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Chemical Characteristics and Physical Properties of Functional Snacks Enriched with Powdered Tomato

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The paper discusses the influence of the addition of freeze-dried tomatoes on the chemical composition and selected physical properties of extruded corn snacks. Corn grits were replaced with dried tomatoes in the amount from 5 to 30% of corn mass. The total lycopene and phenolic content, the scavenging ability and the ferric reducing antioxidant power were determined along with the content of neochlorogenic, chlorogenic, *p*-coumaric acids and rutin. Also evaluated were selected physical properties, colour and the sensory profile of corn snacks enriched with tomatoes. A greater tomato addition increased the volume of bioactive compounds, especially the total phenolic content. Snacks enriched with tomato exhibited a lower expansion ratio, water absorption and solubility indices, lightness and sensory characteristics but higher density, hardness and redness than corn snacks. Powdered tomato seems to be a functional additive with the high content of biologically-active compounds, and the enriched snacks displayed good physical properties if the tomato level did not exceed 20%. A higher amount of the additive significantly lowered the expansion as well as increased the hardness of snacks. Still, the corn products with 25 and 30% of powdered tomato were more valuable due to their much higher level of bioactive components compared with the regular corn snacks.

INTRODUCTION

Tomatoes are important vegetables in the daily diet. Their regular consumption may lower the risk of development of several types of diseases, among them cancer and heart diseases [Chang & Liu, 2007; Sahlin *et al.*, 2004]. As functional food, tomatoes have been confirmed to reduce the risk of and prevent prostate cancer. In many countries, the consumption of raw tomatoes and tomato products is promoted as part of a healthy life style and a good dietary habit [George *et al.*, 2004]. Tomatoes and their preserves are good sources of healthy ingredients, especially lycopene and other carotenoids, folate, ascorbic acid, vitamin E, flavonoids, and potassium, which behave like nutrients, and diverse disease-preventing molecules. Lycopene and β-carotene constitute a major source of carotenoids, and the main red pigment – lycopene – represents about 80–90% of the total carotenoid content in a tomato fruit [Shi & Le Maguer, 2000]. Lycopene is commonly found in tomatoes but also in tomato products processed with different techniques. Some scientific reports have proven lycopene to be an important antioxidant and have demonstrated its potential role in the prophylaxis of cardiovascular disease and in diminishing the risk of prostate, ovarian, gastric, and pancreatic cancers [Kavanaugh *et al.*, 2007]. Also, some studies have shown that lycopene facilitates communication between cells, modulates the immune systems and hormones, and interacts with other metabolic pathways [Abete *et al.*, 2013; Giovannucci, 2005]. Friedman *et al.* [2000] confirmed the reduction of LDL-cholesterol fraction by 44% and 59% and of triglyceride levels in plasma by 31% and 47% when in their study hamsters were fed freeze-dried red and green tomatoes, respectively.

To fulfill the nutritional requirements, substantial quantity of tomato would have to be eaten as raw, processed or dried, or as a component of vegetable dishes [Chang & Liu, 2007]. During a prolonged exposure to heat and oxygen, tomato products might sustain some damage caused by isomeriza-

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tion and oxidation: they cause tomato lycopene degradation during processing. The low molecular weight compounds that incite the antioxidant activity, and which include mainly polyphenolics, can support the innate immune systems in its struggle against oxidative stress [Gülçin, 2012]. According to hypotheses, the consumption of polyphenolics-rich food plays an important role in preventing oxidative stress-based chronic diseases. Several studies have been published on the phenolics content and antioxidant activity of cereals, herbs, vegetables and fruits [Dong *et al.*, 2014; Fernandez-Panchon *et al.*, 2008]. The antioxidant properties of plants can be influenced by many factors, including the cultivation method or environmental conditions, developmental stage, species and varieties, or storage and processing conditions [Radzki *et al.*, 2014].

Extrusion-cooking is a popular processing technology known as high-temperature short-time (HTST) process aimed to produce a wide range of foods and feeds [Mościcki & Wójtowicz, 2011]. Thermo-mechanical treatment during extrusion-cooking may lead to the gelatinization of starch, denaturation of proteins, enzymes, microbes, and to the inactivation of anti-nutrients [Altan *et al.*, 2008]. It is among the most effective processing methods for the conversion of nutritionally valuable raw materials and food wastes into useful products by means of a process that is versatile, high yield, energetically efficient, relatively inexpensive, and offers the possibility of modelling functional properties of food products. Many authors have tested the possibility of using some of the valuable ingredients from food by-products, especially from cereals, but also from fruit, vegetables or other additives to improve the nutritional value of extruded products. Bisharat *et al.* [2015] and Stojceska *et al.* [2010] experimented with the increased quantity of dietary fiber from cauliflower, broccoli or olive waste in extruded snacks. Rogalski *et al.* [2016] reported the increased content of valuable fatty acids, such as α-linolenic acid, form refined linseed oil used as an additive. Finally, Shaviklo *et al.* [2014] demonstrated the enrichment of corn crisps with fishery-derived products with a view to adding some protein and omega-3 fatty acids.

For consumers on a gluten-free diet, corn snacks are a popular source of carbohydrates. They also have a specific texture and are convenient to use. Pseudocereals, like corn, rice and buckwheat, play a significant role in the nourishment of people with celiac disease or gluten intolerance. These consumers must abandon such products as bakery products, snacks or pasta made from common and gluten-rich raw materials [Wójtowicz *et al.*, 2013]. Nowadays, consumers are interested in functional foods, and they are looking for tasty products which may also add to their natural body resistance, may help prevent and/or support therapies in selected diseases, support their physical fitness, and have a positive effect on their mental condition.

The objective of this study was to evaluate the effect of the addition of freeze-dried and powdered tomato to corn grits on the quality of functional ready-to-eat snacks prepared by the extrusion-cooking process. The chemical characteristic of the obtained material was tested by the determination of the total lycopene content, total phenolics content, the ability to scavenge on 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals, and the ferric reducing antioxidant power (FRAP), as well as based on contents of selected functional components, *e.g.* neochlorogenic, chlorogenic, *p*-coumaric acids, and rutin. Selected physical properties were assessed as well, like the expansion ratio, density, hardness, water absorption and water solubility indices, but also the color profile and sensory attractiveness of tomato-enriched corn snacks.

MATERIALS AND METHODS

Chemicals

Folin-Ciocalteu reagent, 1,1-diphenyl-2-picrylhydrazyl radical (DPPH), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,4,6-tripyridyl-1,3,5-triazine (TPTZ) and gallic acid, as well as the standards used for the HPLC analysis: phenolic acids (neochlorogenic, chlorogenic, *p*-coumaric, protocatechuic, ferulic, rosmarinic, ellagic), and flavonoids (rutin) were acquired from Sigma Aldrich (St. Louis, MO, USA). Ethanol, Na_2CO_3, $FeCl_3$ butylated hydroxytoluene (BHT), hexane, and acetone were obtained from POCh (Gliwice, Poland). All used chemicals and solvents were of the analytical grade. Methanol with the chromatographic grade was used for HPLC (J.T. Baker Inc., Netherlands). Water was purified with SimplicityTM system (Millipore, Molsheim, France).

Plant materials

Corn grits (distributor: Vegetus, Lubartów, Poland) with the granulation below 0.8 mm were used as the main raw material. The proximate chemical composition of corn grits was as follows, in g/100 g: protein content 9.2, fat content 1.66, ash content 0.55, dietary fiber content 4.42, and moisture content 12.0%. Fresh tomatoes were collected from the farms of eastern Poland in September 2013 and were processed no later than six hours after picking. The chemical composition of the vegetables was as follows, in g/100 g: protein content 0.9, fat content 0.2, ash content 0.52, and dietary fiber content 1.2. The fresh fruits were cleaned, cut in 5 mm slices and subjected to freeze-drying.

The sliced tomatoes were frozen at -20°C for 24 h and then lyophilized in a freeze-dryer (Christ Alpha 1–2 LD plus, Germany) for 72 h. The temperature of condenser was set at -60°C, the vacuum was kept at 0.8 mbar, and the shelf temperature was set at 25°C. The dried tomatoes (moisture content 6.5%) were powdered (below 300 μm) in a laboratory grinder (Społem WŻ-1, Poland), vacuum sealed and stored up to 4 weeks in darkness at room temperature for further use.

Extrusion-cooking of snacks

Blends of raw materials were prepared by mixing corn grits and powdered tomato added in the amount of 5, 10, 15, 20, 25 and 30% of base dry weight. The blended materials were moistened to 15% of moisture content by spraying with a proper volume of water and mixed continuously for 10 min. The recipes with different tomato contents were processed using the single screw polytrophic extruder TS-45 (ZMCh Metalchem, Gliwice, Poland) equipped with a heating/cooling system, configured as L:D=12:1, and with the screw compression ratio of 3:1. Based on the previous research [Wójtowicz *et al.*, 2013], during snacks processing, the barrel zone temperatures were set at 125–145–135°C and kept constant through the experiments by a water cooling system installed inside the extruder. Snack products were shaped with a single circular open die of 3 mm in dimension. During the processing of snacks, the screw speed was set at 120 rpm [Wójtowicz *et al.*, 2013]. Ready-to-eat snacks were dried at 40°C to the final moisture content of 6.0% and were stored for a maximum of 4 weeks in closed polyethylene bags at room temperature before tests.

Solvent extraction for TPC, DPPH and FRAP assays

The samples were ground for fine granulation (below 300 μm) before the extraction, and ethanol (80% v/v) was used as the solvent. Each sample (1 g) was extracted with 30 mL of the solvent in a shaker at 80°C and 175 rpm for 1 h. The extract was separated by centrifugation at 4200×*g* for 20 min. It was then evaporated to dryness in a vacuum evaporator (at 40°C), lyophilized (Christ Alpha 1–2 LD plus, Germany), and diluted in methanol (concentration of 5 mg/mL). Before the HPLC analysis, the extracts were forced through 0.45 μm nylon syringe filters (Millex-HN, Ireland).

Determination of total lycopene content

Lycopene was extracted according to the procedure described by Fish *et al.* [2002] for the extraction of carotenoids from fruit and vegetables. Approximately 2 g of a ground sample were extracted with 10 mL of hexane/ethanol/acetone (2:1:1) containing 25 g/L butylated hydroxytoluene (BHT). The flask was wrapped and sealed in foil and extracted in a shaker at a speed of 150 rpm for 15 min on ice. Then, 3 mL of distilled water were added and the sample was vortexed again for 5 min. Afterwards, the sample was left for 5 min for phase separation. Absorbance was measured (503 nm) in the hexane phase by using a UV-vis spectrophotometer (Helios Gamma, Thermo, USA), where hexane was a blank sample. Lycopene content was then estimated by the following formula: $L = A_{503} \times 31.2 / m$, where L – lycopene content (μg/g), A_{503} – absorbance of the hexane layer, 31.2 – the molar extinction coefficient for lycopene in hexane, and m – sample weight (g) [Fish *et al.,* 2002].

Determination of total phenolics content (TPC)

The content of phenolic compounds in the extracts was measured with the Singleton and Rossi method with some modifications [Radzki *et al.*, 2014]. Briefly, the samples (0.2 mL) were mixed with 0.8 mL of Folin and Ciocalteu's phenol reagent (10 × diluted). After 3 min, 1.25 mL of 7% Na_2CO_3 was added to the mixture. The sample was kept in darkness for 30 min; the absorbance was read at 725 nm (Helios Gamma, Thermo, USA). The calibration curve was identified at different concentrations of gallic acid as a standard ($y=0.009x$, $R^2=0.999$). The total phenolic content was expressed as gallic acid equivalent (GAE) per 100 g of dry weight of the sample.

1,1-Diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity

The ability to scavenge the 1,1-diphenyl-2-picrylhydrazyl radical (DPPH) was determined using the method designed by Choi *et al.* [2006]. The extracts (0.2 mL) were mixed with 0.8 mL of a DPPH ethanol solution (at a concentration of 0.2 mmol/L) and the mixture was shaken intensely prior to being left in darkness for 15 min. The absorbance was measured at 520 nm against a blank sample. The calibration curve was plotted with various concentrations of Trolox as a standard ($y=-0.0045x+1.869$, $R^2=0.997$). The antioxidant potential was expressed as μmol Trolox equivalent (TE) per 1 g of sample dry weight [Dong *et al.*, 2014].

Ferric reducing antioxidant power (FRAP) assay

Antioxidant capacity was established by the ferric reducing antioxidant assay (FRAP) described by Toor & Savage [2005]. A FRAP reagent was made by mixing 300 mmol/L acetate buffer (pH 3.6) with 10 mmol/L 2,4,6-tripyridyl-triazine (TPTZ) solution in 40 mmol/L HCl and 20 mmol/L $FeCl_3 \times 6H_2O$ (10:1:1 ratio). The assay solutions were prepared by mixing 1.9 mL of FRAP reagent with 0.1 mL of product extract. The mixtures were then incubated at 37°C in darkness for 15 min. The quantity of ferrous tripyridyltriazine complex was estimated by reading the absorbance at 593 nm. The calibration curve was plotted with various concentrations of Trolox as a standard ($y=0.0021x$, $R^2=0.998$); the results were reported as μmol Trolox equivalent (TE) per 1 g of sample dry weight.

Determination of contents of functional components by high performance liquid chromatography (HPLC/DAD)

The HPLC analysis of phenolic acids and rutin was carried out on the Shimadzu high-performance liquid chromatography (HPLC) system (Shimadzu, Japan) equipped with an automatic degasser (DGU-20A 3R), a quaternary pump (LC-20AD), an autosampler (SIL-20A HT), and DAD detector (SPD-M20A). Zorbax Eclipse XDB C_{18} column (250 mm×4.6 mm, 5 μm, Agilent) was used in the following conditions: temperature: 20°C, flow rate of the mobile phase: 1 mL/min, and injection volume: 20 μL. The LC pumps, autosampler, column oven, and DAD were monitored and controlled with the LabSolutions 5.51 software (Shimadzu). An HPLC quantitative analysis was performed according to the previously published method [Skalicka-Woźniak & Głowniak, 2008]. Peaks were identified by comparing their retention times and the UV absorption spectra with those of peaks obtained for individual standards. The quantitative analysis was performed at the wavelengths of 254 and 320 nm. Each calibration curve was analyzed three times at five various concentrations. Each time, the coefficient of determination was calculated (R^2). The precision of the method was evaluated by means of intra-day and inter-day tests. Intra-day experiments were performed by a replicate analysis of six aliquots of the same sample on the same day. Inter-day tests were performed on three consecutive working days in the same way as the intra assay experiments. The relative standard deviation (RSD) used as a measure of intra-day and inter-day precision was <3.02% for all compounds.

Physical properties of snacks

The expansion index of snacks was calculated as a ratio of sample diameter to the diameter of the forming die and was measured with an electronic calliper in 10 replications. Bulk density was evaluated as the weight of the equivalent volume of extrudates. The density measurements were shown as an average of ten replications. The ZwickRoell BDO-FB0.5TH (Zwick GmbH & Co., Germany) universal testing machine was used for the evaluation of snack texture. Cutting force (N) was measured by means of the cutting test with Warner-Bratzler knife, double-edge truncated at an angle of 45°, 3 mm thick and 60 mm long, as an average of 10 replications. The head speed during the tests was set at 500 mm/min. Force–time curves were recorded and analyzed with *testXpertII®v3.3* based on the data from 10 replications [Wójtowicz *et al.*, 2013].

The water absorption index (WAI) was determined as the weight of gel obtained per gram of a dry ground sample [Boualsa *et al.*, 2017]. In brief, the ground extrudates in the amount of 0.7 g were suspended in 7 mL of water having the room temperature and mixed in plastic tubes. After 10 min hydration, the test tubes were closed and centrifuged at 15,000 rpm for 10 min (Centrifuge T24, Leipzig, Germany). The supernatant was decanted and the WAI was calculated as the weight of gel obtained per unit weight of the original solids as dry basis. The water solubility index (WSI) was calculated as the percentage of dry matter recovered after the evaporation of the supernatant from the WAI determination. The supernatant was dried in an air oven at 105°C to a constant weight (about 3 h). WAI and WSI data were gathered in three replications.

Color profile of snacks

The color characteristics of snacks enriched with freeze-dried tomato were evaluated using Lovibond CAM-System 500 Color and Appearance Measurements System (The Tintometer Ltd., UK). The CIE-Lab scale was applied for the evaluation of L^* for brightness (0–100), a^* (+100) for redness and (-100) for greenness, and b^* (+100) for yellowness and (-100) for blueness, respectively. The ΔE was calculated as a color change index [Wójtowicz *et al.*, 2013]. The color check was performed in 20 replications for each sample.

Sensory evaluations

The experiment covered the sensory evaluation of taste, shape, color, flavor, crispness, and the overall quality of snacks. A semi-trained panel with 15 members (9 women, 6 men) assessed the products from each recipe in a 5-point scale. Sensory tests were performed in a laboratory room with bright natural day light; the samples were given out randomly on white plates labelled with codes. The assessment focused on shape, color, flavor, taste, and crispness. The persons involved were briefed about each of the tested sensory attribute. The top scores were given to regular and repeatable shape, uniform color reminding of the used components, fresh flavor reminding of the used components and free from strange odor, pleasant taste reminding of the used components, intense crispness with delicate texture and not hard during the bite. The scores were from 5 for very good down to 1 for very poor, separately for each attribute. The overall quality was the mean value of all tested features.

The final acceptability of the tested samples in relation to the consumers' preferences was evaluated in a 9-point hedonic scale, where 1 stood for "extremely dislike" and 9 for "extremely like". Snacks regarded as acceptable were those scored above 5 [Wójtowicz *et al.*, 2013].

Statistical analysis

The statistical analysis was conducted by means of Statistica ver. 10 (StatSoft, Poland). All analyses were performed in triplicate, but the expansion ratio and hardness were measured in 10 replications. The data was expressed as the mean ± SD (standard deviation). The results were statistically evaluated using the ANOVA analysis of variance with the levels of significance set at $p<0.05$ and $p<0.001$. Statistically different data were compared using the least significant difference (LSD) test. The correlation analysis was conducted with the Pearson's test.

RESULTS AND DISCUSSION

Lycopene content

Lycopene is an important food component in terms of its impact on color but also because of its recognized health benefits. There is no recommended dietary allowance (RDA) established for lycopene, but based on the results of Rao & Shen's research [2002], an intake of 5 to 10 mg lycopene per day is suggested. In the United States, more than 80% of consumed lycopene derive from tomato products. Thermal treatment during the processing of tomato juice, pulp, powder *etc*. may cause degradation of lycopene tomato products [Sahlin *et al.*, 2004]. In our study, in seven variants of snacks supplemented with the tomato powder, lycopene content ranged from 0.2 mg/100 g to 31.2 mg/100 g in the samples before extrusion and from 0.2 mg/100 g to 22.4 mg/100 g in the extruded ones (Table 1). The highest content of lycopene was determined in the samples with 30% addition of the tomato powder, both before and after extrusion. It is worthy of notice that 50 g of tested corn snacks enriched with 30% tomato powder provide the daily required dose of lycopene. Lycopene content in the fresh tomato fruits was 6.3 mg/100 g, and in the lyophilized tomato powder was 92.0 mg/100 g. In the studies of Toor & Savage [2005], lycopene content ranged from 1.6 to 8.7 mg/100 g in different fractions of fresh fruit.

The decrease of the lycopene content in extruded snacks enriched with various levels of powdered tomato ranged from 28.25% to 92.14% compared with the material before extrusion. Mayeaux *et al.* [2006] tested the effect of various heat treatment methods on the stability of lycopene, and showed that 64.4% of lycopene still remained after 1 min of high power microwaving. A similar treatment time was applied during the extrusion-cooking of tomato-supplemented snacks, and the results were comparable to lycopene losses during the aforesaid microwave treatment. Thus, the time and temperature of heating may be responsible for changes in lycopene content in tomato products.

Sahlin *et al.* [2004] reported a lower content of lycopene after the heat treatment of freeze-dried tomatoes by boiling, baking, and frying; nevertheless, the greatest losses of lycopene were observed during frying. The results of a study by Dewanto *et al.* [2002] clearly indicated the formation of *cis*-lycopene in tomato puree during processing. However, it was also suggested that the processing of tomato may increase lycopene bioavailability [Gärtner *et al.*, 1997]. The results presented by Colle *et al.* [2010] and Hwang *et al.* [2012] demonstrated thermal stability of lycopene even during processing at 140°C. In the study of Dehghan-Shoar *et al.* [2010], the temperature range from 140 to 180°C used for the extrusion-cooking of crisps with tomato paste and tomato skin had no significant effect on lycopene content, but lycopene retention in the products containing tomato skin was much higher than in the products containing tomato paste. Lycopene loss during the extrusion-cooking of products containing tomato paste was higher due to the differences in the stability of lycopene in tomato paste and the extreme processing conditions applied. Nevertheless, considering lycopene degradation potential during thermal processing and storage, it is important to assess its content in tomato products and avoid their direct exposure to light [Cámara *et al.*, 2012].

Total phenolics content

Polyphenols are known as secondary plant metabolites, and they are the most desirable phytochemicals because of their strong antioxidant activity. They exert antimicrobial, antiviral and anti-inflammatory effects on the human body and exhibit a disease-preventing potential attributed to several constituents which may show some synergistic interactions. Tomato and tomato products were found as good sources of phenolics in the diet, their content being similar to that reported in corn, pinto beans, potato or onion [George *et al.*, 2004].

TABLE 1. Contents of lycopene and total phenolics, and scavenging ability determined by the DPPH and ferric reducing antioxidant power (FRAP) in samples before and after the extrusion-cooking.

Tomato addition (%)	Lycopene (mg/100 g)	TPC (mg GAE/100 g)	DPPH (μmol TE/g)	FRAP (μmol TE/g)
Before extrusion (raw material)				
0 (corn grits)	0.2 ± 0.1^{a}	67.1 ± 5.7^{a}	0.2 ± 0.1^{a}	1.9 ± 0.2^{a}
5	4.6 ± 0.2^{b}	83.8 ± 4.5^{b}	0.3 ± 0.1^{a}	2.9 ± 0.2^{b}
10	9.7 ± 0.1^{c}	84.2 ± 4.1^{b}	0.9 ± 0.2^{b}	3.0 ± 0.3^{b}
15	15.7 ± 0.1^{d}	96.3 ± 2.0^{c}	1.1 ± 0.2^{b}	3.8 ± 0.3^{c}
20	21.4 ± 0.1^{e}	98.6 ± 2.6^{cd}	1.2 ± 0.2^{b}	4.5 ± 0.2^{cd}
25	25.2 ± 0.2^{f}	103.1 ± 0.9^{cd}	2.0 ± 0.1^{c}	5.0 ± 0.4^{d}
30	31.2 ± 0.3^{g}	109.7 ± 6.9^{d}	2.0 ± 0.2^{c}	7.4 ± 0.2^{e}
After extrusion (corn snacks)				
0 (pure snacks)	0.2 ± 0.0^{a}	48.8 ± 2.6^{a}	0.3 ± 0.2^{a}	2.3 ± 0.2^{a}
5	0.4 ± 0.0^{a}	107.4 ± 3.2^{b}	1.3 ± 0.2^{a}	5.2 ± 0.2^{b}
10	1.6 ± 0.1^{b}	173.9 ± 3.2^{c}	3.6 ± 0.4^{b}	10.0 ± 0.2^{c}
15	4.1 ± 0.1^{c}	202.7 ± 2.4^{d}	3.7 ± 0.3^{b}	11.4 ± 0.5^{cd}
20	7.8 ± 0.1^{d}	214.5 ± 6.2^{de}	3.9 ± 0.8^{b}	11.8 ± 1.2^{d}
25	17.9 ± 0.1^{e}	223.3 ± 13.1^{ef}	4.2 ± 0.3^{b}	12.1 ± 0.5^{d}
30	22.3 ± 0.1^{f}	239.6 ± 4.3^{f}	4.8 ± 0.4^{b}	12.8 ± 0.6^{d}

$^{a\text{-}g}$ statistically significant differences in columns at $p<0.05$ were marked by different letters separately before and after treatment; means ± standard deviations.

Table 1 shows the content of total phenolics as the gallic acid equivalent extracted with ethanol in the tested recipes with different contents of tomato powder before and after the extrusion-cooking, respectively. The content of total phenolics in raw material before extrusion ranged from 67.1 mg GAE/100 g d.w. for corn grits up to 109.7 mg GAE/100 g d.w. for corn mixtures with 30% of freeze-dried tomato powder. After extrusion-cooking, the content of total phenolics was significantly higher, especially for snacks with the highest addition of tomato powder in the recipe (239.6 mg GAE/100 g d.w.). A similar TPC was observed by Dong *et al.* [2014] in three types of corn by-products, *i.e.* from 298.8 to 399.4 mg GAE/100 g d.w. depending on corn variety. In the samples without tomato powder, the content of polyphenolic compounds decreased after heat-treatment. This can suggest the destructive impact of high temperature on corn. In recipes with added tomato, the content of phenolic compounds was by 23–118% higher in the processed snacks than in the material before extrusion. Thus, with the addition of tomato powder, phenolic compounds in the consolidated form (not identified in the material without extrusion-cooking treatment) were introduced into the samples. The literature on the subject [Acosta-Estrada *et al.*, 2014] confirms that a high temperature can trigger the breaking of chemical bonds and the releasing of phenolic compounds, which contributes to their determined level. There is no recommended level of consumption of antioxidants, but the daily intake of antioxidants, phenolics and flavonoids by the Americans was estimated at 591 mg VCE (Vitamin C equivalent), 450 mg GAE and 103 mg catechin equivalents, respectively, especially from vegetables and fruit [Chun *et al.*, 2005].

There are some studies which suggest that heat treatments may have detrimental effects on the quantity of nutrients in vegetables; nevertheless, bioavailability of some nutrients may increase at the same time. Sahlin *et al.* [2004] reported a reduction in the total phenolics content after boiling and frying two cultivars of tomato compared with the respective raw cultivar, but after baking, the total phenolics content was slightly higher. The values were 438 to 354 mg GEA/100 g d.m. of raw tomatoes and 245 to 441 mg GEA/100 g d.m. after the heat treatment. The processing of cereals by means of extrusion-cooking affects the breaking of conjugated moieties and, thus, the release of bound phenolics. The antioxidant activity of free phenolic extracts in extruded mixtures of whole maize and chickpea flours increased although the amount of bound phenolics decreased compared with the unprocessed samples [Acosta-Estrada *et al.*, 2014]. However, this activity depends on the conditions of processing and extraction that are likely to account for differences in results.

1,1-Diphenyl-2-picrylhydrayl (DPPH) radical scavenging activity

Antioxidants are considered important nutraceuticals because of their diverse health benefits. To assess the antioxidant potential, the DPPH reduction of free radicals was performed as a rise to colorless ethanol solution in the presence of antioxidant molecules. The DPPH assay with a spectrophotometric evaluation is one of the easy methods to measure natural antioxidants [Dong *et al.*, 2014].

The DPPH values of the analyzed samples are shown in Table 1. The total DPPH values ranged from 0.2 to 2.0 μmol TE/g d.w. for materials before extrusion and from 0.3 to 4.8 μmol TE/g d.w. for extruded corn snacks. Significantly higher values (from 4 times to almost 14 times) of the antioxidant activity measured by the DPPH method were observed for the extrudates with at least 10% of powdered tomato addition ($p<0.001$) than for the control sample. The results showed that the addition of freeze-dried tomato to a snack recipe increased the content of phenolic acids from 200 to 300% after the heat treatment under the applied conditions compared with untreated raw materials, thus improving their function as hydrogen donors or free radical scavengers in food products.

Ferric-Reducing Antioxidant Power (FRAP)

The ferric reducing-antioxidant power (FRAP) is a commonly used indicator of phenolic antioxidant activity just as the reducing power is [Dong *et al.*, 2014]. The FRAP values of the analyzed samples are shown in Table 1 for raw materials and processed snacks. The total FRAP values ranged from 1.9 for corn grits to 7.4 μmol TE/g d.w. for a blend with 30% of tomato before processing. After extrusion-cooking, corn snacks showed the total FRAP value of 2.3 μmol TE/g d.w. and an increased addition of powdered tomato raised the total FRAP value significantly ($p<0.001$, $r=0.904$, Table 5), *i.e.* up to 12.8 μmol TE/g d.w. for crisps with 30% tomato powder addition. Both the DPPH value and the FRAP values were higher in the samples after extrusion-cooking than in the raw materials before treatment. The values of FRAP determined in the samples with tomato were twice to almost 6 times higher than in pure corn snacks. The ready-to-eat extrudates enriched with tomato powder showed a significantly higher antioxidant activity than the pure corn snacks.

Before the heat treatment, the antioxidant activity (FRAP and DPPH scavenging activity) of raw materials was strongly correlated with the contents of both total phenolic compounds ($r=0.898$ and $r=0.919$, respectively) and lycopene ($r=0.932$ and $r=0.968$, respectively). In the material processed by extrusion-cooking, the antioxidant activity significantly ($p<0.001$) depended only on the content of the total phenolic compounds (Table 5). Corn snacks supplemented with tomato powder exhibited better antioxidant properties than the pure corn crisps.

HPLC/DAD results

Under the applied chromatographic conditions, four functional compounds were separated and quantified over 30 min of running time: neochlorogenic acid, chlorogenic acid, *p*-coumaric acid, and rutin (Table 2). For all the compounds, good linearity of the calibration curve was obtained ($R^2>0.999$) within the tested ranges. Protocatechuic, ferulic, rosmarinic, and ellagic acids were not identified in any of the samples. Phenolic acids were detected at $\lambda=320$ nm, and rutin was quantified at $\lambda=254$ nm. Neochlorogenic acid was only detected in tomato powder (12.1 mg/100 g) and in snacks with the addition of tomato powder (content from 1.6 up to 5.5 mg/100 g). Chlorogenic acid was found in all the tested samples, and its content accounted for 0.4 mg/100 g of corn grits, 6.7 mg/100 g in powdered tomato, from 0.5 up to 2.5 mg/100 g in extruded snacks enriched with tomato powder. The values of *p*-coumaric acid ranged from 0.6 mg/100 g for corn grits up to 0.9 mg/100 g for extruded corn snacks with 20, 25 and 30% of powdered tomato. These values were significantly lower than those observed in the tomato powder (Table 2). The correlation coefficients showed a strong positive effect of the increased content of the additive on the level of neochlorogenic acid ($r=0.886$), chlorogenic acid ($r=0.946$), and *p*-coumaric acid ($r=0.934$).

TABLE 2. The content of phenolic compounds in raw materials and snacks enriched with tomato powder.

	Neochlorogenic acid (mg/100 g)	Chlorogenic acid (mg/100 g)	*p*-Coumaric acid (mg/100 g)	Rutin (mg/100 g)
Ret. time (min)	6.20	9.40	18.70	20.09
Raw materials				
Tomato powder	12.1	6.7	1.6	0
Corn grits	0	0.4	0.6	6.6
Tomato addition (%)	Snacks			
0	0^{a}	0.5^{a}	0.6^{a}	5.0^{a}
5	1.6^{b}	0.6^{ab}	0.7^{ab}	3.7^{b}
10	3.4^{c}	1.0^{b}	0.6^{a}	3.2^{c}
15	5.5^{e}	1.4^{c}	0.8^{b}	3.2^{c}
20	4.9^{cd}	1.2^{bc}	0.9^{c}	3.2^{c}
25	4.9^{cd}	1.8^{d}	0.9^{c}	3.2^{c}
30	5.1^{d}	2.5^{e}	0.9^{c}	3.1^{d}
Correlation coefficients (r)	0.866*	0.946**	0.934**	-0.767*

$^{a-e}$ statistically significant differences in columns at $p<0.05$ were marked by different letters; *significant at $p<0.05$; **significant at $p<0.001$; relative standard deviation (RSD) was <3.02% for all compounds.

The highest concentration of rutin, being an active component of corn grits, was at 6.6 mg/100 g. Much lower values were reported for the extruded products because of the thermal sensitivity of rutin to the processing conditions [Kamiloglu *et al.*, 2014]. In extruded snacks, the content of rutin started from 5.0 mg/100 g in corn snacks and decreased to 3.1 mg/100 g in corn snacks enriched with 30% of tomato ($r=-0.767$). Rutin was not detected in the tomato powder.

Martí *et al.* [2015] analyzed different varieties of fresh tomatoes. Chlorogenic acid showed the highest concentration from 0.72 to 2.55 mg/100 g. The contents of *p*-coumaric acid ranged from 0.05 to 0.28 mg/100 g and of rutin from 0.61 to 0.91 mg/100 g. Slimestad & Verheul [2009] presented the results of phenolics in fresh, red tomatoes from different countries. They reported that the content of chlorogenic acid ranged from 0.17 to 6.90 mg/100 g and *p*-coumaric acid

TABLE 3. Physical properties and color profile of enriched snacks.

Tomato addition (%)	Expansion ratio (-)	Density (kg/m^3)	Hardness (N)	WAI (g/g)	WSI (%)	L^*	a^*	b^*	ΔE
0	5.4 ± 0.1^{a}	78.2 ± 1.6^{a}	8.4 ± 0.9^{a}	6.2 ± 0.0^{a}	20.2 ± 0.5^{a}	83.3 ± 1.3^{a}	-4.5 ± 2.7^{a}	40.7 ± 4.2^{a}	-
5	5.1 ± 0.4^{a}	79.1 ± 3.1^{a}	11.0 ± 1.0^{ab}	5.9 ± 0.0^{b}	13.5 ± 0.4^{b}	81.2 ± 1.3^{a}	-3.3 ± 0.7^{ab}	42.0 ± 1.7^{a}	2.7^{a}
10	4.1 ± 0.3^{b}	101.1 ± 3.9^{ab}	10.7 ± 1.1^{ab}	5.2 ± 0.2^{bc}	10.1 ± 0.6^{c}	74.6 ± 1.4^{ab}	-1.6 ± 0.7^{b}	48.4 ± 2.4^{b}	12.0^{b}
15	3.5 ± 0.3^{c}	160.7 ± 5.2^{b}	12.5 ± 1.4^{b}	5.6 ± 0.1^{b}	9.8 ± 0.2^{c}	70.7 ± 1.7^{b}	3.2 ± 1.6^{c}	55.9 ± 1.7^{bc}	21.2^{c}
20	2.8 ± 0.4^{d}	294.7 ± 10.8^{c}	17.1 ± 3.6^{cd}	4.0 ± 0.1^{c}	12.0 ± 0.4^{bc}	69.7 ± 1.2^{b}	5.8 ± 0.8^{d}	57.6 ± 0.7^{c}	24.1^{c}
25	2.0 ± 0.1^{e}	607.7 ± 18.3^{d}	16.4 ± 1.8^{c}	3.5 ± 0.2^{cd}	12.9 ± 0.5^{bc}	66.2 ± 0.9^{bc}	11.1 ± 1.0^{e}	57.9 ± 0.6^{c}	28.8^{cd}
30	1.7 ± 0.1^{e}	638.5 ± 22.6^{e}	18.5 ± 3.3^{d}	3.2 ± 0.2^{d}	14.3 ± 0.9^{b}	61.5 ± 2.5^{c}	11.8 ± 1.6^{e}	57.5 ± 3.9^{c}	32.0^{d}

$^{a\text{-}e}$ statistically significant differences in columns at $p<0.05$ were marked by different letters; means ± standard deviations; WAI – water absorption index; WSI – water solubility index; L^* – brightness (0–100); a^* (+100) redness and (-100) greenness; b^* (+100) yellowness and (-100) blueness; ΔE – color change index.

ranged from 0.11 to 0.58 mg/100 g. Kamiloglu *et al.* [2014] studied the content of major tomato phenolics in different tomato products. Rutin content ranged from 9.0 mg/100 g in dried tomato up to 14.0 mg/100 g in tomato paste. The same authors reported that the content of chlorogenic acid ranged from 15 mg/100 g in dried and chopped tomatoes up to 31.0 mg/100 g in tomato juice.

Physical properties

A sudden pressure drop in the melted phase exiting the forming die is responsible for the formation of the expanded structure of extrudates [Moscicki & Wójtowicz, 2011; Wójtowicz *et al.*, 2013]. The high expansion index of cereal snacks is desirable if a high extrudate quality is required. The results of the radial expansion index of corn snacks supplemented with freeze-dried tomato are shown in Table 3. It was found that the increased quantity of tomato in the recipe lowered the snack expansion significantly ($p<0.001$) with a high correlation coefficient of $r=-0.993$. The difference of the expansion ratio between the reference sample of corn snacks (5.4) and the extrudate with the highest tomato addition (1.7) was 68%. Consequently, due to the significant reduction in extrudate expansion, the addition of tomato powder to directly expanded ready-to-eat snacks should not exceed 20% during the processing under the applied extrusion-cooking conditions to obtain attractive puffed snacks with high sensory notes (Table 4). The extrudate expansion ratio was significantly correlated with all the tested nutritional components, as well as with product density, hardness and the WAI (Table 5). The reduction of the sectional expansion of snacks may result from the lower quantity of starch replaced by additives in the processed material, which leads to a minor expansion and lowers the intensity of formation of the porous structure characteristic of directly expanded extrudates. As reported by Dehghan-Shoar *et al.* [2010], the expansion of lycopene-enriched snacks was positively correlated with the specific mechanical energy (SME) and the use of fibre-rich tomato derivatives lubricates the melt and, therefore, diminishes the SME and torque. Consequently, the expansion also decreased. An increase in the level of tomato pomace, as shown in the work by Caltinoglu *et al.* [2014], resulted in the limited sectional expansion of the extrudate. It was justified by the dilution effect of pomace on starch due to the increasing fibre content in the processed material. The presence of fibre particles causes the rupture of the cell walls before the gas bubbles expand to their full size. The increased level of fruit and vegetable additives usually results in the reduced sectional expansion index of the extrudate, as reported also by Altan *et al.* [2008] and Stojceska *et al.* [2010].

The measurements of extrudate apparent density yielded values beginning from 78.2 kg/m^3 for corn snacks. Only insignificant effect on density was observed in snacks made with 5% of tomato powder (Table 3). Raising the addition of tomato powder from 10 to 20% doubled the density values. The highest density was reported for snacks with 25 and 30% of the additive. The tendency for greater density along with the increasing level of powdered tomato was significant ($p<0.001$) and ran in parallel with a high correlation coefficient of $r=0.919$. Extrudate density measurement is useful in describing the extent of puffing after the hot dough exits the extruder die, and a porous structure is formed after the evaporation of unbound water. Although, the expansion ratio results showed only some sectional expansion, the density results additionally showed an all-direction expansion and internal integrity of components. The higher value of product density was attributed to the lower expansion of snacks with a high correlation coefficient of $r=-0.918$ (Table 5). Product density or piece density is commonly used as a characteristic of the puffing ability of directly expanded extrudates and strongly depend on the initial moisture content, temperature, feed rate, or the level of an additive. Ondo *et al.* [2013] reported that piece density of extruded cornmeal with the addition of alkalized cocoa powder and the injection of CO_2 at various temperatures ranged from 400 to 1300 kg/m^3. Altan *et al.* [2008] reported bulk density ranging from 370 to 1111 kg/m^3 for extrudates made with barley flour and a tomato pomace mixture. It increased significantly with a greater amount of pomace used. A greater addition of powdered tomato lowered the total content of starch in the processed mixtures, which contributed to the formation of a specific structure of extrudates. It resulted in a lowered expansion

TABLE 4. The results of sensory profile (5-point scale) and acceptance (9-point hedonic scale) of extruded snacks enriched with powdered tomatoes.

Tomato addition (%)	Shape	Color	Flavor	Taste	Crispness	Overall quality	Acceptance
0	4.9 ± 0.3^{a}	4.8 ± 0.4^{a}	4.8 ± 0.5^{a}	4.7 ± 0.4^{a}	4.9 ± 0.2^{a}	4.82^{a}	7.3 ± 1.0^{ab}
5	4.7 ± 0.5^{a}	4.5 ± 0.5^{b}	4.8 ± 0.4^{b}	4.8 ± 0.4^{a}	4.8 ± 0.4^{a}	4.72^{a}	8.1 ± 0.9^{a}
10	4.5 ± 0.6^{ab}	4.4 ± 0.5^{b}	4.7 ± 0.5^{b}	4.5 ± 0.5^{b}	4.3 ± 0.9^{b}	4.48^{ab}	7.5 ± 0.8^{ab}
15	4.0 ± 0.7^{b}	4.1 ± 0.6^{c}	4.5 ± 0.6^{c}	4.1 ± 0.3^{b}	4.1 ± 0.8^{c}	4.16^{b}	6.4 ± 1.1^{c}
20	3.4 ± 0.3^{c}	3.6 ± 0.6^{d}	4.3 ± 0.9^{cd}	4.1 ± 0.5^{b}	3.8 ± 0.8^{d}	3.84^{bc}	6.2 ± 1.0^{d}
25	3.3 ± 0.8^{c}	3.5 ± 0.6^{d}	4.3 ± 0.6^{cd}	4.2 ± 0.4^{c}	3.8 ± 0.5^{d}	3.80^{c}	6.7 ± 0.7^{b}
30	3.3 ± 0.7^{c}	3.3 ± 0.6^{e}	4.0 ± 0.5^{d}	4.3 ± 0.6^{c}	4.0 ± 0.7^{cd}	3.78^{c}	6.8 ± 0.6^{b}
Correlation coefficients (r)	-0.967^{**}	-0.987^{**}	-0.970^{**}	-0.757^{*}	-0.890^{**}	-0.968^{**}	-0.646^{ns}

$^{a-e}$ statistically significant differences in columns at $p<0.05$ were marked by different letters; means ± standard deviations.

and increased density of tomato-enriched snacks depending on the increased quantity of additives used.

The texture characteristic of ready-to-eat snacks very often influences consumers' acceptability [Duizer & Winger, 2006]. The assessment of snack texture with the cutting test showed what force is needed to rupture the sample. This also allows for hardness measurement. The increased addition of tomato resulted in a higher breaking force, or hardness, and a more sudden increase and reduction of force in force-displacement curves. It means that a higher addition of tomato increased the hardness of the enriched snacks and made them more compact and brittle in structure. This is not easily acceptable in puffed snacks, but it could be interesting for the development of new products, such as stick-like snacks. The cutting forces ranged from 8.4 N for corn snacks up to 18.5 N for snacks with 30% of the additive (Table 3). The tomato fibre interferes with the air bubble formation and increases the thickness of air cell walls. As a result, a harder product is obtained [Altan *et al.*, 2008; Dehghan-Shoar *et al.*, 2010]. Hardness was significantly ($p<0.05$) correlated with the nutritional components of corn-tomato snacks as well as with the expansion ratio and the WAI values ($p<0.001$) (Table 5). Altan *et al.* [2008] tested extrudates based on barley flour with tomato pomace as an additive in 2 to 10%. Based on the three-point bending test with the test speed of 120 mm/min, they concluded that the hardness of extrudates varied between 5.6 and 29.8 N. High hardness was highly correlated with high product density ($r=0.925$, $p<0.001$).

The WAI is the amount of water absorbed by starch or other polymers after swelling when making contact with water, while the WSI determines the quantity of unbound polysaccharides in a swollen sample [Bouasla *et al.*, 2017; Stojceska *et al.*, 2010]. The WAI of corn-tomato snacks decreased significantly ($p<0.001$) as the amount of tomato powder increased ($r=-0.952$). This can be attributed to the decrease in the total starch content replaced by tomato and lowering the volume of water absorbed by starch remaining in the extrudate. The WAI reached 6.2 g/g in corn snacks and water absorption was lower almost by half when the highest amount of the additive was used (Table 3). The WAI increase can be temperature-dependent and attributed to the increased content of gelatinized starch. The replacement of starchy raw material by vegetables, fruit, or high-fiber additives means that a lower quantity of starch is subject to swelling and gelatinization during processing, so the WAI is usually much lower with the higher volume of additives, as reported by Altan *et al.* [2008]. The results of snack expansion measurements, as demonstrated earlier in this paper, exhibited the significance of $p<0.001$, corresponding to the high expansion along with the high WAI values of the product ($r=0.955$) and low product density ($r=-0.944$) (Table 5). Ondo *et al.* [2013] concluded that the volume of absorbed water may indicate an indirect estimation of extrudate porosity. The reported WAI values ranged from 6.7 up to 11.2 g/g for increased extrudate porosity in samples expanded with CO_2.

The WSI of extruded products is associated with a wide range of transformations occurring during the processing, for example, starch chain disordering, depolymerization of amylose and amylopectin, starch gelatinization, and increased solubility of starch. The intensity of treatment in the various sections of the extruder, involving variable heating, shearing, pressure, and residence time, is responsible for these transformations [Moscicki & Wójtowicz, 2011; Ondo *et al.*, 2013; Stojceska *et al.*, 2010]. Additionally, the presence of water-insoluble complexes between the macromolecules of amylose and components like proteins and lipids that are formed during the extrusion-cooking may reduce the WSI. The higher expansion of extruded snacks means the greater water-accessible surface that can interact with starch and other water-soluble components. The WSI could also be used to measure the molecular degradation of components released as soluble polysaccharides from starch after the extrusion-cooking. The WSI results, shown in Table 3, indicate lowered solubility of snacks with up to 15% of powdered tomato in the recipe and slightly increased WSI values, but the trend was not significant at this level of the additive. The highest WSI was noted for corn snacks, and 20.2% of components leached into the supernatant during the test. The addition of tomato, replacing starchy components, caused a lower WSI index of the enriched snacks.

TABLE 5. Correlation analysis between nutritional and physical properties of tomato-enriched snacks.

	Additive level	Lycopene	TPC	DPPH	FRAP	Expansion	Density	Hardness	WAI	WSI	*L**	*a**	*b**	Overall quality
Lycopene	0.931**													
TPC	0.933**	*ns*												
DPPH	0.909**	*ns*	0.987**											
FRAP	0.904**	*ns*	0.996**	0.992**										
Expansion	-0.993**	-0.921**	-0.934**	-0.915**	-0.911**									
Density	0.919**	0.993**	*ns*	*ns*	*ns*	-0.918**								
Hardness	0.922**	0.857*	0.819*	0.749*	0.771*	-0.896**	0.853*							
WAI	-0.952**	-0.938**	-0.832*	-0.818*	-0.798*	0.955**	-0.944**	-0.908**						
WSI	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*					
*L**	-0.987**	-0.988**	-0.952**	-0.944**	-0.934**	0.984**	-0.877*	-0.861**	0.911**	*ns*				
*a**	0.983**	0.955**	0.876**	0.842*	0.842*	-0.985**	0.956**	0.908**	-0.945**	*ns*	-0.960**			
*b**	0.922**	0.750*	0.958**	0.927**	0.953**	-0.940**	*ns*	0.816*	-0.820*	*ns*	-0.939**	0.905**		
Overall quality	-0.968**	-0.850*	-0.935**	-0.897**	-0.916**	0.979**	-0.852*	-0.908**	0.918**	*ns*	0.956**	-0.961**	-0.974**	
Acceptance	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	-0.845*	0.790*

^{ns} Not significant; * significant at $p<0.05$; ** significant at $p<0.001$.

TPC – total phenolic content; DPPH – scavenging ability on 1,1-diphenyl-2-picrylhydrazyl radicals; FRAP – ferric reducing antioxidant power assay; WAI – water absorption index; WSI – water solubility index; *L** – brightness; *a** redness-greenness balance; *b** yellowness-blueness balance.

Some previous works showed an increase in the WSI – along with a higher screw speed applied and with higher levels of additives – ranging from 7.1% to 13.0% for the barley flour–tomato pomace extrudate [Altan *et al.*, 2008] and from 7.7 to 29.1%, as reported by Stojceska *et al.* [2010].

Color and sensory attractiveness of snacks

The color assessment showed lower *L** values of snacks extruded with the higher addition of tomato (Table 3). The same was also confirmed by the sensory scores. For basic corn snacks, the *L** value was the highest and reached 83.3. The *L** value was negatively correlated with the level of the additive, lycopene and phenolic content, as well as with the *a** and *b** color coordinates (Table 5). Similar observations were reported by Dehghan-Shoar *et al.* [2010]. The greenness-redness balance in the snacks enriched with tomato varied from -4.5 in control corn snacks without additives up to 11.8 in extrudates with 30% tomato content. The nature of freeze-dried tomato used for snack supplementation may be the key factor of significantly higher redness *a** of snacks improved with the higher level of the additive ($r=0.983$, $p<0.001$). The values of color parameter *b** varied from 40.7 in corn snacks up to 57.5 in tomato-enriched snacks. High yellowness was observed in all tested snack samples due to the presence of carotenoids, both in corn grits as the basic raw material and in tomatoes as the additive. Similar observations were made by Caltinoglu *et al.* [2014] for corn crisps with an addition of tomato pulp. They found some increase in redness in snacks with the addition of tomato pulp due to the presence of lycopene pigment in tomato pulp and a very slight increase in yellowness due to the yellowish pigments present in tomato pulp. The ΔE values showed some significant changes in the snack color profile, influenced by both reduced lightness and intensified redness.

The sensory assessment scores for taste, shape, color, flavor, and crispness of corn-tomato snacks are presented in Table 4. One of the most important factors in sensory assessment is crispness, nowadays associated with new processed foods, like snacks, cereal bars, *etc.* than with fruit or vegetables. Crispness makes products more brittle and easy to break down, while crunchiness allows texture to be maintained for a longer time and requires more chewing [Varela *et al.*, 2008]. Excellent results of crispness were reported for corn snacks and extruded products based on the recipes with 5 and 10% of tomato powder; increasing the quantity of tomato in the recipe reduced crispness and increased crunchiness of the tested snacks. This could be related to the low expansion ratio, high density and lower aeration of the product processed with the increased amount of tomato in the recipe, as indicated by the high correlation coefficients (Table 5). Also notes given to color decreased significantly along with the higher level of tomato in snacks. The consumers taking part in the test noted that the increased level of tomato translated into more intense redness of snacks, which was confirmed in color measurements (Table 5). As regards the shape of extrudates, significant differences ($p>0.05$) between the samples were noticed with a high negative correlation coefficient, which was reflected in the poorer notes given to snacks with the increased level of the additive ($r=-0.967$). This opinion may be attributed to the testers' remarks that even very low-expanded corn extrudates with 30% tomato addition can be used as savoury snacks served with a dip or as extruded sticks. Tomato-like flavor and taste were more intense in the tested samples with the negative correlations of these features with the increased level of used additive (r=-0.970 and r=-0.757 for flavor and taste, respectively), but the sensory notes given to these attributes were still high. Crispness and the overall quality were also negatively correlated with the increasing amount of additive used (r=-0.890 and r=-0.986, respectively). Acceptability, expressed in a 9-point hedonic scale, was 6.4 for the snacks with 15% tomato addition. Also, the use of 25 and 30% of freeze-dried tomato in corn snack recipes was assessed as acceptable (6.7–6.8) and these snacks were found attractive as low-expanded sticks-like snacks. This suggests the possibility of using tomato for the improvement of the chemical composition and specific sensory characteristics of biofortified food, snacks in particular.

CONCLUSIONS

The addition of powdered tomato to corn snacks may increase the assortment of gluten-free and valuable extruded snacks on the market. These savory snacks – served in the attractive form of ready-to-eat functional snacks – seem to be a good source of phenolic compounds. The extrusion-cooking processing of corn-tomato snacks causes an increase in the total phenolics content and improves the scavenging ability and the ferric reducing antioxidant power. With a higher content of tomato powder in corn snacks, a higher concentration of lycopene was obtained. The lowest lycopene losses after the extrusion-cooking were observed in corn snacks with 25% and 30% tomato powder addition. Snacks with powdered tomato can be an alternative source of lycopene and supplementary phenolic compounds with an antioxidative potential in an everyday human diet. They can be an attractive type of appetizer with a high level of bioactive compounds. A greater addition of tomato lowers the expansion and the WAI of snacks but increases their density and hardness. The addition of tomato in combination with corn grits should not exceed 20% to maintain the proper physical properties of directly expanded snacks. Nevertheless, products containing 25 and 30% of tomato may be attractive as sticks-like snacks, ideal for consumption with cheese dips or sauces. The integration of freeze-dried tomato with extruded snacks delivers physiologically active compounds of substances and allows the development of more healthy products with the desired chemical and physical properties.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

REFERENCES

1. Abete I., Perez-Cornago A., Navas-Carretero S., Bondia-Pons I., Zulet M.A., Martinez J.A., A regular lycopene enriched tomato sauce consumption influences antioxidant status of healthy young-subjects: A crossover study. J. Funct. Foods, 2013, 5, 28–35.
2. Acosta-Estrada B.A., Gutierrez-Uribe J.A., Serna-Saldivar S.O., Bound phenolics in foods, a review. Food Chem., 2014, 152, 46–55.
3. Altan A., McCarthy K., Maskan M., Evaluation of snack foods from barley–tomato pomace blends by extrusion processing. J. Food Eng., 2008, 84, 231–242.
4. Bisharat G.I., Lazou A.E., Panagiotou N.M., Krokida M.K., Maroulis Z.B., Antioxidant potential and quality characteristics of vegetable-enriched corn-based extruded snacks. J. Food Sci. Technol., 2015, 52, 3986–4000.
5. Bouasla A., Wójtowicz A., Zidoune M.N., Gluten-free precooked rice pasta enriched with legumes flours: Physical properties, texture, sensory attributes and microstructure. LWT – Food Sci. Technol., 2017, 75, 569–577.
6. Caltinoglu C., Tonyalı B., Sensoy I., Effects of tomato pulp addition on the extrudate quality parameters and effects of extrusion on the functional parameters of the extrudates Int. J. Food Sci. Technol., 2014, 49, 587–594.
7. Cámara M., Fernández-Ruiz V., Fernández Redondo D., Sánchez-Mata M.C., Torrecilla J., Radial basis network analysis to estimate lycopene degradation kinetics in tomato-based products. Food Res. Int., 2012, 49, 453–458.
8. Chang C.H., Liu Y.C., Study on lycopene and antioxidant contents variations in tomatoes under air-drying process. J. Food Sci., 2007, 72, E532-E540.
9. Choi Y., Lee S.M., Chun J., Lee H.B., Lee J., Influence of heat treatment on the antioxidant activities and polyphenolic compounds of Shiitake (*Lentinus edodes*) mushroom. Food Chem., 2006, 99, 381–387.
10. Chun O.K., Kim D.O., Smith N., Schroeder D., Han J.T., Lee C.Y., Daily consumption of phenolics and total antioxidant capacity from fruit and vegetables in the American diet. J. Sci. Food Agric., 2005, 85, 1715–1724.
11. Colle I., Lemmens L., Van Buggenhout S., Van Loey A., Hendrickx M., Effect of thermal processing on the degradation, isomerization, and bioaccessibility of lycopene in tomato pulp. J. Food Sci., 2010, 75, C753-C759.
12. Dehghan-Shoar Z., Hardacre A.K., Brennan, C.S., The physicochemical characteristics of extruded snacks enriched with tomato lycopene. Food Chem., 2010, 123, 1117–1122.
13. Dewanto V., Wu X.Z., Adom K.K., Liu R.H., Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. J. Agric. Food Chem., 2002, 50, 3010–3014.
14. Dong J., Cai L., Zhu X., Huang X., Yin T., Fang H., Ding Z. Antioxidant activities and phenolic compounds of cornhusk, corncob and stigma maydis. J. Braz. Chem. Soc., 2014, 25, 1956–1964.
15. Duizer L.M., Winger R.J., Instrumental measures of bite forces associated with crisp products. J. Text. Studies, 2006, 37, 1–15.
16. Fernandez-Panchon M.S., Villano D., Troncoso A.M., Garcia-Parrilla M.C., Antioxidant activity of phenolic compounds: from *in vitro* results to *in vivo* evidence. Crit. Rev. Food Sci. Nutr., 2008, 48, 649–671.

17. Fish W.W., Perkins-Veazie P., Collins J.K., Quantitative assay for lycopene that utilizes reduced volumes of organic solvents. J. Food Comp. Anal., 2002, 15, 309–317.
18. Friedman M., Fitch T.E., Levin C.E., Yokoyama W.H., Feeding tomatoes to hamsters reduces their plasma low-density lipoprotein cholesterol and triglycerides. J. Food Sci., 2000, 65, 897–900.
19. Gärtner C., Stahl W., Sies H., Lycopene is more bioavailable from tomato paste than from fresh tomatoes. Am. J. Clin. Nutr., 1997, 66, 116–22.
20. George B., Kaur C., Khurdiya D.S., Kapoor H.C., Antioxidants in tomato (*Lycopersium esculentum*) as a function of genotype. Food Chem., 2004, 84, 45–51.
21. Giovannucci E., Tomato products, lycopene, and prostate cancer: a review of the epidemiological literature. J. Nutr., 2005, 135, 2030S-2031S.
22. Gülçin I., Antioxidant activity of food constituents: An overview. Arch. Toxicol., 2012, 86, 345–391.
23. Hwang E.S., Stacewicz-Sapuntzakis M., Bowen P.E., Effects of heat treatment on the carotenoid and tocopherol composition of tomato. J. Food Sci., 2012, 77(10), C1109-C1114.
24. Kamiloglu S., Demirci M., Selen S., Toydemir G., Boyacioglu D., Capanoglu E., Home processing of tomatoes (*Solanum lycopersicum*): effects on *in vitro* bioaccessibility of total lycopene, phenolics, flavonoids, and antioxidant capacity. J. Sci. Food Agric., 2014, 94, 2225–2233.
25. Kavanaugh C.J., Trumbo P.R., Ellwood K.C., The U.S. Food and Drug Administration's evidence-based review for qualified health claims: Tomatoes, lycopene, and cancer. J. Nat. Cancer Inst., 2007, 99, 1074–1085.
26. Martí R., Valcárcel M., Herrero-Martínez J.M., Cebolla-Cornejo J., Roselló S., Fast simultaneous determination of prominent polyphenols in vegetables and fruits by reversed phase liquid chromatography using a fused-core column. Food Chem., 2015, 169, 169–179.
27. Mayeaux M., Xu Z., King J.M., Prinyawiwatkul W., Effects of cooking conditions on the lycopene content in tomatoes. J. Food Sci., 2006, 71, C461-C464.
28. Moscicki L., Wójtowicz A., Raw materials in production of extrudates. 2011, *in:* Extrusion-Cooking Techniques. Applications, Theory and Sustainability (ed. L. Moscicki). Wiley-VCH VerlagGmbH&Co. KGaA., Weinheim, pp. 45–63.
29. Ondo S.E., Singkhornart S., Ryu G.H., Effects of die temperature, alkalized cocoa powder content and CO2 gas injection on physical properties of extruded cornmeal. J. Food Eng., 2013, 117, 173–182.
30. Radzki W., Sławińska A., Jabłońska-Ryś E., Gustaw W., Antioxidant capacity and polyphenolic content of dried wild edible mushrooms from Poland. Int. J. Med. Mushr., 2014, 16, 65–75.
31. Rao A.V., Shen H., Effect of low dose lycopene intake on lycopene bioavailability and oxidative stress. Nutr. Res., 2002, 22, 1125–1131.
32. Rogalski M., Nowak K., Fiedor P., Szterk A. Corn crisps enriched in omega-3 fatty acids sensory characteristic and its changes during storage J. Am. Oil Chem. Soc., 2016, 93, 1275–1287.
33. Sahlin E., Savage G.P., Lister C.E., Investigation of the antioxidant properties of tomatoes after processing. J. Food Comp. Anal., 2004, 17, 635–647.
34. Shaviklo A.R., Kargari Dehkordi A., Zangeneh P., Interactions and effects of the seasoning mixture containing fish protein powder/omega-3 fish oil on children's liking and stability of extruded corn snacks using a mixture design approach. J. Food Proc. Preserv., 2014, 38, 1097–1105.
35. Shi J., Le Maguer M., Lycopene in tomatoes. Chemical and physical properties affected by food processing. Crit. Rev. Food Sci. Nutr., 2000, 40, 1–42.
36. Skalicka-Woźniak K., Głowniak K., Quantitative analysis of phenolic acids in extracts obtained from the fruits of *Peucedanum alsaticum* L. and *Peucedanum cervaria* (L.) Lap. Chromatographia, 2008, 68, S85-S90.
37. Slimestad R., Verheul M., Review of flavonoids and other phenolics from fruits of different tomato (*Lycopersicon esculentum* Mill.) cultivars. J. Sci. Food Agric., 2009, 89, 1255–1270.
38. Stojceska V., Ainsworth P., Plunkett A., Ibanoğlu S., The advantage of using extrusion processing for increasing dietary fibre level in gluten-free products. Food Chem., 2010, 121, 156–164.
39. Toor R.K., Savage G.P., Antioxidant activity in different fractions of tomatoes. Food Res. Int., 2005, 38, 487–494.
40. Varela P., Salvador A., Gámbaro A., Fiszman S., Texture concepts for consumers: a better understanding of crispy–crunchy sensory perception. Eur. Food Res. Technol., 2008, 226, 1081–1090.
41. Wójtowicz A., Kolasa A., Mościcki L., The influence of buckwheat addition on physical properties, texture and sensory characteristic of extruded corn snacks. Pol. J. Food Nutr. Sci., 2013, 63, 239–244.

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