Anthocyanin and antioxidant activity of snacks with coloured potato

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Abstract

Coloured-fleshed potatoes of four varieties were used as raw material for coloured flour and fried snack production. The effects of thermal processes traditionally used in dried potato processing and in snack pellet manufacturing on anthocyanin profiles, total polyphenols and antioxidant properties of obtained half- and ready products were studied. There was a significant influence of potato variety on the experimental flour and snack properties: Flours with the highest antioxidant activities were obtained from Salad Blue and Herbie 26 potatoes; however, the flour prepared from the Blue Congo exhibited a much higher total polyphenol and anthocyanin content. Snacks produced with coloured flour had 2–3 times higher antioxidant activities; 40% higher contents of polyphenols, attractive colour and better expansion compared to control samples. The lowest losses of anthocyanins during snack processing were in snacks with flour from the purple-fleshed Blue Congo and red-fleshed Herbie 26.

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1. Introduction

Pellet snacks are well-known within the world market of food products for having huge versatility regarding taste, raw materials used and some sensory characteristics. Pellet snacks are typically small, have large expansion, a porous structure and a crispy texture; however, these properties can differ depending upon the raw material used. The specific physical and sensory features of these popular snacks are the effect of starch transformation during processing. In the manufacturing of pellet snacks, a raw material containing starch, such as potato starch, flakes, granules or grits, are mixed with water, salt and optionally with other dough components, such as vegetable, cereal or legume flour, semolina or grits, and pellets are formed, usually with the use of low shear extrusion technology. Pellets of approximately 20–30% moisture content are subjected to a drying process under mild temperature conditions to obtain a half-product of approximately 11–12% moisture equally dispersed throughout the pellet’s volume. To obtain ready-to-eat products a thermal process, such as frying or baking, is necessary. During that process, the pellets expand, increasing their volume 3–8 times and the typical porous, light structure and crispy texture of the final product is created (Lusas & Rooney, 2001).

There is suggested by different authors (Brown, 2005; Lachman, Hamouz, Orsák, & Pivec, 2000; Yen & Chen, 1995) that antioxidants naturally presented in food have health-promoting and antiaging effects in the human body. However, depending on the type of bioactive compounds they can be well absorbed and act as antioxidants within the organism or can be abolished during first-pass metabolism in the intestine and liver. Among antioxidants ascorbic acid and α-tocopherol preserve their properties in the organism but another phytochemicals, like polyphenols lose this function as a result of the attachment of a functional group at exactly those positions of the molecule that are responsible for its antioxidant activity. This is one of the reason why the referring total antioxidant capacity (TAC) of food, measured by different in vitro assays, to its importance for human health is to be discouraged (Pompella et al., 2014). However, antioxidants can also play an important role in food technology by contributing to food quality, for instance by the preventing fat deterioration in fried products.

Potatoes are known as one of the richest sources of antioxidant compounds in the human diet. The main antioxidants are polyphenols, ascorbic acid, α-tocopherol and β-carotene. In addition, the antioxidant activity of patatin, a tuber storage protein, has been investigated (Hillebrand, Naumann, Kitzinski, Kohler, & Winterhalter, 2009; Lachman, Hamouz, Orsák, Pivec, & Dvořák, 2008). Polyphenols are the largest group of plant components and can be divided into phenolic acids, flavonoids, stilbenes and lignans (Manach, Scalbert, Morand, Remesy, & Jimenez, 2004). In
potatoes, the major antioxidants are phenolic acids, such as chlorogenic acid that comprises approximately 80% of the total phenolic acids (Brown, 2005), caffeic acid, cinnamic acid, p-coumaric acid, ferulic acid and sinapic acid (Friedman, 1997), and other compounds, such as ascorbic acid, carotenoids, tocopherols, lipoic acid and selenium (Lachman et al., 2009). As stated by Brown (2005), coloured potatoes contain twice as much phenolic acid as yellow-fleshed potatoes. However, these potatoes contain large amounts of flavonoids, particularly catechin, epicatechin and anthocyanidins.

In recent years, there has been an increasing interest in potato varieties with coloured flesh (Manach et al., 2004; Nicoli, Anese, & Parpinel, 1999; Perla, Holm, & Jayanty, 2012; Pęksa et al., 2011; Tajner-Czopek, Rytel, Kita, Pęksa, & Hamouz, 2012), mainly because of the high anthocyanin content of the raw material. The authors emphasise the importance of anthocyanin stability during food processing and discuss changes in the overall antioxidant activity due to thermal processing of potato tissue and preservation procedures.

The aim of the present experiment was to study how thermal processes necessary for potato flour and final snack processing affect particular anthocyanins, total phenolic content and antioxidant properties of the extruded material and ready snacks enriched with coloured potato flour.

2. Materials and methods

2.1. Raw material

Dried potato products, such as starch obtained from Pepees SA potato factory in Lomża and trade grits produced by a potato factory in Lublin, Poland, were used as the main components of pellet snacks in the experiment. Samples of coloured potato flour were obtained from four varieties of red and purple fleshed potatoes supplied by the Czech University of Life Sciences, Prague. Red-fleshed Herbie 26 and the following three purple-fleshed potato varieties were used: Valfi, Blue Congo and Salad Blue. Corn semolina, salt and oil purchased from the trade were used as additives.

2.2. Preparation of coloured potato flour

Eight randomly selected tubers of each potato variety were washed with tap water, strained with the use of paper towels, mechanically peeled and cut into slices of approximately 10 mm thick. Two simultaneous samples of tubers were prepared. Approximately 500 g samples of slices were blanched in a 1 L solution of 0.5% NaHSO₃ at 80 °C for 15 min, strained in a sieve and paper, cooled at room temperature and frozen at −20 °C. The samples were then freeze-dried at 30 °C. Dried slices were ground in a knife grinder, sieved through a sieve of 1 mm mesh size, packed in plastic boxes and stored under refrigeration until further investigation. Additionally, slices of raw tubers not blanched were freeze-dried to obtain samples of raw material for analysis.

2.3. Preparation of dough for pellet extrusion

Fifty percent of trade potato grits in a pellet recipe were replaced by coloured flour from four coloured-fleshed potato varieties. For the control sample of snacks, 335 g of starch and 130 g of potato grits were mixed with corn semolina, salt and rape seed oil to obtain 500 g of dough mixture. The moisture content of the dough for extrusion was established at 40–45% by adding a suitable quantity of water. The moistened mixture was pressed by a sieve and placed in sealed polyethylene bags under refrigeration for 12 h to equilibrate the moisture in the dough.

2.4. Pellet extrusion

Material for pellets was extruded in a single-screw extruder (Brabender DN 20, Germany). The following extrusion parameters were kept constant: die size (0.5 mm × 80 mm), speed of dough supplier (38 rpm), screw speed (120 rpm), screw loading (2.8 A) and barrel temperature distribution (60 °C/70 °C/80 °C). Strands that had previously been subjected to extrusion but were not expanded were cut into pellets of ca. 27 × 27 mm and dried at room temperature for 12 h to ca. 12–13% moisture content and sealed in polyethylene bags to equilibrate moisture until frying.

2.5. Preparation of fried snacks

Snacks were obtained from pellets following 48 h of storage at room temperature. The samples were fried in hot (180 °C) rapeseed oil for 15–20 s (3 s after expanded product appears on the oil surface). The product to oil ratio was kept at 1:20 w/v.

2.6. Analysis

2.6.1. Proximate chemical analysis

The dry weight of the dough, the dough components and snacks were determined by drying at 102 °C until constant weight was achieved (AOAC, 2000). In the raw material and snacks, the total phenolics, anthocyanin content and anti-oxidant activity, as di(phenyl)/(2,4,6-trinitrophenyl)iminooxazinium (DPPH), 2-azino-bis(3-ethylbenzthiazoline-6-sulphonic acid) (ABTS) and the ferric reducing ability of plasma (FRAP), were also determined.

2.6.2. Extraction of polyphenols

The freeze-dried potato samples and the defatted samples of snacks were extracted by 70% aqueous acetone (0.1% acetic acid) in a graduated tube. The mixture was homogenised using a vortex mixer for 30 s and allowed to stand for 2 h at room temperature. The acetone–water solution was partitioned with chloroform to remove the lipophilic compounds. Next, the acetone–water fraction was collected and placed on a Buchi rotary evaporator until all residual acetone was evaporated. The remaining aqueous extract was brought to a known volume with distilled water and stored at −20 °C until analysis. The samples were filtered with 0.2 μm filters before HPLC-MS analysis.

2.6.3. Determination of total polyphenols

The total polyphenolic content of the extracts was determined using the Folin–Ciocalteu colorimetric method, as described by Gao, Bjork, Trajkovski, and Uggla (2000). Potato extract (0.1 ml) and Folin–Ciocalteu reagent (0.2 ml) were pipetted into cuvettes. After 3 min, 1 ml of a 20% aqueous solution of sodium carbonate (Na₂CO₃) and 2 ml of distilled water were added. The absorbance at 765 nm was measured after 1 h, and the results were expressed as mg of gallic acid equivalents per 1 g of dry matter (DM). Data are reported as the mean value for four measurements.

2.6.4. HPLC analysis of anthocyanins

Anthocyanins were determined using a Dionex (USA) HPLC system equipped with a model Ultimate 3000 diode array detector, a LPG-3400A quaternary pump, a EWPS-3005SI auto sampler and a TCC-3000SD thermo stated column compartment, controlled by Chromeleon v.6.8 software. A reverse phase Atlantic T3 (250 mm × 4.6 i.d., 5 μm) column (Waters, Ireland) and an Atlantis T3 (20 × 4.6 i.d., 5 μm) guard column (Waters, Ireland) were used. The following solvents constituted the mobile phase: A. 4.5% formic acid and B. acetonitrile. The following elution conditions were applied: 0–1 min, 5% B isocratic; 1–6 min, linear gradient from 5–10% B; 6–26 min, linear gradient 10–20% B; 26–33 min, linear...
gradient from 20–100% B; and then the initial conditions. The flow rate was 1 mL/min, and the injection volume was 40 μL. The column was operated at 30 °C. Anthocyanins were monitored at 520 nm.

2.6.5. LC–MS/MS analysis of anthocyanins

Compound identification was performed on an Acquity ultra-performance liquid chromatography (UPLC) system coupled with a quadrupole-time of flight (Q-TOF) MS instrument (UPLC/Synapt Q-TOF MS, Waters Corp., Milford, MA, USA) with an electrospray ionisation source (ESI). Separation was achieved on an Acquity TM BEH C18 column (100 mm × 2.1 mm i.d., 1.7 μm; Waters). The detection wavelength was set at 520 nm. The mobile phase was a mixture of 4.5% formic acid (A) and acetonitrile (B). The gradient program was as follows: initial conditions – 99% (A), 12 min – 75% (A), 12.5 min – 100% (B), 13.5 min – 99% (A). The flow rate was 0.45 mL/min, and the injection volume was 5 μL. The column was operated at 30 °C.

Major operating parameters for the Q-TOF MS were set as follows: capillary voltage, 2.0 kV; cone voltage, 45 V; cone gas flow, 11 L/h; collision energy, 50 eV; source temperature, 100 °C; desolvation temperature, 250 °C; collision gas, argon; desolvation gas, nitrogen; flow rate, 600 L/h; data acquisition range, m/z 100–1000 Da; ionisation mode, positive. The data were collected by Mass-Lynx TM V 4.1. software.

2.6.6. Determination of antioxidant activity

The antioxidant activity of aqueous extracts was determined using the Trolox equivalent antioxidant capacity (TEAC) with ABTS and DPPH radicals and the FRAP method. The TEAC assay with ABTS radicals was carried out according to Re et al. (1999), and the TEAC assay with DPPH radicals was carried out according to a procedure described by Yen and Chen (1995). The antioxidant activity measured using FRAP was performed according to a method by Benzie and Strain (1996). TEAC results are expressed as μmol of Trolox equivalents per 1 g of dry matter (DM). Data are reported as the mean of four measurements.

2.6.7. Physical properties of snacks

The texture of the obtained snacks was determined by using an Instron type 5544 texture-measuring device with Merlin software. The minimal force (N) necessary to break up a snack was measured using a share blade at a displacement rate of 250 rpm. The expansion ratio of the snacks was calculated as a quotient of snack size to pellet size. The colour of snacks (Hunter lab scale) was measured using a Minolta CM-5 chromameter against a white reference standard. Hue angle and chroma colour space parameters were calculated from \( a^* \) and \( b^* \) values.

Hue angle = \( \arctan (\frac{b^*}{a^*}) \)

Chroma = \( ((a^{*2} + b^{*2})^{0.5}) \) (Wrolstad, Durst, & Lee, 2005).

2.7. Statistical analysis

Statistical analyses of all data were performed using a one-way analysis of variance (ANOVA). Duncan’s range test was used to determine the differences among samples with a probability level of 0.05. Statistical analyses and standard deviations were determined using Statistica v. 9.0 software (StatSoft Inc., Tulsa, OK, USA).

3. Results and discussion

3.1. The effect of processing coloured potatoes for flour on anthocyanins, total polyphenol content and antioxidant activity

Blanching coloured-flesh potatoes during flour processing resulted in a decrease in anthocyanins, total polyphenols and antioxidant capacity of the obtained flour in an amount dependent on the potato variety.

3.1.1. Anthocyanins

The main anthocyanins found in the purple-fleshed varieties of potatoes studied were petunidin and malvidin. In the red-fleshed potatoes, pelargonidin derivatives were the most abundant anthocyanin (Table 2). In the tubers Blue Congo and Valfi, the presence of anthocyanins such as petunidin–3–rutinoside–5–glucoside, petunidin–3–feruloylrutinoside–5–glucoside and malvidin–3–feruloylrutinoside–5–glucoside were detected. Additionally, differences in the content of petunidin–3–cafeoylrutinoside–5–glucoside, petunidin–2–p–coumaroylrutinoside–5–glucoside and malvidin–3–p–coumaroylrutinoside–5–glucoside were found between the samples of raw potatoes examined, and higher levels of those anthocyanins were found in the Blue Congo variety of potato. In tubers of the Salad Blue variety, the same derivatives were detected; however, in distinctly lower quantities than in the Blue Congo or Valfi potatoes, a decrease that was particularly notable for petunidin–2–p–coumaroylrutinoside–5–glucoside. The red-fleshed Herbie 26 potatoes had the highest level of pelargonidin–3–p–coumaroylrutinoside–5–glucoside and also contained notable quantities of pelargonidin–3–rutinoside–5–glucoside, pelargonidin–3–feruloylrutinoside–5–glucoside and pelargonidin–3–cafeoylrutinoside–5–glucoside.

The current results are in agreement with reports of other authors (Rodriguez Saona, Giusti, & Wrolstad, 1998) who proved that the dominant anthocyanins in potatoes with red-coloured flesh were acylated glucosides of pelargonidin, such as pelargonidin glycosides–3–O–p–coumaroylrutinoside–5–O–glucoside. Lewis, C.E. (1996) identified 5–glucoside–3–rahmnosyl glucoside derivatives of all common anthocyanidins acylated by p–coumaric or ferulic acids in red-fleshed potatoes. Alcade-Eon, Saavedra, de Pascual-Teresa, & Rivas Gonzalez, 2004 showed that acylated glucosides of anthocyanins are present in potatoes with coloured flesh, of which the aglycons were pelargonidin, malvidin, petunidin,

### Table 1
Total polyphenols content [mg * g⁻¹ * DM] and antioxidant activity [μmol Trolox * g⁻¹ * DM] of dried potatoes of four varieties and obtained flour.

<table>
<thead>
<tr>
<th>Potato Variety</th>
<th>Total polyphenols</th>
<th>Antioxidant activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DPPH</td>
<td>ABTS</td>
</tr>
<tr>
<td></td>
<td>( p^* )</td>
<td>( p^{**} )</td>
</tr>
<tr>
<td>Salad Blue</td>
<td>3.34 ± 0.14</td>
<td>1.81 ± 0.09</td>
</tr>
<tr>
<td>Blue Congo</td>
<td>4.27 ± 0.14</td>
<td>1.36 ± 0.11</td>
</tr>
<tr>
<td>Valfi</td>
<td>3.61 ± 0.14</td>
<td>1.19 ± 0.12</td>
</tr>
<tr>
<td>Herbie 26</td>
<td>2.47 ± 0.12</td>
<td>1.57 ± 0.14</td>
</tr>
<tr>
<td>LSD</td>
<td>0.21</td>
<td>0.18</td>
</tr>
</tbody>
</table>

\( p^* \) – Potatoes.  
\( p^{**} \) – Potato flour.
Table 2
Mass spectrometric properties of anthocyanins found in studied coloured fleshed potatoes of 4 varieties.

<table>
<thead>
<tr>
<th>No of pik</th>
<th>[M]+ (m/z)</th>
<th>MS/MS (m/z)</th>
<th>Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>787.229</td>
<td>317.066/479.117/625.177</td>
<td>Petunidin-3-rutinoside-5-glucoside</td>
</tr>
<tr>
<td>2</td>
<td>801.245</td>
<td>331.081/493.144/639.195</td>
<td>Malvidin-3-rutinoside-5-glucoside</td>
</tr>
<tr>
<td>3</td>
<td>949.265</td>
<td>317.067/479.114/787.205</td>
<td>Petunidin-3-caffeylrutinoside-5-glucoside</td>
</tr>
<tr>
<td>4</td>
<td>933.266</td>
<td>317.066/479.119/771.214</td>
<td>Petunidin-2-p-coumarylrutinoside-5-glucoside</td>
</tr>
<tr>
<td>5</td>
<td>963.275</td>
<td>317.067/479.120/801.224</td>
<td>Petunidin-3-feruloylrutinoside-5-glucoside</td>
</tr>
<tr>
<td>6</td>
<td>947.282</td>
<td>331.082/493.137/785.229</td>
<td>Malvidin-3-p-coumarylrutinoside-5-glucoside</td>
</tr>
<tr>
<td>7</td>
<td>977.296</td>
<td>331.083/493.195/815.241</td>
<td>Malvidin-3-feruloylrutinoside-5-glucoside</td>
</tr>
<tr>
<td>8</td>
<td>741.224</td>
<td>271.061/433.113/579.171</td>
<td>Pelargonidin-3-rutinoside-5-glucoside</td>
</tr>
<tr>
<td>9</td>
<td>579.172</td>
<td>271.061/433.113</td>
<td>Pelargonidin-3-rutoside</td>
</tr>
<tr>
<td>10</td>
<td>903.258</td>
<td>271.061/433.112/741.203</td>
<td>Pelargonidin-3-caffeylrutinoside-5-glucoside</td>
</tr>
<tr>
<td>11</td>
<td>887.261</td>
<td>271.061/433.113/725.208</td>
<td>Pelargonidin-3-p-coumarylrutinoside-5-glucoside</td>
</tr>
<tr>
<td>12</td>
<td>917.271</td>
<td>271.061/443.112/755.218</td>
<td>Pelargonidin-3-feruloylrutinoside-5-glucoside</td>
</tr>
</tbody>
</table>

Results suggest that anthocyanins in the Salad Blue potatoes were better stabilised than in the other tuber varieties. Notable losses of anthocyanins (approximately 58%) were observed in the flour of Herbie 26, a red-fleshed potato, because of raw material processing (mainly the blanching stage), mainly affected by changes in the content of pelargonidin-3-p-coumarylrutinoside-5-glucoside (a 62.9% loss). From the results, it can be observed that the highest losses of anthocyanins were in the flour prepared from tubers of the Blue Congo variety and the lowest in the flour from red-fleshed potatoes of the Herbie 26 variety. Lachman et al. (2012) stated that the total anthocyanin contents and their profiles were strongly associated with potato cultivars of red, purple or blue-coloured flesh.

3.1.2. Total polyphenols
Of the coloured-flesh tuber varieties studied, the samples contained from 2.47 to 4.27 mg GA/g DM of total polyphenols (Table 1). The highest content of those compounds was found in tubers of the Blue Congo variety and the lowest content in Herbie 26 potatoes. Experimental flour manufactured from purple and red-fleshed potatoes of the four varieties studied contained from 36% (Herbie 26) to 68% (Blue Congo) less total polyphenols compared to the raw material, and the highest losses were found in the flour from the purple-fleshed Blue Congo and Valfi varieties.

Polyphenolics are soluble in water but susceptible to thermal processes. This may be the reason for the distinct losses of those natural compounds during blanching, which is the typical process in the industry for potato grit production. They are lost by washing out of the potato and undergoing thermal degradation.

Table 3
Pigments [mg cyanidin-3-glucoside * 100 g⁻¹ DM] in coloured fleshed potatoes and obtained flours.

<table>
<thead>
<tr>
<th>No of pik</th>
<th>Potato variety</th>
<th>Salad Blue</th>
<th>Blue Congo</th>
<th>Valfi</th>
<th>Herbie 26</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P*</td>
<td>PF**</td>
<td>P*</td>
<td>PF**</td>
<td>P*</td>
</tr>
<tr>
<td>1</td>
<td>1.77 ± 0.084</td>
<td>2.58 ± 0.345</td>
<td>2.33 ± 0.475</td>
<td>1.74 ± 0.498</td>
<td>1.96 ± 0.048</td>
</tr>
<tr>
<td>2</td>
<td>0.263 ± 0.172</td>
<td>Traces</td>
<td>0.116 ± 0.051</td>
<td>Traces</td>
<td>0.353 ± 0.107</td>
</tr>
<tr>
<td>3</td>
<td>1.71 ± 0.604</td>
<td>2.12 ± 0.760</td>
<td>4.02 ± 0.611</td>
<td>1.34 ± 0.097</td>
<td>2.73 ± 1.542</td>
</tr>
<tr>
<td>5</td>
<td>2.07 ± 0.385</td>
<td>2.09 ± 0.417</td>
<td>3.52 ± 0.155</td>
<td>0.98 ± 0.095</td>
<td>3.64 ± 1.343</td>
</tr>
<tr>
<td>6</td>
<td>3.97 ± 1.125</td>
<td>1.97 ± 0.270</td>
<td>7.03 ± 1.389</td>
<td>1.04 ± 0.800</td>
<td>3.75 ± 1.713</td>
</tr>
<tr>
<td>7</td>
<td>0.617 ± 0.104</td>
<td>0.137 ± 0.083</td>
<td>0.72 ± 0.052</td>
<td>0.035 ± 0.003</td>
<td>0.521 ± 0.139</td>
</tr>
<tr>
<td>8</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>9</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>0.439 ± 0.164</td>
</tr>
<tr>
<td>10</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>1.78 ± 0.778</td>
</tr>
<tr>
<td>12</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>5.99 ± 1.830</td>
</tr>
</tbody>
</table>

P* – Potatoes.
PF** – Potato flour.
3.1.3. Antioxidant activity

Differences in the profiles of anthocyanins contained in raw material and in the flour could contribute to the differences in antioxidant activity. It has been suggested by some authors (Hamouz, Lachman, Vokáš, & Pivec, 1999; Lachman et al., 2000) that the antioxidant activity of potatoes depends on the composition and on the content of particular anthocyanins and also on phenolic acids, mainly chlorogenic acid and its isomers. The antioxidant activity of anthocyanins is mainly determined by the number of free hydroxyl groups in their structure. This may be the reason why petunidin has a higher antioxidant activity when compared to malvidin, peonidin or pelargonidin derivatives.

The antioxidant activity of the studied raw material and the flour manufactured as a supplement of trade grits in snack pellet’s in the conditions related to proceeded in potato industry, was expressed as ABTS and DPPH and by a method utilising the reduction properties of ferric ions (FRAP). As shown in Table 1, the antioxidant and antiradical activity of the potatoes depended on the variety. The highest activity was observed in tubers of the Blue Congo potato variety and significantly lower activity, expressed as FRAP and DPPH, in the red-fleshed potatoes of Herbie 26. Similarly, other authors (Lachman et al., 2008; Lachman et al., 2009) proved that the antioxidant activity of coloured-flesh potatoes depends on the variety and on the place of their cultivation and weather conditions during the growing of the potato plant.

Experimental potato flour obtained from coloured-fleshed tubers that had previously been blanching in a solution of SO2 had higher antioxidant activity than the raw material. The presence of SO2, which is reductive, caused an increase in the reductive power (FRAP) of the experimental flour and the activity was confirmed by the ABTS and DPPH tests. The highest increase of FRAP antioxidant activity was observed in flour from Herbie 26 potatoes (15 times as much as raw material) and the lowest in flour from Blue Congo potatoes (1 – 3 times higher). Experimental flour manufactured from tubers of the purple-fleshed Salad Blue variety and the red-fleshed Herbie 26 had much higher antioxidant activity than the raw material and also had higher or similar activity compared to the flour prepared from the remaining 2 potato varieties.

According to Brown (2005) and Brown, Culley, Yang, Durst, and Wroldstad (2005), the antioxidant activity of potatoes with coloured flesh is affected mainly by polyphenols in tubers and in particular anthocyanins. Quantity differences and the profiles of anthocyanins can significantly affect the antioxidant activity of manufactured ready products from this type of raw material. Nayak, Berrios, Powers, Tang, and Ji (2011) showed that steam blanching potatoes with purple flesh preserved the colour of the product after drying.

3.2. The effect of pellet snack processing on anthocyanins, total polyphenol content and antioxidant activity of ready-to-eat products

3.2.1. Anthocyanins in snacks

There was a significant decrease in the anthocyanin contents in snacks compared to the dough, which is later fried to make the snacks (Table 5). The lowest losses were observed in products supplemented with the flour from purple-fleshed tubers of the Blue Congo variety (37.5%). In the remaining snack samples, much higher losses were observed, ranging from 60% (Herbie 26) to 70% in snacks with flour from Valfi potatoes. Kita, Bąkowska-Barczak, Hamouz, Kukalowska, and Lisińska (2013) fried chips from tubers of the same potato varieties and reported lower contents of anthocyanins in the chips, from 22% to 81%, compared to the raw material. In addition, they showed that the lowest losses of anthocyanins were observed when Herbie 26 potatoes had been used for crisps processing, and the highest losses were found with the use of Blue Congo as a raw material. Lachman et al. (2012) stated that thermal processes, when related to particular potato varieties, showed a preservation of, or even a slight increase in, the anthocyanin content and that this was dependent on the type of process used: baking, microwaving, steaming or boiling.

In potatoes with purple flesh, the most thermal stable anthocyanin was petunidin-3-rutinoside-5-glucoside. Losses of this pigment in snacks containing flour from purple-fleshed potatoes ranged from 30% (Blue Congo) to 61% (Valfi). The most stable anthocyanin in red-fleshed potatoes was pelargonidin-3-rutinoside-5-glucoside. The lowest losses of this pigment (33%) were found in snacks supplemented with flour from Herbie 26 potatoes. The resistance of 3-rutinoside-5-glucoside of petunidin and pelargonidin could be an effect of phenolic acid separation from related acylated anthocyanins, which most likely increased the concentration of 3-rutinoside-5-glucosides.

The basic factors that decrease the anthocyanin content in food products are the conditions of the thermal processes and extrusion, particularly when conducted at high temperatures and pressures (Camire, Chaovanakit, Dougherty, & Briggs, 2002). According to these authors, extrusion cooking at a temperature of 130°C degraded 74–90% of the anthocyanins in the unheated dough prepared from corn meal and fruit concentrates or powders, such as grape, blueberry, cranberry, concord grape and raspberry.

3.2.2. Total polyphenols in snacks

Dough destined for pellet extrusion and subsequently snack frying, enriched with coloured-potato flour, had higher contents of...
total polyphenols than dough containing only industry made potato grits. The highest quantity of polyphenols was found in dough prepared with flour from tubers of the purple-fleshed Blue Congo potato variety.

Dough processing, with low shear extrusion, drying at room temperature and frying in oil at 180 °C for 20 s, caused a stated decrease in polyphenol content. Snacks manufactured with the addition of coloured flour had similar contents of total polyphenols, from 0.240 (Herbie 26) to 0.290 mg GA/g DM (Blue Congo) and higher values than snacks made with trade potato grits (control sample), which contained 0.157 mg GA/g DM total polyphenols.

As shown in Table 4, the highest losses of polyphenolic compounds were observed in snacks produced without the experimental flour (43% loss compared to the dough before extrusion). The total losses of polyphenols in snacks enriched with flour from coloured-fleshed potatoes, as a result of dough extrusion and frying, ranged from 25% (Salad Blue and Herbie 26) to 34% (Valfi). The most polyphenols were found in the products supplemented with flour from Blue Congo potatoes. These results suggest that the polyphenols present in tubers of coloured-fleshed varieties are better stabilised during thermal processes than polyphenolic compounds in potatoes of traditional coloured flesh. These differences also depended on potato variety and on the polyphenolic profile.

Brown, Durst, Wrolstad, and De Jong (2008) stated that the polyphenols in tubers of red and purple-coloured flesh are better preserved in ready-to-eat products after processing by various methods, including frying, compared to potatoes of traditional white, crème or yellow flesh that mainly contain the polyphenol chlorogenic acid.

Table 5
Pigments [mg cyanidin-3-glucoside * 100 g−1 DM] in dough and snacks enriched with coloured potato flour obtained from potatoes of 4 varieties.

<table>
<thead>
<tr>
<th>Nr of pik</th>
<th>Potato variety</th>
<th>Dough</th>
<th>Snacks</th>
<th>Dough</th>
<th>Snacks</th>
<th>Dough</th>
<th>Snacks</th>
<th>Dough</th>
<th>Snacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Salad Blue</td>
<td>0.420 ± 0.028</td>
<td>0.182 ± 0.066</td>
<td>0.272 ± 0.026</td>
<td>0.191 ± 0.069</td>
<td>0.256 ± 0.080</td>
<td>0.098 ± 0.036</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>2</td>
<td>Traces</td>
<td>Traces</td>
<td>Traces</td>
<td>Traces</td>
<td>Traces</td>
<td>Traces</td>
<td>Traces</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>3</td>
<td>0.316 ± 0.053</td>
<td>0.189 ± 0.0014</td>
<td>0.182 ± 0.010</td>
<td>0.258 ± 0.015</td>
<td>0.182 ± 0.010</td>
<td>0.228 ± 0.021</td>
<td>0.072 ± 0.017</td>
<td>n.d.</td>
<td>n.d.</td>
</tr>
<tr>
<td>4</td>
<td>4.084 ± 0.661</td>
<td>1.387 ± 0.195</td>
<td>3.597 ± 0.171</td>
<td>2.229 ± 1.198</td>
<td>1.112 ± 0.262</td>
<td>3.573 ± 0.234</td>
<td>n.d.</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.229 ± 0.022</td>
<td>0.603 ± 0.005</td>
<td>0.118 ± 0.018</td>
<td>0.156 ± 0.108</td>
<td>0.114 ± 0.005</td>
<td>0.051 ± 0.014</td>
<td>n.d.</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.299 ± 0.040</td>
<td>0.096 ± 0.014</td>
<td>0.207 ± 0.007</td>
<td>0.106 ± 0.062</td>
<td>0.219 ± 0.005</td>
<td>0.054 ± 0.006</td>
<td>n.d.</td>
<td>n.d.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.027 ± 0.005</td>
<td>0.011 ± 0.002</td>
<td>0.021 ± 0.004</td>
<td>0.000 ± 0.005</td>
<td>0.019 ± 0.000</td>
<td>n.d.</td>
<td>n.d.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>0.520 ± 0.056</td>
<td>0.347 ± 0.118</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>0.178 ± 0.019</td>
<td>0.065 ± 0.0347</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>0.343 ± 0.043</td>
<td>0.141 ± 0.064</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>4.880 ± 0.536</td>
<td>1.811 ± 0.912</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>n.d.</td>
<td>0.3801 ± 0.047</td>
<td>0.189 ± 0.068</td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>5.375</td>
<td>1.858</td>
<td>4.469</td>
<td>2.853</td>
<td>4.405</td>
<td>1.387</td>
<td>6.301</td>
<td>2.533</td>
<td></td>
</tr>
</tbody>
</table>

3.2.3. Antioxidant activity of snacks

The production conditions of pellet snacks significantly contributed to changes in the antioxidant activity of the final product, compared to the dough (Table 4). The direction of those changes depended on the potato variety used for flour production.

From the data in Table 4, it appears that the antioxidant activities of snacks obtained with flour from the Blue Congo and Valfi potatoes and products that were not supplemented with coloured flour were significantly lower compared to the antioxidant activity of the dough. In contrast, a 50% increase in antioxidant capacity was observed in snacks after the addition of flour from Salad Blue and Herbie 26 potatoes. These differences could be due to a higher degradation of total polyphenols in snacks supplemented with Blue Congo and Valfi potato flour (approximately 35% of total phenolics) than in snacks supplemented with flour from Salad Blue and Herbie 26 potatoes (approximately 25% of total phenolics) (Table 4).

The increase in antioxidant activity could also result from the presence of Maillard reaction products, most likely created during extrusion and frying of dough that contains suitable quantities of necessary substrates, such as reducing sugars and amino acids. Thermal processes can contribute to the creation of brown-coloured complex polymeric compounds known as melanoidin pigments, which can show antioxidant capacity, such as hydroxymethyl furfural. Similarly, other authors (Nicoli et al., 1999) have noted an increase in antioxidant activity as a result of vegetable and fruit processing and explained this increase as the effect of Maillard reactions and fermentation processes or protein hydrolysis. According to Blessington (2005), thermal processes, such as frying and microwaving, can increase the antioxidant activity of vegetables. In addition, Dewanto, Wu, and Liu (2002) stated that heating process increased the antioxidant activity of vegetable products. They found increases of 44% in the phytochemical content, such as ferulic acid and total phenolics, present in sweet corn subjected to 115 °C for 25 min. Other authors (Turkmen, Sari, & Velioglu, 2005) have suggested that the changes in total antioxidant activity depend on the type of vegetable but not on the type of cooking process. Generally, thermal stages of food processing are suggested to be one of most important factors affecting the destruction or changes in the phytochemicals naturally present in raw material and therefore change the antioxidant capacity of the processed food (Nayak et al., 2011; Nicoli et al., 1999).

3.3. The effect on physical properties of pellet snack enrichment with coloured potato flour

3.3.1. Colour

As can be observed from the data presented in Table 6, snacks supplemented with the flour from coloured flesh potatoes had novel visual characteristics not found in traditional snacks. They displayed an interesting colour that was affected by the anthocyanins present in the purple and red-fleshed potatoes that were used as the raw material.

These compounds did not undergo total destruction during snack processing, and this could have affected the resulting colour. All of the snacks that were obtained using coloured flour had lower lightness (L* in the range 64.23–66.80) than control samples. The addition of flour from red-fleshed Herbie 26 potatoes resulted in a pink colour (Hue = 29.55) that was attractive to the consumer. The saturation of the colour (Chroma) of snacks supplemented with flour from the red-fleshed potato variety was more distinct (C = 15.55) than the colour of snacks produced with the flour from...
the purple-fleshed potatoes (C coordinate values between 4.34 and 4.90). Snacks made using a traditional recipe, without the addition of coloured flour, had a more intense crème-yellow colour (C = 20.01, Hue* = 83.17). All of the snacks that were supplemented with the flour from potatoes with purple flesh (independent of the potato variety) were a grey colour with a light blue shade (values of Hue coordinate closed to 0).

Processing can change the anthocyanin content and the colour in fruits and vegetables. The overall colour changes could be due to a number of factors: such as pigment degradation, pigment polymerisation, reactions with other components of the formulation, non-enzymatic browning, oxidation of tannins, and other reactions completely unrelated to the added coloured flour (Wrolstad et al., 2005).

Phenolics, such as phenolic acids and anthocyanins, can be destructed by physical factors during food processing or enzyme activity in vegetables and fruits stored in different conditions (Kader, Irmouli, Nicolas, & Metche, 2002; Rossi et al., 2003). The conditions of food processing can cause a discoloration of polyphenols present in raw material into yellowish or brownish pigments (Clifford, 2000) found in the colour of ready-made products.

3.3.2. Texture and expansion index

Incorporation of the experimental flour into the pellet snack recipe did not significantly change their texture. Similar to the control sample, snacks supplemented with coloured-fleshed potato flour had a hardness of 30 N (Table 6). These results are similar to the data presented by Pe˛ksa, Kita, & Zie˛ba, 2004, who measured the texture of potato snacks supplemented with dietary fibre and Pe˛ksa, Miedzianka, Kita, Tajner-Czopek, and Rytel (2010) who determined the texture of snacks with added potato proteins.

The texture of expanded snacks is dependent on the content of gelatinised starch, its chemical composition and is correlated with the expansion index of the final product (Lucas & Rooney, 2001).

Experimental flour used as a component of pellet snacks improved their expansion ratio, independent of the tuber flesh colour and potato variety. Snacks supplemented with coloured flour were noticeably more expanded than control snacks. The expansion index of snacks with experimental flour ranged from 4.86 to 5.59 and was approximately 40% higher compared to traditional snacks (on average 3.83). The greatest expansions were observed from the addition of flour from Salad Blue, Herbie 26 and Valfi potato varieties.

The texture of pellet snacks and their expansion indexes are directly dependent on the degree of starch gelatinisation, which is the main component of potato snacks. Only products that have almost all of the starch in the gelatinised form expand properly (Lucas & Rooney, 2001). The carbohydrate composition and changes of these compounds in potatoes of coloured flesh are not well recognised but can have an important influence on the creation of physical features and sensory properties of expanded snacks manufactured with their addition.

4. Conclusions

The antioxidant activity of flours from coloured-fleshed potatoes and the pellet snacks produced with the coloured flour serving as one of the dried components varied depending on the potato variety. Blanching in a solution of SO₂ during potato flour production was the most important factor affecting the antioxidant and antiradical activity of coloured flour and increased the antioxidant activity from 2 to 15 times, dependant on the potato variety and method of determination. However, this increase was not found in the snacks obtained from the Blue Congo and Valfi varieties of purple-fleshed potatoes. Flour with the highest antioxidant activity was prepared from Salad Blue and Herbie 26 potato varieties, and Valfi potatoes had the lowest activity. Blue Congo potatoes had much greater total polyphenols and anthocyanins compared to purple-fleshed Salad Blue and red-fleshed Herbie 26 potatoes. In purple-coloured flour, petunidin-2-p-coumarylrutinoside-5-glucoside dominated; and in red-coloured flour, pelargonidin-3-p-coumaorylrutinoside-5-glucoside dominated. Thermal process applied in experimental flour production caused a 38–68% decrease in polyphenols and a 58–72% decrease in anthocyanins and was particularly high in products prepared from tubers of the purple-fleshed Blue Congo and Valfi varieties. The compounds in the dry matter of purple-fleshed Salad Blue and, to a lower degree, present in red-fleshed Herbie 26 affected the higher stability of the anthocyanins present in tubers during the blanching process. The least stable anthocyanins were found in the purple-fleshed potatoes, malwidin-3-p-coumarylrutinoside-5-glucoside and petunidin-2-p-coumarylrutinoside-5-glucoside, and the most stable were petunidin-3-rutinoside-5-glucoside. In Herbie 26 flour, pelargonidin-3-rutinoside-5-glucoside, pelargonidin-3-cafeeylrutinoside-5-glucoside and pelargonidin-3-rutinoside anthocyanins were present in lower quantities but were better stabilised during thermal processes than the same anthocyanins in the other potato varieties examined.

Snacks produced with coloured potato flour had 2–3 times higher antioxidant activity, particularly when measured by DPPH, compared to control samples with commercial potato grits as the flour component and contained on average 40% more of polyphenols. The processes of low shear extrusion and frying utilised for snack production affected a decrease in the antioxidant activity of products with flour from the Blue Congo and Valfi varieties but an increase in activity in snacks with flour from the Salad Blue and Herbie 26 varieties. The anthocyanin content in snacks depends on the variety of potato used for coloured flour production. The highest content of these compounds and the lowest losses during snack processing were in snacks with flour from the purple-fleshed Blue Congo and the red-fleshed Herbie 26 potatoes. The utilisation of experimental, coloured potato flours favourably affected the colour and expansion index of the obtained snacks and did not change their texture. In particular, the red-coloured flour from Herbie 26 potatoes resulted in an attractive snack colour.

---

Table 6

<table>
<thead>
<tr>
<th>Feature</th>
<th>Control*</th>
<th>Potato variety</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour (Hunter Lab)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L* 80.56 ± 0.84</td>
<td>65.24 ± 1.13</td>
<td>64.23 ± 0.21</td>
<td>64.56 ± 0.19</td>
</tr>
<tr>
<td>C 20.01 ± 0.46</td>
<td>4.76 ± 0.39</td>
<td>4.98 ± 0.15</td>
<td>4.90 ± 0.15</td>
</tr>
<tr>
<td>H* 83.17 ± 0.35</td>
<td>4.62 ± 0.25</td>
<td>3.47 ± 0.82</td>
<td>357.55 ± 10.02</td>
</tr>
<tr>
<td>Expansion index</td>
<td>3.83 ± 0.41</td>
<td>5.59 ± 0.49</td>
<td>4.86 ± 0.12</td>
</tr>
<tr>
<td>Texture [N]</td>
<td>29.04 ± 9.49</td>
<td>31.09 ± 17.36</td>
<td>35.69 ± 15.49</td>
</tr>
</tbody>
</table>

Control* – Snacks without the presence of coloured potato flour.
Acknowledgements

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References