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Original research paper

CHEMICAL CHARACTERISTICS AND NUTRITIVE QUALITY OF NOVEL FUNCTIONAL POTATO CHIPS-LIKE PRODUCTS

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Abstract: Developing countries, including Egypt, are suffering from serious nutritional problems among school-aged children and adolescents as they consume snacks and fast food, leading to serious health problems. Therefore, the production of affordable potato chips-like products containing functional ingredients such as sesame seeds and flaxseeds is one of the best ways to deal with such problems. This study found that these ingredients provided several macronutrients to the consumers in the following ranges: 9.62% - 12.88% of crude proteins, 5.23% - 13.73% of crude fat, 2.09% - 5.19% of crude fibres and 7.17% - 8.43% of ash which indicates the presence of important minerals such as phosphorus, calcium, iron, magnesium, manganese, and zinc. Potato chips-like snack that contained whole ground sesame seeds (15%) and flaxseeds (15%), was the highest in minerals except for potassium and sodium, and it was the only sample to contain a small amount of selenium. In addition, it contained the highest amount of omega-3 fatty acids followed by that enriched with 15% partially defatted sesame seeds and 15% whole ground flaxseeds. On the other hand, the potato chips-like snacks enriched with 15% of partially defatted sesame seed and flaxseeds each, and that enriched with 15% whole ground sesame seeds and 15% partially defatted flaxseeds, were more stable in oxidative stability than the previous two potato chips-like snacks. Also, the potato chips-like snacks enriched whole sesame and flax seeds as well as that with partially defatted sesame seeds and whole ground flaxseeds exerted the highest antioxidant activity confirmed by the DPPH scavenging and the number of phenolic compounds. The microstructure of the particles in the samples determined by scanning electron microscopy (SEM) showed that the chips-like snack with partially defatted sesame and flaxseeds was the best sample in terms of particle structure and distribution compared to the rest of the samples. Finally, the sensory properties of the potato chips-like snacks with defatted sesame and flaxseeds and a combination of whole ground sesame seeds/defatted flaxseeds were scored higher for overall acceptability and other sensory attributes.

Key words: *whole flaxseeds, whole sesame seeds, defatted seeds, omega-3 fatty acids, oxidative stability, phenolics*

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INTRODUCTION

Since school-aged children and adolescents represent a critical developmental stage in the human life cycle, novel and functional food products aim to improve their lifestyle and health to manage obesity and the number of chronic diseases such as diabetes and cardiovascular diseases, as well as other relatively common nutrition-related problems among these age groups, such as iron deficiency anaemia, eating disorders, dyslipidaemia, and hypertension (Ayoub, Al Jawaldeh, Taktouk, Leppäniemi & Abul-Fadl, 2022).

Potatoes (*Solanum tuberosum* L.) are a national industrial crop for developing countries as they have high nutritional importance and low economic value (Horton, 1987). Waseem et al. (2020) showed that potatoes are considered the fourth most important food crop right after wheat, rice, and corn, indicating the inclusion of many necessary nutritional elements, antioxidants, vitamins, and minerals (K, Fe, Na, P, Cu, and Mg). Abbasi et al. (2019) reported that there are 1.7g of protein, 20g of carbohydrate, 0.1g of fat, and 1.8g of fibre in every 100g of cooked potato. Woolfe (1987) found that the processing steps lead to the loss of many nutrients, particularly minerals. Conversely, potatoes gain 30% of their fat from processing, which causes many health problems like obesity, cardiovascular disease, and hypertension. Potato-based manufactured products, like chips and French fries, have high sodium content but a low mineral content. Additionally, these products become low in vitamins and antioxidants (Goyal & Goyal, 2018). As a result, we must avoid these unhealthy effects and simultaneously acquire nutritious qualities with a pleasing taste and appearance. The researchers can create novel functional potato chip products.

Sesame (*Sesamum indicum* L.) is an ancient oil seed used as traditional health food and medicine. It has amounts of moisture, protein, ether extract, carbohydrate, fibre, and ash of 10.50%, 27.65%, 47.79%, 8.95%, 3.80%, and 5.56%, respectively. The defatted sesame seed flour contains levels of moisture (2.19%), crude protein (41.15%), nitrogen-free extract (49.02%), crude fibre (3.46%), and ash (6.15%), along with a low amount of good oil, which reaches 1.49% (Onsaard, Pomsamud & Audtum, 2010). Sesame seeds can be used as a functional food in the form of oil, meal, or seed. They can also be combined with other ingredients to make value-added products that can prevent malnutrition and improve nutritional status at a lesser cost. Sesame seeds are incorporated in several foods as snacks and sweets, for example, sprinklers, which are made with whole or coarsely ground flour (Nagar, Agrawal & Agrawal, 2022). Due to their unique bioactive component, including sesamin, sesaminol, and γ-tocopherols, which have antioxidant properties, antihypertensive effects, and the ability to increase plasma tocopherol and stimulate the activity of vitamin E, which helps in the prevention of cancerous and cardiac diseases. Abbas et al. (2022) reported that sesame seeds are considered a source of healthy fatty acids, such as oleic acid (35.9-47.0%), linoleic acid (35.6-47.6%), stearic acid (5.41-6.42%), palmitoleic acid (0.09-.0.14%), and a trace amount of linolenic acid (0.30-0.40%). Also, the seeds contain myristic acid (9.15%), which has anticancerous activity. The sesame seeds fibre has antidiabetic, antitumor, antiulcer, cardioprotective, chemoprotective, and laxative properties. Furthermore, the seeds exhibit antioxidant and hepatoprotective activities. Low-glycaemic index bars made from sesame flour have proven successful in reducing the negative effects of several diseases because they contain antioxidant activity, which has been shown to have a therapeutic effect against cancer and to be effective in lowering the risks of human exposure to diseases over time. All of the aforementioned make sesame seeds an ideal ingredient for the production of functional food (Abbas, Sharif, Shah & Ejaz, 2016).

Flaxseed (*Linum usitatissimum* L.) contains high levels of alpha-linolenic acid and fibre which makes it a good choice for functional and nutritional ingredients. It is an oilseed that contains moisture (8%), protein (20%), fat (37-45%), carbohydrate (25-30%), dietary fibre (28%), and ash (3%) (Goyal, Sharma, Upadhyay, Gill & Sihag, 2014). Flaxseed is rich in α-linolenic acid (ALA), lignans, and fibre. In addition, this oil seed is a good source of vitamins and minerals, particularly phosphorus, magnesium, calcium, iron, zinc, and sodium (Kajla, Sharma & Sood, 2015). However, after defatting to create flaxseed flour, the amount of oil decreases from 39g/100g to 3.8 g/100g (Karakurt, Özkaya & Saka, 2022). The most popular seed used as a functional component in foods is flaxseed. Also, it is known as an oil seed rich in unsaturated fatty acids such as oleic acid (26.20%), linoleic acid (18.36%), linolenic acid (44.0%), and alpha-linolenic acid (ALA), which makes up 52% of total fatty acids in the seeds. In addition, it contains a high concentration of phenolic acids, such as ferulic acid, chlorogenic acid, and gallic acid. It has been demonstrated that taking flaxseed daily as a functional food significantly lowers total cholesterol. The researchers have demonstrated that flaxseed is beneficial for patients with cancer, obesity, and type II diabetes. Flaxseed is a good source of omega-3, and they found that it can be incorporated into many kinds of foods, such as baked, extruded, and milk products (El-Demery, Mahmoud, Bareh & Albadawy, 2015).

The purpose of this study was to develop a formulation and evaluate the quality of functional potato chips alternatives that contain whole ground sesame and flax seeds and/or partially defatted sesame and flax seed flour, which are beneficial sources of minerals, omega-3 fatty acids, antioxidants, and phenolic compounds.

MATERIALS AND METHODS

Materials

Potatoes, flaxseeds, sesame seeds, table salt (NaCl), and potato flavouring were purchased from a local market in Alexandria Governorate, Egypt. The partially defatted sesame seed flour and defatted flaxseed flour were purchased from Eco Health Egypt Trading Company. The sesame seed flour had 20.0% total fat, 46.67% proteins, 20.0% carbohydrates, 10 mg iron, 0 mg potassium, 0 mg sodium, 800 mg magnesium, and 12 mg zinc, while the flaxseeds flour had 10.71% total fat, 28.57% proteins, 42.86% total carbohydrates, 6.43 mg iron, 857.14 potassium, and 71.43 sodium. The chemicals used in this study were of analytical grade.

Manufacturing of potato chips-like snack products

Potato chips-like products were produced by using either whole ground or defatted flour of sesame seeds and whole ground or defatted flour of flaxseeds at 15.0% level for each ingredient. The other ingredients were kept constant in each alternative chips formulation and contained 60.0% potato paste, 2.0% salt, 3.0% flavouring, and 5% water, as shown in Table 1. Potatoes were boiled in water until they were tender, then peeled and mixed until they reached the paste form with an electric mixer. The salt and flavouring were added to the same mixer. The whole seeds were cleaned by sorting to remove extraneous materials, milled, and sieved. The milled seeds or flour of sesame and flax seeds were added as shown in Table 1, and finally, water was added gradually until dough was formed. The dough was steamed in a boiling water bath for half an hour and then left to cool down. Then the dough was formed to create the chip shapes with a forming tool. The chips were baked in the oven at 180 °C for 10 minutes (Fig. 1). The four samples were packed in polyethylene bags, and the samples were frozen at -18 °C after cooling down until the analysis, and the oxidative stability was measured after 0, 3, and 6 months of storage at room temperature.

Table 1.
Formulation of functional potato chips-like products

Ingredients (%)	Samples			
	S1	S2	S3	S4
Potato paste	60.0	60.0	60.0	60.0
Whole-ground sesame seeds	-	15.0	15.0	-
Partially defatted sesame seed flour	15.0	-	-	15.0
Whole-ground flaxseeds	-	15.0	-	15.0
Partially defatted flaxseed flour	15.0	-	15.0	-
Sodium chloride	2.0	2.0	2.0	2.0
Potato flavouring	3.0	3.0	3.0	3.0
Water	5.0	5.0	5.0	5.0

S1 (15% partially defatted sesame seeds flour + 15% partially defatted flaxseeds flour); S2 (15% whole ground sesame seeds +15% whole ground flaxseeds; S3 (15% whole ground sesame seeds + 15% partially defatted flaxseeds flour); S4 (15% partially defatted sesame seed flour + 15% whole ground flaxseeds)

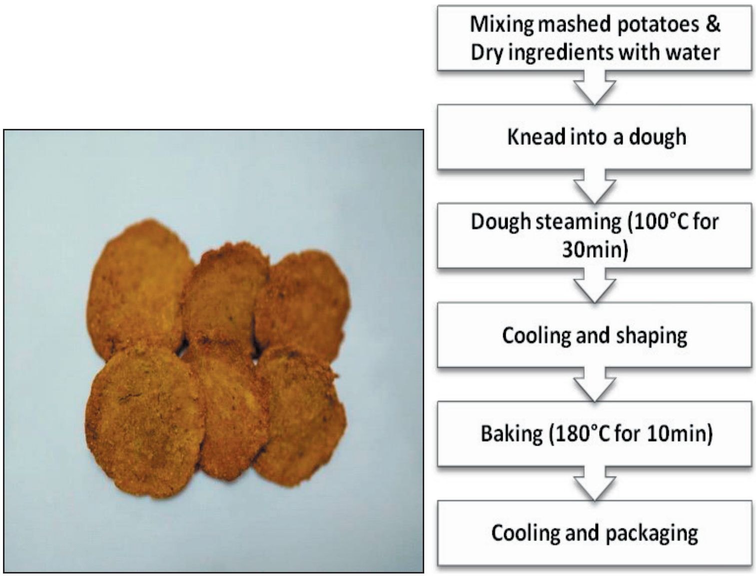

Figure1. Schematic presentation of the manufacturing of functional potato chips alternatives

However, the sensory evaluation was evaluated once the chips were prepared (Abou-Taleb et al., 2019).

Chemical composition

The samples were milled in a clean and dry mill and then sieved. Also, they were prepared in triplicate for analysis. Proximate analysis of the samples was determined according to the AOAC official method (2000). Crude protein was determined using the Kjeldahl method and calculated by multiplying the nitrogen content by 6.25. Finally, the nitrogen-free extract was calculated based on the differences.

Minerals content

The samples were taken to the ICP-OES Lab at the Alexandria University, Institute of Postgraduate Studies and Research, to measure Fe, Ca, Mg, Fe, K, Na, Mg, Mn, Se, Zn, and P. The metals analysis and quality control were carried out according to standard methods U.S. EPA Method 200.7 (U.S. EPA, 1994a) and U.S. EPA Method 6010 C (U.S. EPA, 2014). Operating conditions on Agilent ICP-OES 5100 VDV were controlled (temperature (15-30 °C) and relative humidity (20–80%)) (U.S. EPA, 1994b).

Fatty acid composition

Fatty acid methyl esters were prepared from the oil of the sample according to Md Ali and Dimick (1994) who extracted the oil by keeping the sample overnight in chloroform: methanol (2:1 v/v) mixture. The solvents were evaporated, and the oil was extracted. Fatty acid methyl esters of the extracted oil were analysed by a GC Agilent 7890A system with FID, an auto-injection module for liquid, equipped with a fused silica capillary column (DBWAX 30 m, 0.25 mm, 0.50 um). Helium was used as a carrier gas (purity > 99.9997 vol %, flow rate = 1.26 ml/min).

Peroxide value (PV) determination

PV as (meq O_2/kg oil) was assessed using the standard AOAC method (AOAC, 2000). 30 ml acetic acid and chloroform were added to 0.5g of the previously extracted oil until dissolution. After that, 0.5 ml of saturated potassium iodide solution was added and kept for exactly one minute. Then 30 ml of distilled water was added. Afterwards, 0.5 ml of 1% starch solution was added and titrated with 0.01 N sodium thiosulfate until the blue colour disappeared. The same steps were followed in a blank sample.

p-Anisidine value (AV) determination

AV was assessed according to the IUPAC method (1987). 0.5 g of the previously extracted oil was dissolved in hexane. The sample was then reacted with a p-anisidine solution in acetic acid (0.25% w/v) for 10 minutes to produce a coloured complex. The absorbance of the samples with and without p-anisidine solution was measured using a UV-VIS spectropho-tometer at 350 nm.

Totox value calculation

Totox value was used as an indicator of the whole oxidation history of the extracted oil and was calculated as follows:

Totox value = AV + 2 PV.

Antioxidants and phenolic compound extraction

Ten grams of the sample were added to 100 ml of methanol and left overnight in a shaker at room temperature. The mixtures were filtered on a Whitman paper 1, after 24 h of shaking. The solvent was evaporated completely at room temperature without exposure to heat treatment (Chaves, Santiago & Alias, 2020).

Antioxidant activity determination

DPPH (1,1-diphenyl-2-picrylhydrazyl) radical scavenging method was used to evaluate the antioxidant activity of the samples according to Ruttarattanamongkol and Petrasch (2016). 0.1 mM solution of DPPH in ethanol was prepared. Three millilitres of different extracts in ethanol at different concentrations (3.9, 7.8, 15.62, 31.25, 62.5, 125, 250, 500, and 1000 μg/ml) were mixed with one millilitre of this solution. Only the ethanol-soluble extracts that were utilized in this case were prepared at different concentrations using the dilution method. After giving the mixture a good shake, it was left to stand at room temperature for 30 minutes. The absorbance was then measured at 517 nm on a UV-VIS spectrophotometer. The experiment was carried out using ascorbic acid as the reference standard compound.

Phenolic compound determination

Phenolic compounds were analysed by HPLC according to Boligon, De Brum, Frolhich, Froeder and Athayde (2012) using an Agilent 1260 series instrument. The separation was carried out using an Eclipse C18 column (4.6 mm x 250 mm i.d., 5 μm). The mobile phase consisted of water (A) and 0.05% trifluoroacetic acid in acetonitrile (B) at a flow rate of 0.9 ml/min. The mobile phase was programmed consecutively in a linear gradient as follows: 0 min (82% A); 0–5 min (80% A); 5-8 min (60% A); 8-12 min (60% A); 12-15 min (82% A); 15-16 min (82% A) and 16-20 (82% A). The multi-wavelength detector was monitored at 280 nm. The injection volume was 5 μl for each of the sample solutions. The column temperature was maintained at 40 °C.

Scanning electron microscopy (SEM) of samples

The microstructure of samples was evaluated by scanning electron microscopy (JEOL, Model JSM–IT 200 Series, Tokyo, Japan) using an anion-sputtering apparatus (EM SCD500, LEICA), according to Yi, Hwang, Choi and Lim (2015).

The specimens were coated with a fine gold layer using an ion sputter coater, and photographs were captured at 1500 × magnification.

Sensory analysis

To evaluate the acceptability of the samples, sensory analysis was performed by ten panellists recruited from the staff of the Food Science and Technology Department, Faculty of Agriculture, Alexandria University, Egypt. The samples were presented to the panellists and scored for colour, texture, flavour, and overall acceptability on a 9-point hedonic scale (Larmond, 1977).

Statistical analysis

The data were analysed for statistical significance at a 95% confidence level ($P \leq 0.05$) to find any significant difference between samples via analysis of variance (ANOVA) using the statistical package for social science software (SPSS) version 22 (2018).

RESULTS AND DISCUSSION

Chemical composition

Table 2 displays the proximate composition of the studied samples representing different formulations of potato chips-like products (S1-S4). The S1 chips formula was significantly higher in the crude protein content and the lowest in the crude ether extract at $P \leq 0.05$. The samples differentiated significantly ($p \leq 0.05$) in the crude ether extract and the crude fibre content. There was no significant difference among all four samples in the ash content at $P \leq 0.05$. The S2 formula was significantly lower in the carbohydrate content at $P \leq 0.05$. The results illustrated that the content of fat, fibre, and ash improved when the potato chips-like formulation contained whole ground seeds, whereas the protein content improved when the formula included partially defatted seeds. On the other hand, the whole ground sesame seeds increased the fibre and ash content, whereas, the whole ground flaxseeds increased the fat content of samples. Kaur et al. (2019) found that the content of proteins and dietary fibres considerably improved in cookies when supplemented with raw flaxseed flour high in proteins and fibres. Also, the supplementation of bread flour with different levels of flaxseed beneficially affected the levels of proteins, fat, fibres, and ash. Defatted flaxseed flour had higher ratios of moisture, crude proteins, crude fibres, and ash than whole-seed flour (Mansour, Galal & Abu El-Maaty, 2018). Melo et al. (2021) reported that sesame flour that was remaining after the extraction of oil still contained an oil fraction rich in unsaturated fatty acids in amounts which can provide increased nutritional value and health benefits. Also, it has other components, such as protein, dietary fibres, and total minerals, in higher amounts than the whole seeds. El-Adawy (1995) reported that the addition of sesame meal may increase the protein level by up to 16%, and this finding is useful in the creation of functional products. Table 3 shows the mineral composition of the studied samples. The results found that the calcium content was the highest in the formula that contained the whole ground seeds (S2). The iron content was the lowest in the formula that contained the partially defatted seeds (S1), and it increased upon the inclusion of the whole seeds in the potato chips formulation. On the other hand, potassium and sodium contents were the highest in the defatted seeds formula, and they decreased by approximately half in the other chips formulations.

However, the opposite was noticed regarding the manganese and zinc contents that were doubled. Unfortunately, selenium was not detected in any of the samples but in S2, in which it was present only in trace amounts. Melo et al. (2021) reported that the minerals in sesame seeds such as K, P, Mg, Na, Fe, Zn, and Mn were recorded at 525.9 mg/100 g, 516 mg/100 g, 349.9 mg/100 g, 516 mg/100 g, 15.28 mg/100 g, 11.39 mg/100 g, 8.87 mg/100g and 3.46 mg/100 g, respectively. On the other hand, Abdel-Nabey, Abu-Tor and Abou-Gharbia

Table 2.
Chemical composition (%) of novel potato chips alternatives

Component (%)	Samples			
	S1	S2	S3	S4
Moisture	6.65±0.25[a]	6.58±0.24[a]	6.46±0.28[a]	6.42±0.15[a]
Crude protein (N×6.25)	12.88±0.65[b]	9.99±1.25[a]	9.62±0.78[a]	10.92±0.30[a]
Crude ether extract	5.23±0.30[a]	13.73±0.76[c]	8.90±.5 7[b]	9.72±0.83[b]
Crude fibres	4.80b±0.17	5.19±0.36[c]	4.65±0.07[b]	2.09±0.17[a]
Ash	7.58±0.87[a]	8.43±0.38[a]	8.37±0.50[a]	7.17±0.71[a]
Total carbohydrates*	67.26±0.76[b]	61.66±2.57[a]	66.65±2.11[b]	66.77±1.48[b]

S1 (15% partially defatted sesame seeds flour + 15% partially defatted flaxseeds flour); S2 (15% whole ground sesame seeds +15% whole-ground flaxseeds; S3 (15% whole ground sesame seeds + 15% partially defatted flaxseeds flour); S4 (15% partially defatted sesame seed flour + 15% whole ground flaxseeds)
**Calculated by difference*
Values are means of triplicates ± S.D. [a,b]Means within a row not sharing the same superscript are significantly different at P ≤ 0.05

Table 3.
Mineral composition of novel potato chips functional alternatives

Mineral (mg/100g sample)	Samples				
	S1	S2	S3	S4	LOD
P	434.89	493.75	397.49	435.34	0.025
Ca	390.57	2370.58	440.25	499.58	0.025
Fe	7.30	47.18	39.50	40.72	0.008
K	102.15	57.18	41.36	45.43	0.009
Mg	55.91	62.22	45.08	49.70	0.006
Mn	0.972	2.28	1.85	1.97	0.001
Na	134.38	44.22	40.11	42.50	0.022
Se	ND	0.079	ND	ND	0.033
Zn	3.78	5.62	4.41	4.62	0.032

S1 (15% partially defatted sesame seeds flour + 15% partially defatted flaxseeds flour); S2 (15% whole ground sesame seeds +15% whole-ground flaxseeds; S3 (15% whole ground sesame seeds + 15% partially defatted flaxseeds flour); S4 (15% partially defatted sesame seed flour + 15% whole ground flaxseeds)
LOD limit of detection
ND not detected < LOD

(2013), Khattab, Zeitoun and Barbary (2012), and Vaisey-Genser and Morris (1994) reported that flaxseed flour is a good source of minerals (K, P, and Mg) when applied to some functional foods such as biscuits, cookies, crackers, cake, and beef burgers. Also, Folasade and Oyenike (2012) stated that phosphorus, potassium, magnesium, and iron were among the minerals that were increased in sorghum-based beverages when supplemented with sesame seeds at varying levels (0-50%).

As shown in Table 4, the fatty acid composition in the functional potato chips alternative fatty acid profile showed that palmitic and stearic acid contents varied between 8.83% to 12.07% and 5.09% to 6.42%, respectively. Also, oleic acid, linoleic acid, and linolenic acid values varied between 29.19% to 41.36%, 26.86% to 40.10%, and 0.34% to 28.96%, respectively. Saturated fatty acids (SFAs) ranged from 14.15% to 23.74% of the total fatty acid profile, and the lowest content was in S2 (14.15%). Monounsaturated fatty acids (MUFAs) ranged from 30.03% to 49.17%, although the lowest levels were found in S2 and the highest in S3. The polyunsaturated fatty acids (PUFAs) ranged from 33.03% to 55.82% with the lowest content found in S3 and the highest in S2. From what was previously mentioned, sample S2 which contained whole ground seeds, exerted the best fatty acid profile, being the lowest in SFAs, the highest in PUFAs, and having the highest ratio (28.96%) of linolenic fatty acids (C18:3ω-3). The rest of the samples exhibited ω-3 ratios ranging from 3.27% to 0.34%. Finally, the ω-6/ω-3 ratios were the best in S2 (0.93%) followed by S4 (11.49%), in contrast to S1 and S3 which had unfavourable ratios, 117.94% and 36.97%, respectively. As reported in the literature, sesame seed meal may be incurporated into other foods because its oil has a high amount of unsaturated fatty acids such as linoleic acid, oleic acid, palmitoleic acid, and traces of linolenic acid (Nagar et al., 2022). Also, Yuksel, Karaman and Kayacier (2014) observed that flaxseed flour had a high amount of total unsaturated fatty acids (ω-3) that can be used in wheat chips as a functional omega-3 ingredient. Mentes, Bakkalbasi and Ercan (2008) and Conforti and Davis (2006) found that in the bread with 15 or 20% of flaxseed flour in its recipe, linolenic acid varied between 50.25% and 55.55% in contrast to the control (5.37%). They also found that the linolenic acid in flax bread and soy/flax bread varied from 48.63 to 55.75%. Linoleic acid is an essential fatty acid that must be absorbed through the daily diet, and it is converted to arachidonic acid, which has healthy effects on the human body. 1–2% of linoleic acid is converted to 0.5% arachidonic acid. The sesame seed components are considered healthy to be incorporated into daily diets due to the presence of linoleic acid (Melo et al., 2021). The results of oxidative stability are illustrated in Table 5. The primary oxidation products, such as hydroperoxides expressed by peroxide value (PV), were measured at time zero and after 3 and 6 months. No significant difference could be traced between S1 (2.08 meq O_2/kg) and S4 (2.10 meq O_2/kg), then S3 (3.01 meq O_2/kg) at zero time, and PV reached 9.03 meq O_2/kg, 9.71 meq O_2/kg and 15.47 meq O_2/kg, respectively, after 6 months at room temperature. On the other hand, S2 had a high PV value (8.48 meq O_2/kg) which is due to fact that it had the highest percentage of PUFAs (55.82%) and linolenic acid (C18:3), but this PV is still within the permitted limit (20 meq O_2/kg). The secondary breakdown products, such as carbonyls, aldehydes, and ketones, were monitored by p-anisidine value (AV). The AV may need to be as low as 10 to indicate the better quality of the oil. The results showed that the AVs ranged from 3.14 to 4.21 at zero time and gradually increased with storage until they reached 3.56 to 6.88 after 6 months at room temperature. Finally, the Totox values, usually used to indicate the oils' overall oxidation state, could be arranged in ascending order as follows: S1<S4<S3<S2, which is in line with the antioxidant scavenging (%) and the phenolic compounds concentrations for all samples except S2 that may refer to its content of high PUFAs. The ability of phenolic compounds to protect fats from oxidation appeared to depend not only on their chelating and free radicals. scavenging activities but also on the stability of their free radical forms. Mentes et al. (2008) found that the peroxide value of bread enriched with 10% flaxseeds reached 2.63 meqO_2/kg of oil. Conforti and Davis (2006) reported that the peroxide value of flax bread and soy/flax bread formulation varied between 2.04 and 2.92 meqO_2/kg during the storage period (8 weeks). Abou-Gharbia, Shehata and Shahidi (2000) noticed the high oxidative stability of raw and roasting sesame seeds measured by the changes in peroxide value (PV) and p-anisidine value

(AV).The antioxidant activity of the potato chips according to the DPPH scavenging assay is displayed in Fig. 2. The two samples, which contained the partially defatted seed flour (S1) and the whole ground seeds (S2), had high and similar abilities to scavenge the DPPH free-radical; 62%, 72%, and 80%; 61%, 70%, and 78% at varied concentration; 250 µg/ml, 500 µg/ml, and 1000 µg/ml, respectively.

On the other hand, the chips that contained whole flaxseeds (S4) were higher in DPPH scavenging percentage than those that with partially defatted flaxseeds (S3). That agreed with the results of Melo et al. (2021) who reported that the antioxidant activity was not different in whole sesame seeds and the defatted seeds flour. The results revealed that the oil extraction does not affect the antioxidant ability,

Table 4.
Fatty acid composition of functional potato chips alternative

Fatty acids (%)	Samples			
	S1	S2	S3	S4
C 16:0	10.24	8.83	12.07	17.57
C18:0	6.42	5.32	5.09	6.17
C20:0	0.80	-	0.64	-
C16:1	0.20	-	0.57	-
C18:1 ω-9c	41.36	29.19	48.60	35.44
C18:1 ω-9t	0.37	0.84	-	-
C18:2 ω-6c	40.10	26.86	32.16	32.40
C18:2 ω-6t	-	-	-	5.16
C18:3n ω-3c	0.34	28.96	0.87	3.27
C20:1	0.16	-	-	-
SFAs	17.46	14.15	17.16	23.74
MUFAs	41.93	30.03	49.17	35.44
PUFAs	40.44	55.82	33.03	40.38
MUFAs/SFAs	2.40	2.12	2.87	1.49
PUFAs/SFAs	2.32	3.95	1.93	1.70
∑ ω -6	40.10	26.86	32.16	37.56
∑ ω -3	0.34	28.96	0.87	3.27
ω -6/ ω -3	117.94	0.93	36.97	11.49

S1 (15% partially defatted sesame seeds flour + 15% partially defatted flaxseeds flour); S2 (15% whole ground sesame seeds +15% whole ground flaxseeds; S3 (15% whole ground sesame seeds + 15% partially defatted flaxseeds flour); S4 (15% partially defatted sesame seed flour + 15% whole ground flaxseeds)

Table 5.
Oxidative stability of oil extracted from functional potato chips alternatives following 0, 3 and 6 month(s) storage at room temperature

Storage period (months)	Parameters	Samples			
		S1	S2	S3	S4
0	Peroxide value (meq O_2/kg oil)	2.08±0.08^{a}	8.48±0.15^{c}	3.01±0.29^{b}	2.10±0.08^{a}
	p-Anisidine value	3.14±0.08^{a}	4.21±0.06^{c}	3.52±0.33^{ab}	3.67±0.15^{b}
	Totox value	7.30±0.20^{a}	21.17±0.25^{c}	9.54±0.24^{b}	7.87±0.18^{a}
3	Peroxide value (meq O_2/kg oil)	7.46±0.17^{a}	13.51±0.05^{d}	8.29±0.16^{b}	11.97±0.12^{c}
	p-Anisidine value	3.29±0.17^{a}	5.26±0.26^{c}	4.35±0.16^{b}	5.12±0.11^{c}
	Totox value	18.21±0.30^{a}	32.28±0.50^{d}	20.93±0.73^{b}	29.06±0.36^{c}
6	Peroxide value (meq O_2/kg oil)	9.03±0.08^{a}	15.44±0.17^{b}	9.71±0.07^{a}	15.47±0.25^{b}
	p-Anisidine value	3.56±0.22^{a}	6.88±0.05^{d}	5.39±0.11^{b}	6.39±0.15^{c}
	Totox value	21.62±0.07^{a}	37.76±0.39^{c}	24.81±0.25^{b}	37.33±0.35^{c}

S1 (15% partially defatted sesame seeds flour + 15% partially defatted flaxseeds flour); S2 (15% whole ground sesame seeds +15% whole ground flaxseeds; S3 (15% whole ground sesame seeds + 15% partially defatted flaxseeds flour); S4 (15% partially defatted sesame seed flour + 15% whole ground flaxseeds)
Values are means of triplicates ± S.D.
Means within a row not sharing the same superscript are significantly different at $P \leq 0.05$

which made the seed flour a good choice for creating new functional foods. Both the sesame cake and the seeds have antioxidant activity of 78 and 86 mg Trolox equivalents /100 g, respectively. Brodowska, Catthoor, Brodowska, Symonowicz and Łodyga-Chruścińska (2014) found that the extract of defatted flaxseed had a level to scavenge the DPPH radical ranged from 19.7% to 76.1%, while the scavenging capacity of the extract of whole flaxseed ranged from 25.7% to 76.3%. The content of phenolic compounds of the experimental potato chips-like products is illustrated in Table 6, which shows that S1 had more phenolic compounds (16 compounds) and a higher concentration (877.47µg/g) than the other samples, which had 13 compounds. The concentration of these compounds in S2 reached 665.06 µg/g, and finally, S3 and S4 nearly had the same phenolic compound concentration (341.46 µg/g and 342.69 µg/g, respectively). Gallic acid, chlorogenic acid, and catechin were the highest in all samples, and coffeic acid was high in S1 and S2, but ferulic acid was high in S4. On the other hand, rutin and quercetin disappeared in S3 and S4, ferulic acid was absent in S2, cinnamic acid did not appear in S2 and S3, and finally, kaempferol was not detected in S1, S2, and S3. Incorporation of phenolic compounds in functional food products reduces antioxidant agent addition because they have high antioxidant ability and play as anti-oxidative agents. They became strict goals to improve the stability of functional foods in addition to their positive effects on general health. Previous results found that defatted sesame seed flour was higher in total phenols, which sometimes reach 153 mg gallic aid equivalents/100g and other times reach either up to 787 mg gallic aid equivalents /100 g or up to 1355 mg catechin equivalents/100 g than the whole seeds (Melo et al., 2021). Also, the sesame seeds may have a total phenol amount of 107.11 mg/kg of gallic acid, and this value was affected by heat treatment depending on the temperature and the period of treatment (Khashaba, Shaltout, El-Difrawy, El-Yazeed & El-Sorady, 2014). Brodowska et al. (2014) showed that the defatted flaxseed extract had a recorded amount of total phenolic compounds reached by 98.8 mg/100g, and the last was decreased in the whole seeds by about 33%.

They also reported that the phenolic acids in flax inhibit lipid peroxidation, platelet aggregation, and capillary permeability and lower the incidence of cardiovascular diseases. Flaxseeds contain lignans, which are a biologically important class of phenolic compounds that have a very promising effect in reducing the growth of cancerous tumours, mainly breast and prostate cancer. Pérez-Jimenez, Neveu, Vos and Scalbert (2010) stated that generally, flaxseed had the highest phenolic compound contents. Figure 3 shows SEM images of examined samples, revealing differences between them in the distribution of particles in the sample matrix, particle size, and spacing between them. That may refer to the sample composition, especially the oil content. The particles were irregularly distributed and different in size; the distances between them were not equal, and there were a lot of pores through them except in the S4 sample. The particles in S1 were homogenized in size and particle distribution. On the opposite side, the particles in S2 were found in clustered conditions. This may refer to the presence of both sesame and flax as whole ground seeds in the S2 sample and it was the highest in its oil content (13.73%), whereas the first sample (S1) contained partially defatted sesame and flax seeds flour and it was the lowest in its oil content (5.23%). On the other hand, the particles in the S3 sample were homogenized and arranged into a matrix as S1 but the particle size were bigger than the particle size in the S1 matrix. Meanwhile, S4 was distinguished from the rest of the samples by the absence of pores, in addition to the absence of individual particles, but gathered in groups as a result of the high oil content (9.72%), the adhesion between the particles due to addition of partially defatted sesame seed flour, and the aggregation of the whole ground flaxseed particles in the protein matrix of sesame seeds. The afore-mentioned results are probably due to the kneading step during manufacturing, as it affects the homogeneity of the particle distribution and their size, as well as the presence or absence of pores. Yi et al. (2015) showed that SEM photographs of potato chips illustrated that the temperature of cooking was found to affect the particle size and their distribution during frying. Also, these results are consistent with the SEM results of the Labneh production containing sesame seeds with Attia, Kherouatou and Dhouib (2001), where the protein matrices of Labneh samples were compacted by the addition of sesame seed powder, and the particles exhibited more adhesion in the form of large agglomerations than those made from skimmed milk.

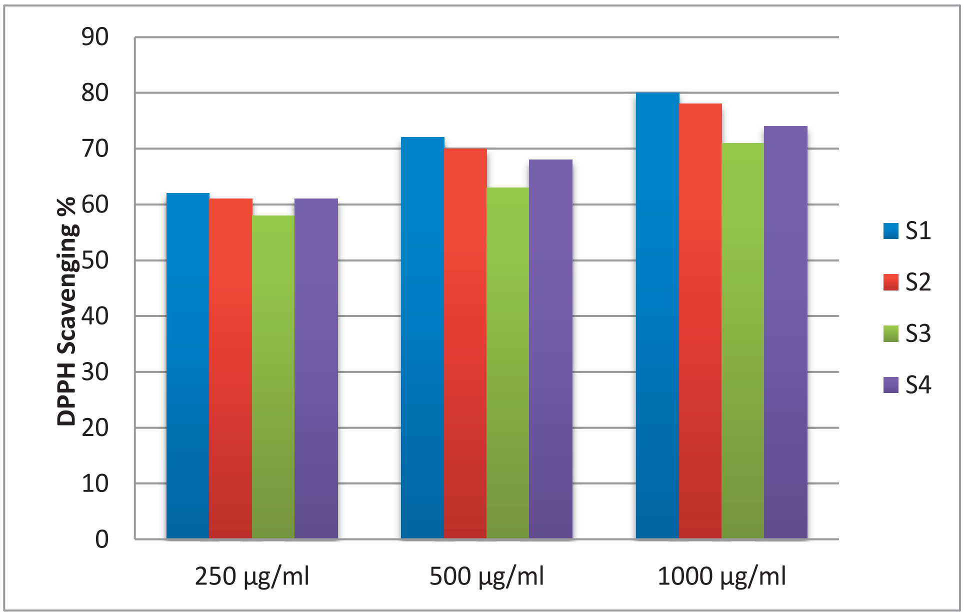

Figure 2. DPPH scavenging % of functional potato chips-like products

S1 (15% partially defatted sesame seeds flour + 15% partially defatted flaxseeds flour); S2 (15% whole ground sesame seeds +15% whole ground flaxseeds; S3 (15% whole ground sesame seeds + 15% partially defatted flaxseeds flour); S4 (15% partially defatted sesame seed flour + 15% whole ground flaxseeds)

Table 6
The content of phenolic compounds in the functional potato chips alternatives

Phenolic compounds (µg/g)	**Samples**			
	S1	**S2**	**S3**	**S4**
Gallic acid	219.24	156.63	63.57	54.41
Chlorogenic acid	135.48	89.28	39.89	82.32
Catechin	324.20	298.83	137.12	101.79
Methyl gallate	2.45	1.55	1.17	1.83
Coffeic acid	66.52	44.45	10.14	7.76
Syringic acid	17.59	10.92	5.63	8.27
Rutin	5.31	2.85	0.00	0.00
Ellagic acid	39.98	29.20	17.60	7.24
Coumaric acid	12.37	2.96	8.61	13.41
Vanillin	4.43	2.21	5.25	10.10
Ferulic acid	13.34	0.00	17.00	40.08
Daidzein	4.70	3.61	3.60	3.99
Quercetin	4.74	17.43	0.00	0.00
Cinnamic acid	1.69	0.00	0.00	0.75
Apigenin	5.59	5.14	12.44	0.00
Kaempferol	0.00	0.00	0.00	10.74
Hesperetin	19.84	0.00	19.44	0.00
Total	877.47	665.06	341.46	342.69

S1 (15% partially defatted sesame seeds flour + 15% partially defatted flaxseeds flour); S2 (15% whole ground sesame seeds +15% whole ground flaxseeds; S3 (15% whole ground sesame seeds + 15% partially defatted flaxseeds flour); S4 (15% partially defatted sesame seed flour + 15% whole ground flaxseeds)

Sensory properties are reported in Table 7 for color, taste odour, texture, and general acceptability.

These properties were measured using the nine-point hedonic scale because it is a simple measurement method that can be used to predict the acceptance of new functional foods by expected consumers.

There were no significant differences in odour and texture between the samples and the scores ranged from "neither like" or "dislike" to "slightly like" for odour and "moderately like" for texture. However, the remaining properties varied significantly (P≤ 0.05) as follows: for colour, S1 and S2 were evaluated as "neither like nor dislike", while S3 and S4 were perceived as "moderately like."

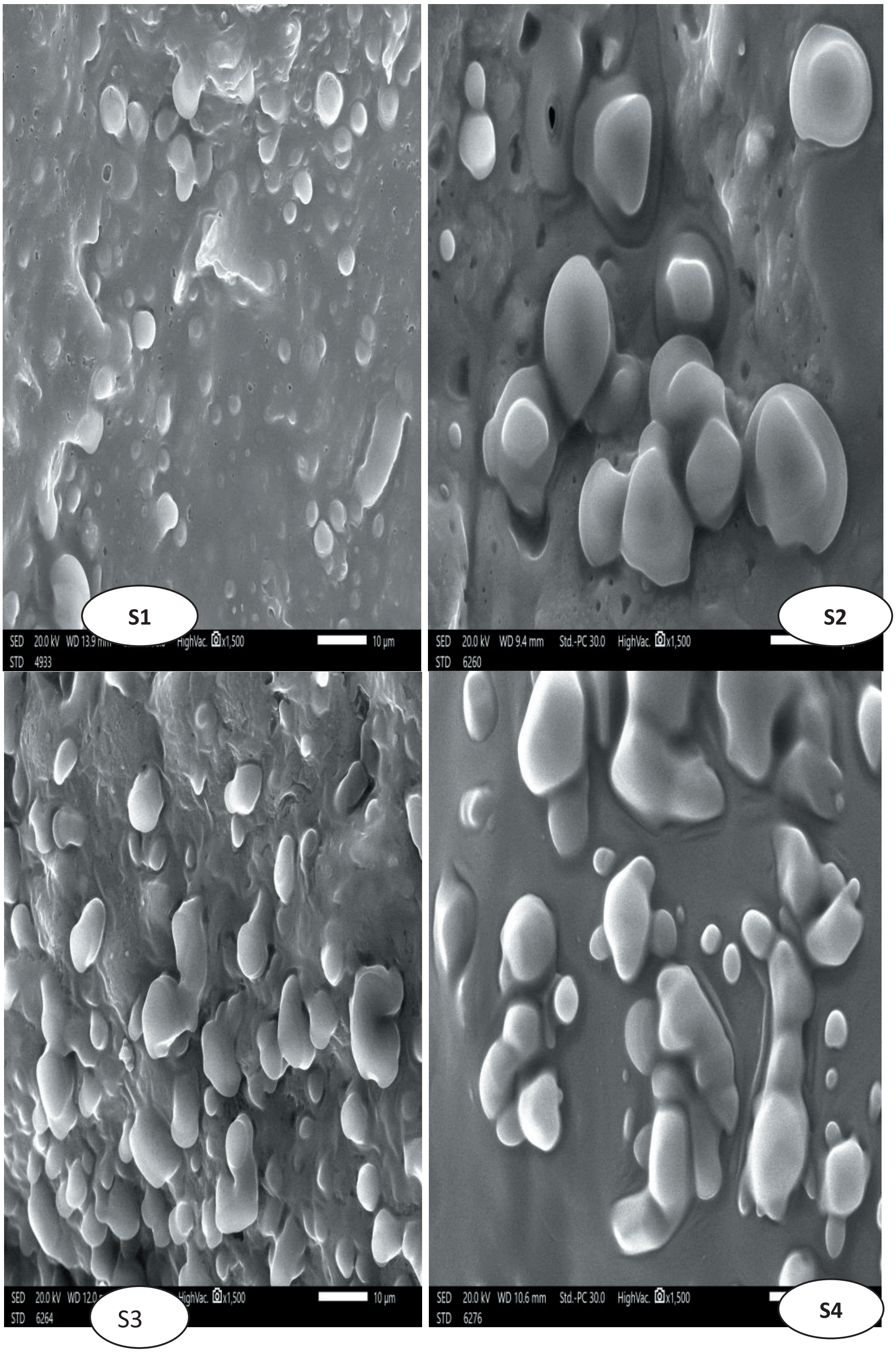

Figure 3. SEM micrographs of functional potato chips alternatives at 20 kV with 1500 × magnification

S1 (15% partially defatted sesame seeds flour + 15% partially defatted flaxseeds flour); S2 (15% whole ground sesame seeds +15% whole ground flaxseeds; S3 (15% whole ground sesame seeds + 15% partially defatted flaxseeds flour); S4 (15% partially defatted sesame seed flour + 15% whole ground flaxseeds)

Table 7.
Sensory evaluation of functional potato chips alternatives

Attributes	**Samples**			
	S1	**S2**	**S3**	**S4**
Colour	5.00±1.94^{a}	5.30±1.77^{a}	6.95±1.46^{b}	6.90±1.45^{b}
Taste	4.40±2.12^{a}	6.35±0.82^{b}	5.00±1.89^{ab}	6.30±1.57^{b}
Odour	5.05±1.77^{a}	5.60±1.84^{a}	6.30±1.64^{a}	5.85±1.70^{a}
Texture	5.50±1.96^{a}	6.20±1.55^{a}	6.90±1.37^{a}	6.30±1.34^{a}
Overall-acceptability	5.00±1.4^{a}	5.40±1.27^{ab}	6.40±1.35^{b}	6.40±0.97^{b}

S1 (15% partially defatted sesame seeds flour + 15% partially defatted flaxseeds flour); S2 (15% whole ground sesame seeds +15% whole ground flaxseeds; S3 (15% whole ground sesame seeds + 15% partially defatted flaxseeds flour); S4 (15% partially defatted sesame seed flour + 15% whole ground flaxseeds)
^{a,b} Means within a row not sharing the same letter are significantly different at P ≤ 0.05

These ratings are acceptable and expected for a functional potato product that contains sesame and flax seeds that lead to a somewhat darker colour.

The taste graduated from “slightly dislike” for S1 as a result of its low-fat content (5.23%), “neither like nor dislike” for S3, and “slightly like” for S2 and S4, which coincides with the percentage of fat in the samples. Fat gives a palatable taste to these products like potato chips. Finally, the overall acceptability was positive for all samples, and the most accepted samples were S3 and S4 at the same score (6.40). These findings are in line with those reported by Lucini Mas et al. (2022) related to the acceptance of novel cookies supplemented with defatted sesame seeds. In another study, Karakurt et al. (2022) reported that all sensory properties of the cookies using full-fat and defatted flaxseed flour were affected by the addition ratio. The appearance, texture, taste, odour and overall acceptability properties of the flax seed cookies significantly (P≤ 0.05) decreased. Meanwhile, the defatted flaxseed flour decreased the score values more than the full-fat flaxseed flour. Also, the sensory properties of cookies decreased by increasing the addition ratio of flaxseed and increasing the darkness of their colour. In the related research, the wheat supplementation with flaxseed (10%) in wheat chips enhanced the overall acceptability, while the flaxseed addition increased the fat quantitatively and qualitatively (Yuksel et al., 2014). Manthey, Lee and Hall III (2002) showed that the incorporation of flaxseeds into snacks gives a distinct texture and nutty flavour.

CONCLUSIONS

The incorporation of whole-ground sesame seeds or partially defatted sesame seeds flour and whole-ground flaxseeds or partially defatted flaxseeds flour as complementary ingredients into functional potato-like chips alternatives showed many advantages. The incorporation of sesame seeds and flaxseeds improved the product formulation in their contents of proteins, ether extract, fibre, and ash. Also, the potato chips samples were increased in the mineral contents, especially the calcium and iron. Among the studied functional potato-like chips samples, we found that S2 contained the highest ratio of ω-3: ω-6 fatty acids followed by S4. Moreover, S1 and S3 were the highest in oxidative stability, whereas S1 and S2 were the highest in antioxidant activity confirmed by the DPPH scavenging assay and the number of phenolic compounds. Fortunately, these functional potato-like chip alternatives had acceptable sensory properties such as colour, taste, odour, texture, and overall acceptability, especially S3 and S4. Each studied sample had its nutritional feature, according to each experimental parameter, that will make each novel formula applicable.

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HEMIJSKI SASTAV I PREHRAMBENI KVALITET NOVOG FUNKCIONALNOG PROIZVODA SLIČNOG ČIPSU OD KROMPIRA

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Sažetak: Zemlje u razvoju, uključujući Egipat, suočavaju se sa ozbiljnim nutritivnim problemima među populacijom dečjeg i adolescentskog školskog uzrasta zbog česte konzumacije grickalica i brze hrane, što dovodi do dalekosežnih zdravstvenih problema. Stoga je proizvodnja pristupačnih proizvoda nalik čipsu koji sadrže visokovredne funkcionalne sastojke kao što su susam i lan jedan od pristupa u strategiji borbe protiv ovakvih problema. Ova studija je pokazala da je dodatak susama i lana u proizvod nalik čipsu od krompira obezbedio nekoliko makronutrijenata u sledećim rasponima: 9.62% - 12.88% sirovih proteina, 5.23% - 13.73% masti, 2.09% - 5.19% of sirovih vlakana i 7.17% - 8.43% pepela koji ukazuju na prisustvo važnih minerala kao što su P, Ca, Fe, Mg, Mn i Zn. Snek proizvod nalik krompirovom čipsu koji je u svojoj formulaciji sadržao po 15% mlevenog celog zrna susama i lana imao je najviše mineralnih materija osim K i Na i bio je jedini uzorak u kome je određeno prisustvo Se ali samo u tragovima. Ovaj uzorak je takođe sadržao najviše omega-3 masnih kiselina, a nakon njega je sledio uzorak sa po 15% obezmašćenog semena susama i celog zrna lana. Uzorci snek proizvoda nalik čipsu koji su sadržali po 15% delimično obezmašćenog semena susama i lana, kao i oni sa po 15% celog zrna susama i delimično obezmašćenog lana su imali najveću oksidacionu stabilnost u odnosu na ostale dve formulcije. Najveću antioksidacionu aktivnost i najveći broj fenolnih jedinjenja su imali uzorci snek proizvoda sa celim zrnom susama i lana kao i oni sa delimično obezmašćenim susamom i celim zrnom lana. Mikrostruktura čestica je određena skening elektronskom mikroskopijom (SEM) i pokazano je da je snek proizvod nalik krompiru sa delimično obezmašćenim susamom i lanom imao najbolju strukturu i distribuciju čestica. Senzorska ocena je pokazala da su snek proizvodi sa obezmašćenim susamom i lanom kao i kombinacijom celog zrna susama i obezmašćenog lana ocenjeni najvišim ocenama za ukupnu prihvatljivost i ostale sensorske attribute.

Ključne reči: *celo zrno lana, celo zrno susama, obezmašćena zrna, omega-3 masne kiseline, oksidaciona stabilnost, fenolna jedinjenja.*

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