, most of them were focused on protein and legume additives, less on fruit and only a few studies were done on vegetables.

Korus *et al.* (2007) observed that the amount of total polyphenols decreased in extrudates with a share of common beans, as compared to control. Similarly, Delgado-Licon *et al.* (2009) reported a significant loss of TPC after extrusion of bean/maize mixture. A drop in TPC was also observed by Shih *et al.* (2009) in extrudates with yellow and orange sweet potatoes, as compared to control. No change in the content of polyphenols in comparison to control was found by Stojceska *et al.* (2008) the study on application of cauliflower by-products in extrudates. Similarly, no changes in TPC could be measured after an addition of brewery spent to extrudates done by Ainsworth *et al.* (2007) On the other hand, Gumul *et al.* (2011) reported an increase of TPC in the range 192-1000% in comparison to control due to the enrichment of extrudates with defatted blackcurrant seeds. 50% share of defatted blackcurrant seeds resulted in ten-fold increase of TPC in extrudates, as compared to control (Gumul *et al.*, 2011). It could be concluded that the enrichment of extruded snacks with polyphenols depends mostly on the type and quantity of applied raw material, and especially on the content of bioactive substances. Taking this into account, it seems that freeze-dried red and purple potatoes are very suitable to be used for such a purpose. Even 5% share caused approximately 10% increase in the content of polyphenols, and at 25% share the change in their level was about 200% (Table 5). The change in polyphenols with 5% share of freeze-dried red and purple potatoes was the same as after 10% share of defatted blackcurrant seeds (approximately 1.7 mg of catechin/ g) and 25% level caused

greater increase in TPC (approx. 4.4 mg catechin/g) than 30% share of blackcurrant seeds (4.04 mg catechin/g) (Table 5) (Gumul *et al.*, 2011).

The application of freeze-dried red and purple potatoes caused a substantial elevation of TPC, flavonoids and anthocyanins (the compounds are thermally labile) in the final product. According to Lachman *et al.* (2009) potatoes contain mostly acylated anthocyanins, which are more stable and bioavailable than non-acylated anthocyanins present in blueberries or cranberries. Therefore the content of these compounds increased in extrudates with 15 and 25% share of red potatoes, variety Magenta Love, by 24 and 64% in comparison to control, respectively (Table 4).

It is an important result, because anthocyanins have prominent pro-health properties, including anti-mutagenic, anti-carcinogenic and anti-hypertensive activity, and reduce the risk of chronic diseases and neuronal degeneration (Ahmed *et al.*, 2010; Teow *et al.*, 2007).

It could be suggested that the application of freeze-dried red and purple potatoes to extruded snacks is a beneficial alternative to fruit derived products, usually utilised in the production of pro-health snacks. In the studies concerning cereal extrudates with defatted blackcurrant seeds an absence or low level of anthocyanins (in the range 0.017-0.03 mg cyanidin-3-glucoside/ g d.m.) was found, because of their thermal lability (Gumul *et al.*, 2011). In the current study the level of anthocyanins in extrudates prepared

with a share of freeze-dried red and purple potatoes was much higher (0.361-0.479 mg cyanidin-3-glucoside/g d.m.), probably because of better thermal stability of these compounds present in potato tubers.

Antiradical and antioxidant activity was determined with the use of DPPH and by FOMO methods. The samples with freeze-dried red and purple potatoes were characterised by higher antioxidant activity in comparison to control (Table 5). The results of both methods proved an increase of antioxidant and antiradical activity proportional to the applied share of freeze-dried coloured potatoes (Table 5). Moreover an application of freeze-dried red potatoes, variety Magenta Love, was more effective than Blue Star variety activity, which could be expected from the content of bioactive compounds in both raw materials.

It is worth mentioning that according to Leo *et al.* (2008), the TPC and anthocyanins are directly related to antioxidant activity.

Significant correlations could be found between TPC and DPPH ($r^2=0.847$), TPC and FOMO ($r^2=0.890$), content of flavonoids and DPPH ($r^2=0.846$), content of flavonoids and FOMO ($r^2=0.861$), content of phenolic acids and DPPH ($r^2=0.798$), content of phenolic acids and FOMO ($r^2=0.843$), content of anthocyanin and DPPH ($r^2=0.630$), and content of anthocyanin and FOMO ($r^2=0.663$).

Table 5. Total phenolic content and antioxidant, antiradical activity of extrudates with a share of freeze-dried red and purple potatoes.^{1,2}

Samples	TPC (mg catechin/ g d.m.) with F-C reagent	DPPH TEAC (mg Trolox/g d.m.)	FOMO TEAC (mg Trolox/g d.m.)
Control	1.52±0.13 ^a	0.40±0.01 ^a	18.84±0.27 ^a
EML5	1.9±0.05 ^c (+25%)	1.77±0.04 ^c (+342%)	28.46±0.81 ^c (+51%)
EML15	3.02±0.08 ^e (+99%)	2.78±0.00 ^f (+595%)	32.31±1.63 ^d (+72%)
EML25	4.39±0.07 ^g (+188%)	3.10±0.04 ^g (+675%)	36.49±0.34 ^e (+93%)
EBS5	1.67±0.05 ^b (+10%)	1.52±0.03 ^b (+280%)	24.51±0.13 ^b (+30%)
EBS15	2.18±0.05 ^d (+43%)	2.32±0.01 ^d (+480%)	29.47±0.34 ^c (+56%)
EBS25	3.56±0.09 ^f (+134%)	2.57±0.00 ^e (+542%)	32.88±2.31 ^d (+74%)

¹ Presented data are mean values ± standard deviation (values signed the same letters in particular columns are not significant at 0.05 level of confidence). Values between parentheses indicate changes (%) in comparison to control.

² TPC = total polyphenols content; F-C reagent = Folin-Ciocalteu reagent; DPPH = 2,2-diphenyl-1-picrylhydrazyl; TEAC = Trolox Equivalent Antioxidant Capacity; FOMO = phosphomolybdenum complex.

Summarising, it could be concluded, that maize extrudates with a share of freeze-dried red and purple potatoes are an innovative, valuable pro-health product which could be used by healthy consumers, but also by the people with certain dietary disorders, such as celiac disease. Though the use of coloured potatoes in other food products, such as gluten-free bread results in significant improvement of their pro-health properties (Gumul *et al.*, 2017) maize snacks seem to be better products for such enrichment, because the levels of antioxidants are in their case much higher, as it could be seen from the above results. Moreover extrudates are more stable during storage and less prone to microbiological deterioration than bread (Riaz, 2002).

4. Conclusions

Taking into account the effects on pro-health characteristics and physical and sensory properties of extruded snacks, 25% share of freeze-dried red potatoes, variety Magenta Love seems to be most promising. In this case the levels of total polyphenols, phenolic acids, flavonoids, flavonols and anthocyanins, and high antioxidant activity were substantially improved in comparison to control and other studied samples. Also the colour, high sensory scores and improved texture properties suggest that such a product could be well accepted by the market.

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Conflict of interest

The authors declare that they have no conflict of interest.

Compliance with ethics requirements

This article does not contain any studies with human or animal subjects.

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