



The effect of the addition of gold flax (*Linum usitatissimum* L.) and chia seeds (*Salvia hispanica* L.) on the physicochemical and antioxidant properties of cranberry jams

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Abstract

Different form of seeds (whole or ground) may have a gelling effect and can substitute pectin in jams, moreover the type of their form have a remarkable impact on jams quality. The objective of this study was to ascertain if the form of added seeds have an influence on the physicochemical and antioxidant properties of cranberry jams incorporated in gold flax and chia seeds. Compared to traditional cranberry jam, the addition of both chia and gold flax seeds to the jams enhanced the nutritional value of samples by significant increase in protein, dietary fiber and polyunsaturated fatty acids content. Moreover, the enrichment of cranberry jams with seeds caused an increase in total polyphenols and phenolic acids content as well as their antioxidant activities. The texture measurement showed that both chia and flax seeds (irrespectively of their form) exhibited a gelling properties, however, the jams with the addition of ground seeds were characterized by similar texture as the control cranberry jam. Based on the obtained results, both gold flax and chia seeds can be considered as promising substitute for the gelling agents which additionally can change the physicochemical and antioxidant properties of jams.

Keywords Seeds · Cranberry jam · Physicochemical properties · Antioxidant activity

Introduction

Nowadays, functional foods have gained a great interest among consumers, resulting from the increasing knowledge and awareness about a healthy lifestyle and the impact of various food components on human health. Functional foods offer not only nutritional value inherent in their chemical compositions, but also health benefits, and may have potential role in reducing the risk of diet-related diseases. According to the latest dietary recommendations, functional foods,

that should be daily basis consumed, include fruits and vegetables which are a rich source of nutrients, dietary fiber, minerals, vitamins and phenolic compounds [1, 2]. Unfortunately, the fresh fruits are seasonal and therefore they are widely processed in order to be available all year round. The most popular fruit preserves are jams. They owe their popularity mainly due to their common availability, organoleptic properties and low costs of production. Generally, jams are intermediate moisture food products prepared by cooking of fruits with sugar, water, acid, pectin and other ingredients since a required consistency is obtained. Nevertheless, the disadvantage of this process is that it decrease the nutritional value and content of bioactive compounds in finished products, when compared to fresh fruits [3, 4]. To provide a nutritional value and increase the health-promoting properties jams are enriched with components of natural origin such as herbs (i.e. lemon balm and mentha), other fruits with high nutritional value (i.e. chokeberry, elderberry, and quince) or natural fiber (i.e. peach fiber and wheat germs) [5–7].

Flax (*Linum usitatissimum* L.) belongs to the *Linaceae* family and is the oldest plant grown by humans. Due to its nutritional benefit and positive effect in disease prevention,

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nowadays, flaxseeds is widely used in food industry. The main component of flaxseeds is oil (approximately 40%) containing especially α -linolenic acid, which can account even 52% of all the fatty acids. Flaxseeds is also a rich source of dietary fiber and high quality proteins (about 30% and 20%, respectively). Moreover, this plant contains a significant amount of lignans responsible for its antioxidant activities as well as vitamins (B_1 and A) and minerals (Mg, P, Mn, Se and Zn) [8–11].

Chia (*Sativa hispanica* L.) is an annual plant which belongs to the *Lamiaceae* family and grows naturally from western Mexico to northern Guatemala. Its seeds, along with corn, beans, and amaranth were the main source of plant-based food for the Aztecs living in these areas. Currently, chia seeds due to their high nutritional potential are widely used both in the food and animal feed industries. Chia seeds contain about 35% of fat, which in the vast majority are polyunsaturated fatty acids, in which α -linolenic acid constitutes even 68% of all fatty acids. They contain a significant quantity of a high biological value protein (approximately 19% of the total weight) and dietary fiber (over 30% of the total weight). Moreover, chia seeds are a good source of macro- and microelements (Ca, P, K, Mg, Zn, Fe, and Cu), vitamins (thiamine, riboflavin, niacin, folic acid, and ascorbic acid), antioxidant compounds (*p*-coumaric, gallic and caffeic acids as well as flavonoids, e.g. quercetin and kaempferol) [12–14].

The composition of both flax and chia seeds offers opportunities for the development of functional food. Many studies are carried out on the application of these seeds in food products, such as bread, biscuits, snack bars, cakes, and milk cocktails [15–17]. However, to the best of our knowledge there are only a few available studies devoted to the effect of flax or chia seeds on the properties of fruit jams, but there is no information concerning the impact of form of added seeds. Thus, the aim of this study was to ascertain, if the form of added seeds have an influence on the physicochemical and antioxidant properties of cranberry jams incorporated in gold flax and chia seeds.

Materials and methods

Materials

The cranberry jams with the addition of gold flax (*Linum usitatissimum* L.) and chia (*Salvia hispanica* L.) seeds (BioPlanet, Warsaw, Poland) were the research material. The jams were prepared from fresh cranberry fruits (*Vaccinium macrocarpon* L.) cv. ‘Pilgrim’ harvested at processing maturity in October 2018 in Kolbuszowa (Poland). The fruits were sorted, washed and the inedible parts were removed. Seeds were added into the jams in the whole

and ground form. The seeds were grinding in a knife mill Grindomix GM 200 (Retsch, Düsseldorf, Germany) at 6000 rpm for 1 min. The remaining semi-products used in this jams preparation were: sucrose (Pfeifer & Langen, Poznań, Poland), citrus-apple pectin (DE: 34.4%, DA: 14.7%, Pectowin, Jasło, Poland) and fresh lemon juice.

Procedure of jams production

The five cranberry jams were prepared in the laboratory conditions according to the recipe described in the Table S1 (Supplementary).

- CJ—jam with the addition of citrus-apple pectin (control sample),
- CJWF—jam with the addition of whole flaxseeds,
- CJGF—jam with the addition of ground flaxseeds,
- CJWC—jam with the addition of whole chia seeds,
- CJGC—jam with the addition of ground chia seeds.

The appropriate amounts of cranberry fruits, sucrose, and water were weighted and cooked in an open pan (for 20 min at 98–100 °C) until the refractometric extract was about 30%. Then, the pectin solution or the seeds (whole or ground) were added to the mixture; the whole was thoroughly mixed and cooked again for 10 min. At the end of the process, lemon juice was added to the mixture and the whole was carefully stirred. Afterwards, the jams were poured into the glass jars (0.2 l), then pasteurized at 95 °C in the water bath for 15 min and cooled to room temperature (20 °C \pm 2 °C). Each sample was prepared in 3 repetitions. The final products were stored at 8 °C prior to further analyses.

Methods

A representative sample was obtained by combining each jams from three different jars and homogenizing resulting mixture using a homogenizer Ultra-Turrax T 25 (Ika, Warsaw, Poland) at 13,500 rpm for 3 min.

Determination of the physicochemical properties

The AOAC [18] methods were used to examined basic jams composition: the dry matter, protein, lipid, ash, dietary fiber and extract contents. Water activity (a_w) was measured using a LabSwift-aw (Novasina, Lachen, Switzerland) hygrometer. pH were determined by potentiometric method and the total acidity (as citric acid) by the titratable method [18].

Determination of the sugar content

Sugar content was determined by using high-performance liquid chromatography and a refractometric detection (LaChrom, Merck, Hitachi, Japan) according to the method described by Bogdanov et al. [19]. The extraction was performed by treating the homogenized jams with distilled water in an ultrasonic cleaner Sonic 14 (Polsonic, Warsaw, Poland) at a temperature of 40 °C for 45 min. The obtained sample was clarified using Carrez reagents I and II, and filtered. The sample solution was purified by using a Millex-LCR-type filters (PTFE) with 0.45 µm pore size directly prior to HPLC analysis. A mixture of acetonitrile with water (80:20, v/v) was used as a mobile phase. A flow rate was 1 ml/min. Separation was carried out using a Purospher Star NH2 column (Merck, Darmstadt, Germany) (25 × 4.6 mm, particle size 5 µm) equipped with a precolumn and thermostated at 30 °C. Quantification of individual saccharides was based on a comparison with standards.

Fatty acids composition

The extraction of the lipids from the samples were performed in an automatic fat extractor (Buchi Labortechnik, Flawil, Switzerland). The fatty acid composition was estimated after the acids esterification into methyl esters following the procedure described in the standard analytical method (AOAC, 2016). The composition of fatty acids was determined by using a gas chromatograph (GC) Trace Ultra (Thermo Electron, Parma, Italy) with a flame ionization detector and a Supelcowax 10 capillary column: 30 m long, 0.25 mm of internal diameter and 0.25 mm film thickness (Sigma-Aldrich, St. Louis, MO, USA). The injector and detector temperatures were maintained at the temperature of 220 °C and 250 °C, respectively. The column temperature was programmed from 160 °C to 210 °C at 3 °C/min, then kept constant at 210 °C for 25 min. The peaks were identified by comparing the retention times with the standards.

Procedure of extraction

The ethanolic extraction was carried out according to the method described by Pająk et al. [20]. The samples (5 g) were extracted for 20 min by shaking with 20 ml of ethanol/water solution (80:20, v/v) in a screw-capped tube. Extractions were carried out three times. The combined extracts were centrifuged at 10,000 rpm for 10 min and then stored in a fridge (6 ± 2 °C) until analysis. The extraction procedure was carried out in triplicate.

Determination of total phenolic content

The total phenolic content (TPC) of ethanolic extracts of the cranberry jams was determined using Folin–Ciocalteu reagent following the procedure described by Socha et al. [21]. An aliquot of 0.5 ml of the ethanolic extract was mixed with 2.5 ml of 0.2 M Folin–Ciocalteu reagent. After 5 min, 2 ml of 7.5% (m/v) sodium carbonate was added. The resulted mixture was incubated at room temperature for 2 h. The absorbance was measured at 760 nm using an UV/VIS V-530 spectrophotometer (Jasco, Tokyo, Japan). The total phenolic content was expressed as equivalents of gallic acid in mg per 100 g of cranberry jam.

Determination of ABTS cation radical-scavenging activity

Determination of ABTS cation radical-scavenging activity was based on the reduction of the ABTS^{•+} by ethanolic extract of cranberry jams according to procedure described by Socha et al. [21]. An aliquot of 0.1 ml of the ethanolic extract was mixed with 6 ml of ABTS cation radical solution and after 30 min of incubation an absorbance of the sample was measured spectrophotometrically at 734 nm. The antioxidant activity against ABTS was expressed as Trolox equivalents in µM per 100 g of cranberry jam.

Determination of DPPH radical-scavenging activity

The DPPH radical-scavenging activity was measured spectrophotometrically at 515 nm according to the procedure of Socha et al. [21]. An aliquot of 0.1 ml of the ethanolic extract of cranberry jam was mixed with 3.9 ml methanolic solution of DPPH (0.1 mM). The antioxidant activity against DPPH was expressed as Trolox equivalents in µM per 100 g of cranberry jam.

Extraction and analysis of phenolic acids content

Phenolic acids were extracted from the samples with using ethyl acetate according to Socha et al. [21]. A 10 ml of ethanolic extract from the cranberry jam was subjected to an alkaline hydrolysis (90 ml 2 M NaOH with 10 mM EDTA and 1% L-ascorbic acid) at 30 °C for 30 min. Afterwards, the sample was cooled to room temperature, adjusted to pH = 2 with HCl solution and saturated with NaCl. Subsequently, the phenolic acids were extracted three times with 25 ml of ethyl acetate. The combined organic fractions were evaporated to a dryness at 35 ± 3 °C under reduced pressure using a rotary evaporator. The obtained dry residue was dissolved in 5 ml of methanol and stored at –18 °C in a capped test tube until the further analysis. Phenolic acids were analyzed by using the high-performance liquid chromatograph (HPLC) and an UV detection (LaChrom, Merck-Hitachi,

Japan) according to the method described earlier by Socha et al. [21]. The samples were analyzed on a reserved-phase ODS Hypersil column (Thermo Scientific, Waltham, MA, USA, 250 × 0.46 mm × 5 μm) at a temperature of 30 °C in a gradient mode with two phases: phase A – 2.5 g acetic acid per 100 ml and phase B – acetonitrile. Phenolic acids were identified at λ = 280 nm and λ = 340 nm by comparison their retention times with those of the standards (Sigma-Aldrich). The quantitative measurement was carried out using calibration curves plotted for each individual standards at concentrations in the range of 0.02–0.2 mg/ml.

Color parameters

The color parameters of cranberry jams were measured in reflectance using a Colour i5 spectrophotometer (X-Rite, Grand Rapids, MI, USA). The results were expressed using the CIE $L^*a^*b^*$ system (measuring geometry d/8°, illuminant D65, observer 10°). The color parameters of the cranberry jams were expressed as L^* (lightness; from 0 = black, to 100 = white), a^* (+a = redness, –a = greenness), and b^* (+b = yellowness, –b = blueness). The total color differences (ΔE) between control jam (L_0^* , a_0^* and b_0^*) and jams with seeds were calculated according to the formula [22]:

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2}$$

Texture parameters

Jam texture was determined according to the procedure given by Genovese et al. [23] using an EZ-SX Texture Analyzer (Shimadzu, Tokyo, Japan). The compressing force applied was 20 N. Five grams of sample was put in a tube (32 mm of diameter) and the cylindrical probe was penetrated sample at a rate of 30 mm/min to a penetration depth of 15 mm. The following texture parameters were established: hardness force [N], energy of penetration [N·mm] and adhesiveness [N·mm].

Statistical analysis

Statistical analysis was conducted using Statistica version 13.0 (StatSoft, Poland). Significant differences ($p < 0.05$) between means were calculated by an one-way ANOVA and Tuckey's multiple range test. Coefficients of Pearson's linear correlations between selected determined parameters were calculated at a significance level of 0.05. All the measurements (except phenolic acids profile) were performed in at least three repetitions.

Results and discussion

Physicochemical properties of cranberry jams

The addition of golden flax and chia seeds to the cranberry jams did not have significant ($p > 0.05$) effect on the pH, total acidity and extract values of cranberry jams (Table S2-Supplementary). The cranberry jams with the addition of all seeds exhibited significant ($p < 0.05$) decrease in the values of water content and water activity (Table 1), compared to the control jam. This may be due to the water-absorbing properties of the dietary fiber contained in both flax and chia seeds [17, 24]. The cranberry jams with the ground seeds had a lower values of water activity, when compared to jams with the whole seeds. Ruszkowska and Rogowska [25] reported that grinding of chia seeds improves their water absorption properties. The enrichment of jams with flax and chia seeds increased their ash and protein content, as compared to control jam. However, no significant differences ($p < 0.05$) were found within the jams with seeds. These data correspond with the results for pineapple jam and strawberry marmalade enriched with chia seeds [2, 3]. The higher protein content in jams with seeds additives is due to the fact that both flax and chia seeds are a good source of protein. According to the different studies, chia seeds contain about 18.3% of protein while flaxseeds 21.8% [1, 9]. The total sugar content in all studied cranberry jams did not differ statistically and was about 30 g/100 g of product (Table 1). The samples were characterized by a relatively high content of reducing sugars and low amount of sucrose. The sucrose added to the jams during their preparation may have been partially inverted, resulting in a mixture of an equal amount of glucose and fructose. This inversion takes place intensely in an acidic environment and at high temperature [26]. The cranberry jams with flax and chia seeds contained a significantly higher content of TDF (Table 1) as compared to control jam. The obtained results are similar to those reported by Nduko et al. [3] and Pérez-Herrera et al. [4] for pineapple jams with chia seeds and *Physalis* spp. fruits jams with seeds. Both flax and chia seeds are considered as a rich source of soluble and insoluble fiber which is confirmed by other studies [9, 24]. The soluble dietary fiber (SDF) was the main indigestible component of control jam, accounting for over 66% of the TDF. A similar SDF/TDF ratio has been reported previously in fruit gels or plum jam [27, 28]. In turn, the opposite results (the insoluble dietary fiber (IDF) was the major fraction) has been observed by Marlett and Volendorf [29] and Guow et al. [30] who investigated cranberry sauce and cranberry pomace, respectively. In our paper, a higher SDF content may be due to the addition

Table 1 The composition of the cranberry jams

Type of jams	Water [g/100 g]	Water activity	Ash [g/100 g]	Protein [g/100 g]	Dietary fiber content [g/100 g]			Sugar [g/100 g]			
					Insoluble fraction	Soluble fraction	Total	Fructose	Glucose	Sucrose	Total
CJ	66.47 ± 0.38 ^a	0.915 ± 0.001 ^a	0.13 ± 0.02 ^b	0.07 ± 0.00 ^b	0.62 ± 0.04 ^c	1.22 ± 0.02 ^a	1.84 ± 0.03 ^d	13.57 ± 0.39 ^a	15.49 ± 0.28 ^a	1.90 ± 0.02 ^a	30.97 ± 0.43 ^a
CJWF	63.86 ± 0.86 ^b	0.904 ± 0.001 ^b	0.21 ± 0.00 ^a	0.14 ± 0.00 ^a	2.49 ± 0.05 ^b	0.56 ± 0.02 ^c	3.05 ± 0.07 ^a	13.12 ± 0.09 ^a	15.40 ± 0.37 ^a	1.84 ± 0.03 ^a	30.36 ± 0.38 ^a
CJGF	59.66 ± 0.32 ^c	0.902 ± 0.001 ^c	0.21 ± 0.01 ^a	0.14 ± 0.00 ^a	1.55 ± 0.03 ^c	0.90 ± 0.05 ^b	2.44 ± 0.05 ^b	13.27 ± 0.06 ^b	15.02 ± 0.41 ^a	1.82 ± 0.04 ^a	30.11 ± 0.50 ^a
CJWC	64.34 ± 0.39 ^b	0.905 ± 0.001 ^b	0.22 ± 0.01 ^a	0.14 ± 0.00 ^a	2.72 ± 0.02 ^a	0.31 ± 0.03 ^d	3.03 ± 0.04 ^a	13.58 ± 0.07 ^a	15.46 ± 0.26 ^a	1.85 ± 0.04 ^a	30.88 ± 0.25 ^a
CJGC	60.30 ± 0.14 ^c	0.901 ± 0.001 ^c	0.21 ± 0.01 ^a	0.15 ± 0.00 ^a	1.41 ± 0.05 ^d	0.60 ± 0.03 ^c	2.01 ± 0.06 ^c	13.36 ± 0.12 ^a	15.83 ± 0.24 ^a	1.76 ± 0.07 ^a	30.96 ± 0.41 ^a

*Mean values from three repetitions ± standard deviation

**Within columns, values subscribed by the same small letters did not differ significantly at $p < 0.05$

of an apple-citrus pectin during the preparation of control jam, which is considered as a soluble dietary fiber. In the cranberry jams with added flax and chia seeds IDF was the main fiber fraction, while SDF constituted only a minor part. Cranberry jams with the whole chia seeds had the highest IDF content (90% of TDF), while cranberry jams with ground chia seeds had the lowest IDF (70% of TDF). The addition of both types of ground seeds resulted in a significantly ($p < 0.05$) lower IDF content, but also a higher SDF content in analyzed jams, as compared to jams with the whole seeds. According to the literature data some methods of grinding and processing (i.e., extrusion, steam heating) can change a composition of dietary fiber [31–33]. Lui et al. [33] found that the decrease of IDF content in dietary fiber from orange peel after grinding may be due to the degradation of hemicellulose, cellulose and lignin, which were converted into the SDF fraction and some other small particles. According to the authors, mechanical forces during grinding may break some intramolecular hydrogen bonds which might be attributed to cellulose degradation. Similar conclusions were reached by Zhu et al. [32] who explained that the increase of SDF fraction in wheat bran during ultrafine grinding is caused by a redistribution of fiber components from the insoluble to the soluble fractions. The relatively high IDF content in cranberry jams with the addition of seeds, both flax and chia, suggests their possible applications as a valuable supplement of a diet. Intake of this fraction of fiber is linked to a sensation of satiety and improved functioning of the digestive system [34].

Determination of fatty acids profile and total lipids content

The addition of both gold flax and chia seeds significantly increased the total lipids content in all cranberry jams (Table 2). Özbek et al. [2] also reported that the addition of chia seeds to strawberry marmalade increases the lipids content (even 17 times). The higher lipids content in cranberry jams with flaxseeds compared to chia seeds may results from the differences in the seeds lipid profile. The average lipids content of flaxseeds is about 40% while in chia seeds it is about 35% [35, 36]. The addition of seeds to the cranberry jams changed the lipid profile of jams, increasing the proportion of polyunsaturated fatty acids (PUFA) in the composition of total fatty acids. The control jam was characterized by the relatively similar levels of saturated, mono- and polyunsaturated fatty acids (Table 2). While all jams with the addition of seeds were characterized by a significantly higher proportion of PUFA content (about 70%). The jams with the addition of ground seeds were characterized by a significantly lower PUFA content. This phenomenon may be due to that an increased surface area caused by

Table 2 The lipid profile of the cranberry jams (expressed as % of total fatty acids)

Fatty acid	Type of jams				
	CJ	CJWF	CJGF	CJWC	CJGC
Saturated fatty acids—SFA [%]					
Capric acid (C10:0)	0.180 ± 0.005 ^a	0.013 ± 0.001 ^c	0.076 ± 0.003 ^b	0.005 ± 0.001 ^c	0.008 ± 0.001 ^c
Lauric acid (C12:0)	0.806 ± 0.038 ^a	0.096 ± 0.004 ^b	0.140 ± 0.002 ^b	0.075 ± 0.001 ^b	0.059 ± 0.000 ^b
Myristic acid (C14:0)	2.064 ± 0.013 ^a	0.193 ± 0.006 ^c	0.570 ± 0.006 ^b	0.280 ± 0.006 ^b	0.160 ± 0.007 ^c
Pentadecanoic acid (C15:0)	0.497 ± 0.013 ^a	0.004 ± 0.001 ^c	0.013 ± 0.001 ^b	0.005 ± 0.001 ^c	0.004 ± 0.002 ^c
Palmitic acid (C16:0)	22.201 ± 0.144 ^a	8.229 ± 0.100 ^c	8.552 ± 0.109 ^c	9.389 ± 0.075 ^b	9.946 ± 0.106 ^b
Margaric acid (C17:0)	0.330 ± 0.001 ^a	0.061 ± 0.002 ^d	0.083 ± 0.003 ^b	0.07 ± 0.001 ^{dc}	0.079 ± 0.003 ^{bc}
Stearic acid (C18:0)	6.092 ± 0.066 ^a	3.454 ± 0.012 ^c	4.394 ± 0.146 ^b	3.473 ± 0.048 ^c	4.482 ± 0.063 ^b
Arachidic acid (C20:0)	0.865 ± 0.017 ^a	0.153 ± 0.004 ^c	0.170 ± 0.003 ^b	0.223 ± 0.002 ^b	0.187 ± 0.001 ^b
Total	33.033 ± 0.168 ^a	12.388 ± 0.173 ^d	14.070 ± 0.048 ^c	13.635 ± 0.187 ^c	15.061 ± 0.071 ^b
Monounsaturated Fatty Acids—MUFA [%]					
Myristoleic acid (C14:1)	0.049 ± 0.002 ^a	0.004 ± 0.001 ^c	0.013 ± 0.002 ^b	0.005 ± 0.001 ^c	0.004 ± 0.001 ^c
Palmitoleic acid (C16:1, n-7)	0.910 ± 0.043 ^a	0.147 ± 0.009 ^b	0.203 ± 0.013 ^b	0.186 ± 0.011 ^b	0.191 ± 0.004 ^b
Palmitoleic (C16:1, n-9)	1.461 ± 0.001 ^a	0.174 ± 0.011 ^b	0.159 ± 0.007 ^b	0.169 ± 0.003 ^b	0.155 ± 0.009 ^b
Margaroleic acid (C17:1)	0.133 ± 0.015 ^a	0.026 ± 0.001 ^b	0.042 ± 0.003 ^b	0.025 ± 0.004 ^b	0.035 ± 0.004 ^b
Vaccenic acid (C18:1, n-7)	1.642 ± 0.009 ^a	0.966 ± 0.016 ^d	1.389 ± 0.007 ^b	0.937 ± 0.066 ^d	1.192 ± 0.014 ^c
Oleic acid (C18:1 n-9)	22.544 ± 0.149 ^a	12.272 ± 0.010 ^d	19.669 ± 0.104 ^b	7.757 ± 0.062 ^c	13.813 ± 0.083 ^c
Eicosenoic acid (C20:1)	0.357 ± 0.013 ^a	0.153 ± 0.003 ^c	0.170 ± 0.001 ^c	0.223 ± 0.006 ^b	0.187 ± 0.010 ^c
Total	27.095 ± 0.159 ^a	13.740 ± 0.008 ^d	21.642 ± 0.168 ^b	9.301 ± 0.187 ^e	15.576 ± 0.138 ^c
Polyunsaturated Fatty Acids—PUFA[%]					
Linoleic acid (C18:2 n-6)	28.356 ± 0.274 ^b	29.977 ± 0.016 ^a	27.808 ± 0.046 ^b	21.494 ± 0.004 ^c	21.356 ± 0.136 ^c
γ-Linolenic acid (C18:3, n-6)	0.032 ± 0.001 ^a	0.003 ± 0.001 ^b	0.004 ± 0.001 ^b	0.004 ± 0.001 ^b	0.005 ± 0.001 ^b
Linolenic acid (C18:3 n-3)	11.485 ± 0.280 ^e	43.891 ± 0.089 ^c	36.477 ± 0.108 ^d	55.565 ± 0.268 ^a	48.005 ± 0.087 ^b
Total	39.872 ± 0.008 ^e	73.870 ± 0.163 ^b	64.288 ± 0.216 ^d	77.063 ± 0.373 ^a	69.365 ± 0.066 ^c
Lipid [%]	0.10 ± 0.01 ^d	0.75 ± 0.03 ^b	0.99 ± 0.05 ^a	0.57 ± 0.25 ^b	0.65 ± 0.41 ^b
n6/n3	2.47	0.39	0.44	0.68	0.76

*Mean values from three repetitions ± standard deviation

**Within rows, values subscribed by the same small letters did not differ significantly at $p < 0.05$

a reduced seeds particle size after grinding may accelerate lipids oxidation [37]. Moreover, the oxidative deterioration can be initiated by lipoxygenases that are dioxygenase enzymes containing nonheme iron protein. Lipoxygenase is distributed throughout many seeds, but this enzyme is inactive because of its limited contact with oxygen. Breaking of cell structure during the grinding causes the lipoxygenase to catalyze reactions of polyunsaturated fatty acids with oxygen [38]. The main PUFAs in the analyzed jams were linoleic (LA) and α-linolenic acid (ALA). LA (ω-3 fatty acid) was the dominant PUFA in the control jam, while ALA (ω-6 fatty acid) was the predominant in jams with the addition of all seeds. Moreover, the cranberry jams with chia seeds were characterized by higher level of ALA, when compared to the jams with flaxseeds. It corresponds with the data reported by Nitrayova et al. [39] in which the level of ALA in chia seeds was higher than that in flaxseeds (63.79% and 56.37%, respectively). In the human body, ω-3 and ω-6 fatty acids are the competitive substrates of the same enzyme

systems and their metabolites antagonize each other. Thus, the level of consumption of ω-3 fatty acids and its proportion to ω-6 fatty acids is one of the indicators of the health quality of a diet [40]. According to the current dietary recommendations, the ratio of ω-6:ω-3 in the diet of an adult should not exceed 4–5:1. However, due to the excessively high consumption of ω-6 fatty acids in an average diet, this proportion is significantly higher than the recommended (15–20:1), which suggests that the supply of products rich in ω-3 acids should be increased. In our study, the enrichment of cranberry jams with both flax and chia seeds significantly ($p < 0.05$) decreased the ratio of ω-6:ω-3. The control cranberry jam was characterized by the ratio of ω-6 to ω-3 as 2.47:1, whereas jams with flax and chia seeds about 0.4:1 and 0.7:1, respectively.

In all cranberry jams studied, monounsaturated fatty acids (MUFA) were represented mainly by oleic acid. The highest oleic acid content was observed in control cranberry jam, while the lowest was stated in cranberry jam with the whole

chia seeds. The cranberry jams with flaxseeds exhibited a higher level of oleic acid, as compared to jams with chia seeds. These results are in accordance with the data of Ciftci et al. [36] who reported that the flaxseeds contain more oleic acid than chia seeds (18.10 and 10.53%, respectively).

The highest percentage of saturated fatty acids (SFA) was found in control cranberry jam and this content was above twice higher as compared to jams with the addition of flax and chia seeds, irrespective of their form. Among saturated fatty acids, palmitic acid and stearic acid were presented in major quantities in all analyzed jams.

Total phenolic content (TPC) and antioxidant activity (AA)

The addition of all seeds had a significant ($p < 0.05$) effect on the TPC in the analyzed jams (Fig. 1). The highest phenolic content was observed in cranberry jams with the whole chia seeds (43% higher than in control jam), while cranberry jams with the ground flaxseeds was the poorest in this respect. The amount of TPC in cranberry jams with added ground seeds were higher by 15–21% as compared with the cranberry jam. Banaś et al. [41] also reported that enriching strawberry jam with flaxseeds caused about 11% increase of TPC (as compared to control sample without seeds), whereas Banaś et al. [7] did not observe a significant change in TPC of gooseberry jam after addition of flaxseeds. The opposite result obtained by the last cited authors may be due to the different conditions of the jam preparation process or differences in the phenolic composition of seeds added to the jams. Moreover, a Folin–Ciocalteu method has low selectivity resulting from the presence of other non-phenolic compounds capable to react with F–C reagent. A significantly ($p < 0.05$) higher level of TPC in jams with flax and chia seeds as compared to control jam are due to these seeds

are a rich source of antioxidants [10]. Saphier et al. [42] reported that the extract from chia seeds had a significantly higher TPC (approximately 42%) than the extract from flaxseeds, what is in accordance with the results obtained in our study. On the basis of the obtained results it was stated that cranberry jams with the whole seeds, both flax and chia were characterized by a higher values of TPC when compared to jams with ground seeds. It could be due to the used mechanical treatment (grinding) was responsible for an increase of polyphenol oxidase (PPO) activity, what resulted in a decay of phenolic compounds in the studied seeds. Most plant polyphenol oxidases are capable of oxidizing a broad spectrum phenolic compounds, in particular other than lignans (e.g., phenolic acids or flavonoids). Demeke et al. [43] have investigated the effect of mechanical treatment (abrasion) on polyphenol oxidase activity in wheat seeds containing lignans similar to flaxseeds. According to these Authors, mechanical damage in seeds resulted in an increase of polyphenol oxidase activity when using a short time of this treatment (60 s or less). What is more, in vitro studies indicate that PPO are heat-tolerant [44]. Thus, differences in the amount of heat released between different various types of mechanical treatment (i.e., abrasion and grinding) may not significantly affect the polyphenol oxidase activity.

The addition of seeds to cranberry jams resulted in a significant increase of jams AA, both against DPPH and ABTS assays (Fig. 2). However, the sample with the whole flaxseeds did not show a significant ($p > 0.05$) difference in AA against DPPH radical as compared to the control jam. The differences in the results obtained using DPPH and ABTS assays could be due to the various mechanism of scavenging of these two free radicals, e.g. differences in kinetics of reaction, concentration of reagents or time of incubation. The performed statistical analysis showed a high and significant ($p = 0.05$) linear correlation between antioxidant activity

Fig. 1 The total polyphenols content in the cranberry jams

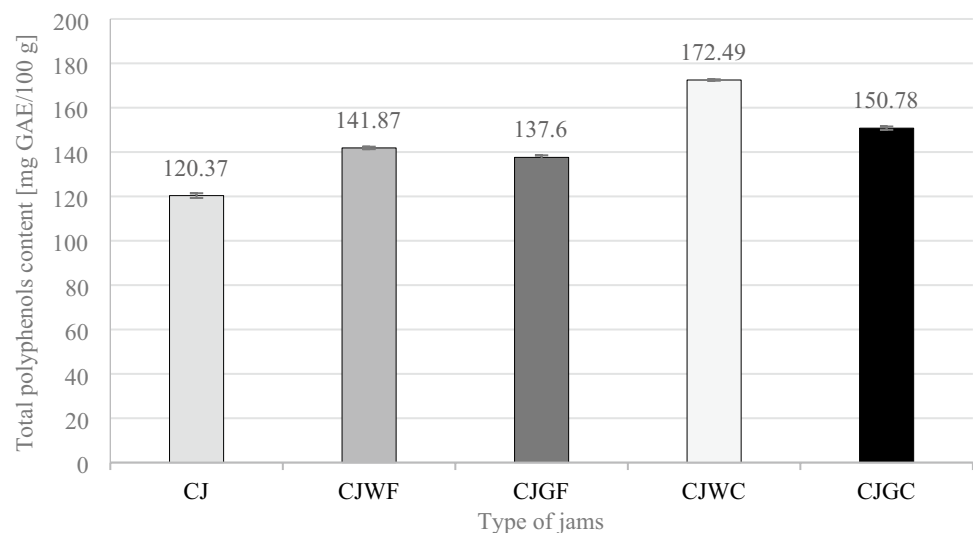
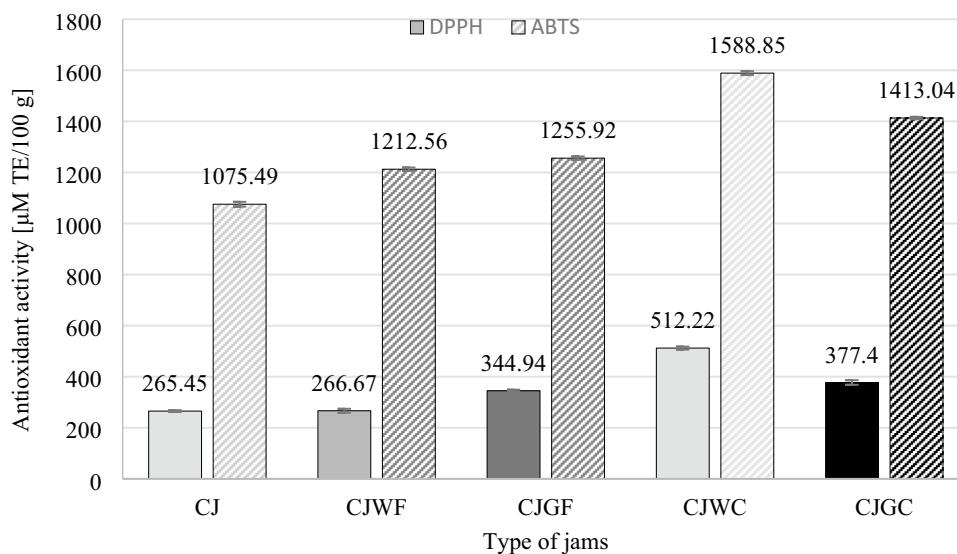


Fig. 2 Antioxidant activity (DPPH and ABTS) of the cranberry jams



against DPPH and ABTS radicals ($r=0.95$). Moreover, TPC significantly correlated with the antioxidant activity measured using both DPPH ($r=0.89$) and ABTS ($r=0.98$) assays. On the basis of the obtained results it was stated that the cranberry jam with the whole chia seeds was characterized by the highest TPC and AA compared to the others samples. The obtained values maybe due to different polyphenol profile between chia and flax seeds. Chia seeds are a rich source of low molecular weight polyphenols, such as phenolic acids (in particular caffeic acid), whereas flaxseeds contain mainly lignans [45, 46]. Lignans, which are high molecular oligomers, may be characterized by a lower share of hydroxyl groups in relation to the molecule, when compare to the low molecular weight phenolic acids present in chia seeds. Since it is known that hydroxyl groups of phenolics play a crucial role in reduction of Folin reagent, as well as free radicals (e.g., DPPH and ABTS), the seeds rich in the low molecular phenolic acids have a higher antioxidant capacity and a higher ability to reduce the both Folin reagent and free radicals what resulted in a higher values of TPC and AA in case of jams containing whole chia seeds compared with flaxseeds.

Profile of phenolic acids

Most of phenolic acids in plant materials occur mainly in the insoluble or bound forms as a complexes of phenolic acids with cell wall structural components (such as lignin, hemicellulose, cellulose, pectin and rod-shape structural proteins). Both hydroxycinnamic and hydroxybenzoic acids form ether linkages with lignin through their -OH group on the aromatic ring and ester linkages with structural carbohydrates and proteins through their carboxyl group. Alkaline hydrolysis is one of the effective methods of releasing

phenolic compounds from cereal grains and seeds. It enables the breaking of ester bonds connecting phenolic acids with the cell wall or of ester bonds occurring in the ester and glycoside forms of phenols. Furthermore, the addition of ethylenediaminetetraacetic acid (EDTA) and ascorbic acid in this procedure prevent the loss of phenolic acids susceptible to oxidative degradation [47] According to Nardini et al. [48] alkaline hydrolysis influences the release of phenolic compounds from the cell walls to a greater extent, compared to acid hydrolysis. For this reason, in our research, in order to detect phenolic acids occurring in the analyzed cranberry jams with the addition of seeds, we used alkaline hydrolysis.

The highest level of total phenolic acids was reported in the cranberry jam with the whole flaxseeds and it was almost four times higher than obtained in the control jam (Table 3). Among identified phenolic acids in the control jam the most abundant was *p*-coumaric acid, while ferulic acid was in the minority. In contrary to all cranberry jams with seeds, the gallic acid was not detected in the control jam. According to Abeywickrama et al. [49] fresh cranberry fruits (cv. "Pilgrim") contain a low amount of gallic acid (about 3 µg/g). The thermal treatment of the cranberry fruit during the jam production could contribute to the total loss of this compound in the control jam. The addition of seeds to the cranberry jams resulted in the detection of gallic acid, which has an impact on the health-promoting properties of the enriched jams. It is worth to mention, that gallic acid due to the presence of three hydroxyl (-OH) groups attached to the aromatic ring of phenolic acid has the highest antioxidant activity among the analyzed acids. The addition of flax and chia seeds to cranberry jams resulted in a significant ($p < 0.05$) increase in the level of all identified phenolic acids. Gallic and *p*-coumaric acids were the predominant phenolic acids in cranberry jams with the seeds. It was also

Table 3 Phenolic acids content in the cranberry jams

Type of jams	Phenolic acids content [mg/100 g]					
	Gallic	Caffeic	<i>p</i> -Coumaric	Synapic	Ferulic	Total
CJ	n.d	0.55 ± 0.02 ^d	2.06 ± 0.03 ^b	0.61 ± 0.05 ^b	0.10 ± 0.01 ^b	3.32
CJWF	6.62 ± 0.19 ^a	0.76 ± 0.04 ^c	2.25 ± 0.08 ^a	1.58 ± 0.08 ^a	1.15 ± 0.06 ^a	12.36
CJGF	2.41 ± 0.19 ^d	0.70 ± 0.00 ^c	2.35 ± 0.01 ^a	1.64 ± 0.04 ^a	1.17 ± 0.05 ^a	8.27
CJWC	4.01 ± 0.16 ^c	1.01 ± 0.04 ^b	2.30 ± 0.03 ^a	1.76 ± 0.00 ^a	1.03 ± 0.01 ^a	10.11
CJGC	5.19 ± 0.00 ^b	1.24 ± 0.01 ^a	2.24 ± 0.03 ^a	1.66 ± 0.04 ^a	1.02 ± 0.08 ^a	11.35

*Mean values from two repetitions ± standard deviation

**Within columns, values subscribed by the same capital letters did not differ significantly at $p < 0.05$

found that the addition of chia seeds to the jams caused a higher increase of caffeic acid content (about 2 times) than the addition of flaxseeds (about 0.4 times), when compared to the control jam. In the jams with the addition of flaxseeds irrespective of their form, caffeic acid was found in the lowest level among the identified phenolic acids. The sinapic and ferulic acids content in the enriched cranberry jams were 3 and 10 times higher, respectively than in the control jam. The increase of the content of individual phenolic acids in the cranberry jams enriched with flax and chia seeds are due to the major presence of these acids in seeds which is confirmed by other studies [11, 14]. According to Ross et al. [50] the extraction and hydrolysis procedure had a substantial effect on the detection of phenolic acids presents in plant materials. The direct base mild hydrolysis (2 N NaOH) used in this study probably was not enough to release compounds present in flax and chia seeds from their bound form. Therefore, following base treatment, acid hydrolysis should be performed to liberate bound phenolic that had not been previously hydrolyzed [50]. In our study, there were no significant correlations ($p = 0.05$) between the phenolic acids content and the TPC and AA. This is due to the fact that both flax and chia seeds contain not only phenolic acids but also other compounds possessing antioxidant properties, such as lignans, flavonoids, tannins, tocopherols [14, 45]. Moreover, lack of the significant correlation between TPC and phenolic acids content could result from the fact that the Folin–Ciocalteu reagent can inference with other non-phenolic reducing agents (e.g., amino acids, sugars, aldehydes, peptides, tocopherols, and ascorbic acid, as well as from the fact that TPC and AA assays was measured before hydrolysis, whereas phenolic acids content after that [46].

Color parameters

Color is one of the most important features determining the jam's quality. It is determined by parameters (Table 4) that affected the first impression, and have significant impact on consumer's acceptance. The addition of ground seeds to the cranberry jam increased their lightness, compared to sample with the whole seeds. It may be due to that ground seeds

Table 4 Color parameters of the cranberry jams

Type of jam	L*	a*	b*	ΔE
CJ	10.43 ± 0.27 ^{cd}	14.88 ± 0.26 ^d	0.80 ± 0.09 ^c	Standard
CJWF	10.97 ± 0.45 ^c	17.20 ± 0.44 ^c	3.95 ± 0.32 ^{ab}	3.99
CJGF	15.39 ± 0.17 ^a	22.70 ± 0.10 ^a	4.71 ± 0.03 ^a	10.06
CJWC	11.03 ± 0.64 ^c	17.36 ± 0.60 ^c	3.87 ± 0.56 ^b	3.99
CJGC	13.34 ± 0.26 ^b	20.19 ± 0.32 ^b	4.24 ± 0.25 ^{ab}	6.96

*Mean values from three repetitions ± standard deviation

**Within columns, values subscribed by the same small letters did not differ significantly at $p < 0.05$

(both flax and chia) are characterized by a lighter color, compared to whole seeds. The cranberry jams with the addition of the whole seeds were characterized by similar, but slightly higher value of parameter L*, when compared to the control jam. The increase of jams lightness was also observed by Banaś et al. [51] in the gooseberry jams enriched with plant ingredients, and by Grigelmo-Miguel et al. [52] in the strawberry jam with peach fiber. In all samples with the addition of plant seeds, irrespective of their type and form, increase of a* value and b* value was observed. The addition of ground seeds to cranberry jams increased the color parameter values more than the whole seeds. The obtained results suggest that other factors (e.g. compounds formed during jam production as a result of the Maillard reaction) may have an impact on jams color changes. Due to the fact that jams with flax and chia seeds contain more protein compounds, which are one of the Maillard reaction reactant, the color changes in these samples may occurred in a greater extent. Moreover, the grinding of the seeds may cause direct penetration of the proteins into the fruits pulp, thus also accelerating Maillard reactions. The total color difference values (ΔE) of all jams were calculated with comparison to control cranberry jam. The value of the ΔE parameter for cranberry jams with the addition of seeds ranged from 3.99 to 10.06. It indicates that the color of all analyzed jams differed from the color of the control jam. The smallest ΔE values were noticed in the jams with the addition of whole seeds, both flax and chia seeds, however, these differences

Table 5 Texture parameters of the cranberry jams

Type of jams	Hardness Force [N]	Energy of penetration [N·mm]	Adhesiveness [N·mm]
CJ	7.06 ± 0.08 ^d	77.67 ± 5.24 ^d	− 19.93 ± 1.04 ^b
CJWF	13.64 ± 0.26 ^b	127.88 ± 3.94 ^b	− 19.51 ± 0.71 ^b
CJGF	9.39 ± 0.26 ^c	98.54 ± 4.92 ^c	− 14.08 ± 0.92 ^a
CJWC	18.93 ± 0.42 ^a	146.80 ± 4.45 ^a	− 19.14 ± 0.35 ^b
CJGC	7.99 ± 0.40 ^{cd}	79.78 ± 5.32 ^d	− 12.36 ± 1.08 ^a

*Mean values from three repetitions ± standard deviation

**Within columns, values subscribed by the same small letters did not differ significantly at $p < 0.05$

were visually recognizable by every observer ($3.5 > \Delta E > 5$). The addition of ground seeds to jams caused a much greater deviation in color, which could be recorded by the observer as two different colors ($\Delta E > 5$) [53].

Texture parameters

Jam texture is one of the most important feature that may have an impact on sensory acceptance, and it depends on the equilibrium between the pectin, sugar and organic acid contents present in the fruits. The cranberry jams with the addition of all the seeds, except the ground chia seeds, were characterized by a higher values of hardness parameters (as compared to control jam); the jam with the whole chia seeds was characterized by the highest hardness (Table 5). The hardness force and the energy penetration values of these sample accounted for 268% and 189% of the control jam, respectively. The addition of ground chia seeds did not significantly increase both the hardness force and energy of penetration values of the jam, and it was comparable to the texture of control jam. The resulting texture of the cranberry jams may be owing to the presence of a large amounts of proteins and fiber (both in flax and chia seeds), which exhibit gelling and water holding capability properties. Similar results were reported by Banaś et al. [51] who enriched jams with flaxseeds and wheat germs. In the present study, the performed statistical analysis showed a high and significant ($p = 0.05$) linear correlation between the total dietary fiber content and the hardness parameters of jams. The correlation coefficient between TDF in jams and the value of energy of penetration was $r = 0.95$, whereas between TDF and the value of hardness force was $r = 0.89$. Moreover, mucilages located in layers of the seed coat of both flax and chia seeds also can have an impact on the final texture of the jam. In contact with water, the mucilage appears immediately and forms a transparent coating, which surrounds the seed. According to data reported by Vázquez-Ovando et al. [34] chia seeds can absorb water up to 12 times their weight. It was also found that using the ground seeds in jam's recipe had lower effect on the hardness of jams than using the whole seeds. Similar effect on

textural parameters was stated by Stankow et al. [54] for the jellies with the addition of basil seeds. As observed by the authors, the energy required to destroy the jelly with the seeds were significantly higher than jelly without seeds indicating stronger gel due to the formation of the denser network microstructure. Also according to Samateh et al. [55] the seed mucilage present outside of seeds coats create a nanoscale 3D network improving the gelation process. The addition of the whole flax and chia seeds to cranberry jams did not significantly affect the adhesiveness parameter. A reduction in the adhesiveness values was observed only in the jams with the ground flax and chia seeds (41% and 61%, respectively). Our results are differ than those reported by Banaś et al. [51, 56] who observed an increase in the adhesiveness of gooseberry jams and sour cherry puree after addition the ground flaxseeds. Different results may be due to the application of a various recipes during preparation of jams in our work and in the study of Banaś et al. [51, 56] and due to the interactions between jams components, which could determine the changes in the texture parameters.

Conclusion

The form of added flax and chia seeds to cranberry jams had an essential effect on the nutritional value, antioxidant properties, color and texture parameters. The enriched jams, irrespective of the form of added seeds, were characterized by a higher values of protein, dietary fiber and polyunsaturated fatty acids. It was also found that the enrichment of cranberry jams with the seeds significantly increased the level of total polyphenols and phenolic acids, as well as their antioxidant activities. Based on the obtained texture parameters of the analyzed cranberry jams, it can be concluded that both flax and chia seeds can be a good substitute for the gelling agent, however, the ground forms of the seeds created a texture that is more similar to traditional pectin-containing jams.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subject.

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