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HIGH NUTRITIONAL VALUE INSTANT FLAKES PRODUCED FROM VARIOUS CEREAL GRAINS

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KEY WORDS:
whole grains, cereal flakes, sensory evaluation, physicochemical characteristics, functional properties

ABSTRACT

The current study was carried out to prepare functional flakes from various cereals and to assess the nutritional value of breakfast cereal flakes and their sensory acceptability. Oat, soft wheat and durum wheat, barley (hull-less and hulled), triticale, millet and sorghum grains have been used. Physicochemical, functional, phytochemical properties and sensory evaluation were determined. The developed cereal flakes have high nutritional value and are high in dietary fiber. Concerning the overall acceptability of flakes, durum wheat, hull-less barley and triticale were more preferred than the other samples. Meanwhile, hulled barley and millet flakes showed the lowest scores compared with other flake samples due to the lowest score of their appearance and color. Triticale, durum wheat and hulled barley turned to be good alternatives for oat to prepare flakes of high-quality characteristics, as they have high protein (13.46, 11.92 and 11.67%, respectively) and ash contents along with low content of fat and low calories. In terms of nutritional quality, the results indicated that oat flakes were higher in Mg and P content, durum wheat flakes showed higher content of Mn, triticale had the highest content of K and Ca, and millet had the highest content of Zn and Fe. Triticale flakes showed significantly higher content of dietary fiber and water absorption index at room and hot temperatures when compared with other flakes. While comparing total phenolic content, the millet and barley flakes showed the highest values. Additionally, most flake samples had significantly higher values of antioxidant activity compared to oat flakes used as control samples.

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ВЫСОКАЯ ПИЩЕВАЯ ЦЕННОСТЬ ГОТОВЫХ ХЛОПЬЕВ, ПРОИЗВЕДЕННЫХ ИЗ РАЗЛИЧНЫХ ЗЛАКОВ

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КЛЮЧЕВЫЕ СЛОВА:
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АННОТАЦИЯ

Настоящая статья посвящена исследованию функциональных хлопьев для завтрака из разных зерновых для оценки их питательной ценности и чувственного восприятия. Были использованы сорта овса, мягкой пшеницы и твердой пшеницы дурум, сорта ячменя (без шелухи и с шелухой), тритикале, просо и сорго зерна. Проведены исследования физико-химических характеристик, функциональных, фитохимических свойств и проведена органолептическая оценка. Хлопья для завтрака имеют высокую питательную ценность и высокое содержание диетической клетчатки. Исследования показали, что пшеница, ячмень без шелухи, тритикале, как сырье для изготовления хлопьев оказались более предпочтительными, чем другие злаки. В то же время хлопья из ячменя и проса, показали самые низкие оценки по сравнению с другими образцами хлопья из-за низких показателей внешнего вида и цвета. Тритикале, твердая пшеница дурум и ячмень являются хорошей альтернативой овсу для приготовления высококачественных хлопьев, поскольку они имеют высокое содержание белка (13,46, 11,92 и 11,67% соответственно) и содержания золы, в то время как содержание жира более низкое, также как и калорийность. С точки зрения качества питания, результаты показали, что овсяные хлопья отличались более высоким содержанием Mg и P, хлопья из твердой пшеницы дурум отличались более высоким содержанием Mn, у хлопьев из тритикале было самое высокое содержание K и Ca, а просяные хлопья имели самый высокий уровень содержания Zn и Fe. Хлопья из тритикале показали значительно более высокое содержание диетических волокон и водопоглощения при комнатной и повышенной температуре по сравнению с другими образцами. Сравнивая общее содержание фенола, следует отметить, что хлопья из сортов проса и ячменя показали самые высокие значения. Кроме того, большинство образцов имели значительно высокие значения антиоксидантной активности по сравнению с овсяными хлопьями, используемыми в качестве контрольного образца.

1. Introduction

Cereal products cover about half of the daily calorie intake of humans worldwide, ranging from 25 to 55% in several European countries and some developing countries, respectively [1]. Recently, breakfast cereals have become considered one of the staples in the human diet [2]. They are common food products made of whole grain cereals. Cereal grains have nourished humanity since their domestication thousands of years ago and they continue to be the most important food source for human consumption.

Whole grain food consumption has received considerable attention for its health benefits. It is a main factor that maintains a healthy lifestyle to achieve and keep a healthful body mass index [3]. Generally, cereal grains are the most substantial source of energy in the human diet, as they have high contents of carbohydrates (70–80%), proteins (7.5–15%), and minerals (1.5–3%), and low content of fat (1–4%) [4,5]. They are rich sources of vitamins (E and B), minerals (in particular zinc, highly available iron, copper, manganese, phosphorus, potassium, calcium and magnesium), carbohydrates, fats, protein and phytochemicals. Whole grains of cereals and pseudo-cereals contain various dietary fiber profiles such as arabinoxylan, ß-glucan and fructan. These help to reduce the risk of obesity, diabetes of type-2, heart and cardiovascular diseases, certain types of cancer and other health concerns [6,7].

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Wheat, triticale, sorghum and corn have a high content of arabinoxylan, whereas oat, barley, and triticale feature functional properties due to high ß-glucan level [8,9]. From a nutritional point of view, triticale grains are more nutritionally valuable than other cereals such as wheat, due to their high essential amino acid content [10]. Furthermore, soluble dietary fiber such as that found in oats and barley, slows carbohydrate absorption and suppresses rising of blood sugar and regulates insulin response [11]. According to the modern science of nutrition, food is not only a source of energy but also a complex of biologically active matters that regulate the different functions of the human body. There is increased demand for functional foods as a main source of external antioxidants [12]. Millet and sorghum contain a wide variety of phenols and possess antioxidant activity [13,14]. Millet grains have a high potential as a gluten-free food for human consumption, as well they have a high content of dietary fiber and essential amino acids [15].

Whole grains can be consumed as intact, cracked, ground, flaked, or processed kernels after the removal of inedible parts [16]. Thus, the processing is an important task to enhance the bioavailability of nutrients and sensory properties and to decrease the content of antinutrients [17,18]. Additionally, quick and easy-to-prepare whole grain foods would help people increase their consumption of these foods. Ready-to-eat cereals are produced by various technological processes such as cooking, drying, shaping, flavoring, and enrichment with micronutrients [19].

Globally, oat flakes are the most common commercial oat products [20]. They can be classified according to the processing technology into rolled oats, steel-cut oats (Irish oats), instant oats and quick oats [21]. Part of consumers prefer to use traditional flakes for not only making porridge but also for consuming them with milk or yogurt. Traditional cereal flakes are produced by steam treatment up to definite moisture content and then flaking. Various techniques are developed for flake production technology to produce high-quality food products. These techniques could influence the bulk density and sensory properties of products [22]. Ready-to-cook foods based on nutritious grains such as millet, sorghum and triticale would be more reasonable in the modern times in the management of lifestyle disorders.

Owing to the high nutritional value and versatile health benefits of various cereals, this study has been carried out to develop functional cereal flakes as alternatives for oat. Various local whole grains (wheat, barley, triticale, millet and sorghum) have been used to produce the cereal flakes samples. The produced flakes from various cereal grains were compared with commercial oat flakes and the differences in the physicochemical and functional properties, nutrient composition and sensory characteristics between the flakes were evaluated.

2. Materials and methods

Various cereal grains: soft wheat (*Triticum aestivum* L. Misr-3 variety), durum wheat (*Triticum durum* L. Sohag-3 variety), hull-less barley (*Hordeum vulgare*. Giza-129 variety), hulled barley (Giza-123 variety), triticale (*Triticosecale*, Balady variety), millet (*Cenchrus americanus*, Shandawel-1 variety), and white sorghum (*Sorghum bicolor*, Giza-10 variety) were obtained from the Field Crops Research Institute, Agricultural Research Center, Giza, Egypt. Naked oat grains (*Avena sativa*) and commercial ready-to-eat rolled oat flakes as a control sample obtained from a local market (Harraz).

The weight of 1,000 kernels in grams was determined by weighing 100 kernels in triplicate and then extrapolating this weight to 1,000 kernels. Test weight (hectoliter) of different cereal grains was carried out according to the method of AACC (2010) [23].

Cereal flakes were produced simply, as shown in Figure 1, from various cereal grains after being cleaned and washed with water. Flakes were manufactured according to the method of Takhellambam *et al.* [24] with some modifications. Processing technology includes soaking for 8 h, cooking (for 20–40 min at 80 °C), and then flattening to flake shape between two spinning rollers (at a roll clearance of 0.6 mm) using a simple rolling pasta machine (Pastadrive, Atlants, China). The produced flakes were air dried for 4–6 h at 45 °C, then packed in polyethylene bags and stored in the refrigerator till further analysis.

The produced flake samples mixed with warm milk were evaluated, using a nine-points hedonic scale, by ten members of the Food Technology Research Institute, Agricultural Research Center, Giza, Egypt [25]. They were asked to score the various flakes by general appearance, color, odor, taste, mouth feel and overall food acceptability. All samples were coded and presented in a randomized arrangement.

The colorimetric measurements were measured in triplicate using a colorimeter (Konica Minolta Chroma Meter CR-400, Japan) according to McGurie [26]. The color values were recorded as: L^* = lightness (0 = black, 100 = white), a^* = greenness- redness ($-a^*$ = greenness, $+a^*$ = redness) and b^* = blueness- yellowness ($-b^*$ = blueness, $+b^*$ = yellowness).

Figure 1. **A photograph of the produced flakes from various cereal grains**

Рисунок 1. **Фотография хлопьев, произведенных из различных злаков**

Bulk density (specific mass) of flake samples was determined according to the method of Akaaimo and Raji [27] as a ratio of the mass of the flake sample to its volume occupied as shown in the following formula.

$$\text{Bulk density (g/ml)} = \frac{\text{Flakes weight (g)}}{\text{Flakes volume (ml)}} \quad (1)$$

The true density of the flakes was measured according to the method of Mwithiga and Sifuna [28] using the toluene displacement method. It is calculated as a ratio of the flakes weight to the volume of toluene displacement using the following formula:

$$\text{True density (g/ml)} = \frac{\text{Flakes weight (g)}}{\text{Rise in toluene level (ml)}} \quad (2)$$

Water activity (a_w) was determined using LabStart-aw (Novasina, Switzerland) equipment. The a_w values were ranged from 0 to 1 for a completely dehydrated food and for pure water, respectively.

Room temperature water absorption index (RTWAI) of cereal flakes was determined according to the developed method for cereals [29]. Twenty grams of flakes were weighed (W1) in a 250 ml beaker and 150 ml of distilled water was added. The beaker was kept in a water bath at 25 °C for 20 min. The samples were filtered, weighed (W2), and then calculated according to the following equation:

$$\text{RTWAI (\%)} = [(W_2 - W_1)/W_1] \times 100 \quad (3)$$

High temperature water absorption index (HTWAI) of different cereals flakes were examined according to the method of Hu et al. [21]. Twenty grams of flakes (W_1) were placed in a 250 ml centrifuge tube, 150 ml of distilled water was added, and kept in a water bath at 80 °C for 10 min. After that, the slurry was centrifuged at 3,000 rpm for 15 min, and the precipitate was collected and weighed (W_2) and then calculated according to the following equation:

$$\text{HTWAI (\%)} = (W_2/W_1) \times 100 \quad (4)$$

Rehydration ratio was calculated according to Huang et al. [30]. Two grams of each flake sample were rehydrated in (20 ml) distilled water in a water bath at constant temperature and was agitated at constant speed. The samples were taken out from the bath after 10 min and weight. The rehydration ratio was defined as the ratio of the weight of rehydrated samples to the dry weight of the samples. The rehydration ratio was calculated using the weight of samples before and after rehydration as follow:

$$\text{Rehydration ratio} = \frac{W_2 - W_1}{W_1} \quad (5)$$

W_1 is the initial weight of the flake samples and *W2* is the final weight of the flakes.

Chemical parameters (moisture, crude protein, fat, ash, crude fiber and carbohydrates) of various cereal grains and produced flake samples were determined according to the methods outlined in AOAC [31]. The values obtained for fat, protein, and carbohydrate contents were used to calculate the food energy or calorific value of the cereal flake samples according to the AOAC methods [31]. It was expressed as the following equation:

$$\text{Calorific value (kcal/100 g)} = (\text{Fat} \times 9) + (\text{Protein} \times 4) + (\text{Carbohydrates} \times 4) \quad (6)$$

The total dietary fiber (TDF) content was determined in the all studied flake samples according to AOAC [31]. Duplicate samples are processed which enabled subtraction of protein and ash for TDF content calculation.

The minerals content of different flake samples were determined by using the flame photometer (Galienkamp, FGA 330, England) and Perkin Elmer Atomic Absorption Spectrophotometer (Model 80, England) as described in AOAC [31] for magnesium, potassium, zinc, calcium, manganese and iron. Phosphorus content was detected calorimetrically using a spectrophotometer at 650 nm according to the method of AOAC [32].

Total phenolic content (TPC) was determined according to Singleton and Rossi [33] using the Folin-Ciocalteu reagent method. Total flavonoid content (TFC) was determined using the aluminum chloride colorimetric method as reported by Eghdami and Sadeghi [34].

The free radical scavenging activity was determined using the 2.2-diphenyl-2-picryl-hydrazyl (DPPH) method and the absorbance at 517 nm according to Fischer et al. [35]. The scavenging activity was calculated using the following equation:

$$\text{DPPH radical-scavenging activity (\%)} = [(A - B)/A] \times 100 \quad (7)$$

where A is the absorbance of the control sample, and B is the absorbance of the cereal flake extracts.

Statistical analysis of experimental data was performed by analysis of variance (ANOVA) of the producers using SPSS16.0 software to examine differences of statistical significance among the analysis means of experimental data. Duncan's multiple range tests at ($P \leqslant 0.05$) level was used to compare the mean values.

3. Results and discussion

Physical and chemical characteristics of various cereal grains (soft wheat and durum wheat, hull-less and hulled barley, triticale, millet, sorghum, and oat as a control sample) are shown in Table 1. A significant difference was observed in the 1,000-kernel weight among the used cereals, and the weights ranged from 9.34 g for millet to 53.20 g for durum wheat grains. The specific weight (hectoliter) of various grains ranged from 65.89 to 81.72 kg/hl for triticale and durum wheat grains, respectively.

The moisture content of cereal grains was in the range of 9.06–10.50%. All used cereals, except triticale, contain significantly lower protein content compared to the oat as a control sample. Significantly, triticale flakes have the highest protein content (13.71%) among other cereals which is consistent with the obtained results of Glamočlija et al. [36] who reported that the protein content of triticale was higher than in other cereals. Also, they mentioned that the increasing interest in triticale grains is due to the high protein content compared to other cereals. Regarding the fat content, it could be noticed that millet has the highest content (6.41%) followed by oat and sorghum grains (5.68 and 4.05%, respectively). Millet grain has a high content of fat because the germ represents about 21% of the whole grain [37]. On the other hand, triticale has the lowest fat content (1.84%). Among all cereal grains, triticale has the highest ash content (2.68%) while sorghum and soft wheat have the lowest content (1.76 and 1.77%, respectively). The crude fiber content of cereal grains varied from 1.82% for hull-less barley to 3.45% for triticale.

Sensory parameters should be taken into account as important values of flakes where consumers can select flakes from the markets depending on sensory evaluation and price. The sensory attributes of the flakes from different cereal grains assessed on a 9-point hedonic scale are given in Table 2 in comparison with commercial oat flake sample.

Whole grains contain biopolymers and flavor-active compounds as well as cell wall structures which may change flavor and texture attributes during processing [38]. Various cereals and varieties may cause major variations in the results, due to the sensitivity of some cereals and varieties to the hydrothermal treatment and form toasted characteristics more than others [39]. Results showed that no significant differences were observed in appearance scores of oat, soft wheat, durum wheat and sorghum flakes compared with commercial oat. Concerning the color parameter, there were no significant differences among all samples except that of hulled barley, triticale and millet flake samples. All flake samples were not significantly different in odor at a 0.05 level of significance. The higher scores of the taste parameter were recorded for commercial oat, hull-less barley, triticale and durum wheat samples. Millet flakes had

Table 1. **Physicochemical characteristics of whole grain cereals**

Таблица 1. **Физико-химические характеристики цельнозерновых хлопьев**

Cereal grains	Physical properties		Chemical properties					
	1,000-kernel wt. (g)	Hectoliter (kg/hl)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Crude fiber (%)	Carbohydrate content (%)
Oat	25.44 ± 0.31^{f}	73.11 ± 0.26^{e}	9.47 ± 0.10^{d}	13.07 ± 0.06^{b}	5.68 ± 0.06^{b}	2.17 ± 0.02^{cd}	2.55 ± 0.09^{cd}	76.53 ± 0.07^{e}
Soft wheat	45.25 ± 0.4^{b}	81.65 ± 0.44^{a}	9.44 ± 0.02^{d}	10.81 ± 0.08^{d}	1.92 ± 0.05^{de}	1.77 ± 0.03^{e}	2.28 ± 0.04^{ef}	83.22 ± 0.05^{a}
Durum wheat	53.20 ± 0.05^{a}	81.72 ± 0.04^{a}	9.06 ± 0.10^{e}	12.24 ± 0.12^{c}	1.86 ± 0.02^{e}	1.84 ± 0.09^{e}	2.40 ± 0.05^{de}	81.66 ± 0.17^{b}
Hull-less barley	35.68 ± 0.58^{d}	79.33 ± 0.21^{b}	10.22 ± 0.03^{b}	10.51 ± 0.10^{d}	1.97 ± 0.10^{de}	2.23 ± 0.02^{c}	1.82 ± 0.02^{g}	83.47 ± 0.03^{a}
Hulled barley	44.51 ± 0.52^{b}	76.19 ± 0.03^{c}	9.84 ± 0.05^{c}	11.75 ± 0.05^{c}	2.06 ± 0.13^{d}	2.43 ± 0.05^{b}	2.12 ± 0.18^{f}	81.64 ± 0.06^{b}
Triticale	28.13 ± 0.18^{e}	65.89 ± 0.33^{f}	10.31 ± 0.04^{b}	13.71 ± 0.07^{a}	1.84 ± 0.09^{e}	2.68 ± 0.05^{a}	3.45 ± 0.06^{a}	78.33 ± 0.08^{d}
Millet	9.34 ± 0.53^{g}	81.55 ± 0.06^{a}	10.50 ± 0.02^{a}	10.79 ± 0.04^{d}	6.41 ± 0.02^{a}	2.12 ± 0.06^{d}	2.70 ± 0.10^{bc}	77.98 ± 0.10^{d}
Sorghum	39.03 ± 0.61^{c}	73.62 ± 0.36^{d}	9.85 ± 0.11^{c}	10.42 ± 0.75^{d}	4.05 ± 0.02^{c}	1.76 ± 0.06^{e}	2.76 ± 0.06^{b}	81.01 ± 0.44^{c}

Values are means of three replicates ± standard deviation. Values in the same column followed by different superscripts are significantly different ($P \leqslant 0.05$). Carbohydrate content is calculated by the difference.

Table 2. **Sensory evaluation of the produced flakes from various cereal grains**

Таблица 2. **Оценка органолептических свойств хлопьев, произведенных из различных злаков**

Flake samples	Appearance (9)	Color (9)	Odor (9)	Taste (9)	Mouth feel (9)	OA* (9)	AI** (%)
Commercial oat	8.94 ± 0.33^{a}	8.94 ± 0.00^{a}	8.78 ± 0.35^{a}	8.83 ± 0.33^{a}	8.61 ± 0.65^{a}	8.79 ± 0.22^{a}	97.94
Oat	8.56 ± 0.73^{abc}	8.67 ± 0.56^{a}	8.72 ± 0.78^{a}	8.22 ± 0.86^{bc}	7.83 ± 0.96^{bc}	8.31 ± 0.53^{bc}	93.17
Soft wheat	8.56 ± 0.46^{abc}	8.83 ± 0.35^{a}	8.67 ± 0.73^{a}	7.89 ± 0.83^{bc}	7.81 ± 0.88^{bc}	8.21 ± 0.49^{bc}	92.54
Durum wheat	8.78 ± 0.44^{ab}	8.89 ± 0.33^{a}	8.72 ± 0.44^{a}	8.33 ± 0.35^{abc}	8.11 ± 0.70^{abc}	8.45 ± 0.44^{ab}	94.96
Hull-less barley	8.39 ± 0.93^{bc}	8.44 ± 0.68^{ab}	8.61 ± 0.60^{a}	8.47 ± 0.69^{ab}	8.06 ± 0.76^{abc}	8.37 ± 0.52^{abc}	93.22
Hulled barley	8.06 ± 0.66^{cd}	7.78 ± 0.74^{c}	8.56 ± 0.53^{a}	8.00 ± 0.61^{bc}	7.67 ± 0.43^{c}	7.97 ± 0.39^{c}	88.96
Triticale	8.28 ± 0.71^{bc}	8.08 ± 1.06^{bc}	8.72 ± 0.57^{a}	8.42 ± 0.56^{abc}	8.33 ± 0.90^{ab}	8.37 ± 0.49^{abc}	92.96
Millet	7.56 ± 0.97^{d}	7.61 ± 0.84^{c}	8.33 ± 0.68^{a}	7.83 ± 0.98^{c}	8.17 ± 0.88^{abc}	7.94 ± 0.46^{c}	87.85
Sorghum	8.50 ± 0.71^{abc}	8.56 ± 0.58^{ab}	8.61 ± 0.49^{a}	7.89 ± 0.89^{bc}	7.89 ± 0.74^{bc}	8.22 ± 0.34^{bc}	91.98

Values in the same column followed by different letters indicate a significant difference ($P \leqslant 0.05$). Liking scale ranged from 1 to 9 for extremely dislike to extremely like, respectively. OA*: The Overall Acceptability. AI**: the Acceptability Index (%).

the lowest appearance and the less taste values among all flake samples. Similar findings were reported by Cabrera et al. [40], who observed a decreased food acceptability of millet based products. Furthermore, higher scores in mouth feel were observed in commercial oat, hull-less barley, triticale and millet when compared with other flakes (P ≤ 0.05).

Regarding the overall acceptability, commercial oat, durum wheat, hull-less barley and triticale flakes were preferred over other samples. Meanwhile, hulled barley and millet flakes showed the lowest scores compared with other flake samples. Color is an important sensory parameter that affects the appearance and is used as an index of the acceptability of the product [40]. Consumers mostly prefer flakes to be not sticky or adhering to teeth and should not require much mastication or break down [41]. All the produced flakes were well accepted by the panelists with an acceptability index of more than 87% as shown in Table 2. From the obtained results, it could be concluded that durum wheat, hull-less barley and triticale flakes are the good alternatives to oat flakes with good characteristics due to their highest scores in numerous sensory characteristics compared with commercial oat flakes as a control sample. Although millet flake had the lowest overall score as well as the appearance and color scores, it still has a high acceptability index (87.85%) as shown in Table 2. Nonetheless, millet as well as sorghum can be used as a functional gluten-free alternative to oat, wheat and barley.

Physical and functional characteristics of flakes produced from various cereal grains such as color, density, water activity (a_w), RTWAI, HTWAI and rehydration ratio are presented in the Table 3. Color is an essential quality parameter that directly effects on the acceptability of food products. For color parameters, dark whole-grain products are not attractive for the consumers who choose refined products. Results showed that commercial oat flakes showed significantly the highest L* and b* values, while Sorghum flake has the highest a* value compared with the other samples. Hulled barley flake has the lowest L* and b* values but millet has the lowest a* value among all samples.

There was no significant difference in the true density among all produced flakes from various cereal grains and it ranged from 1.10 to 1.27 g/ml. Millet flakes have the highest value of bulk density (0.51 g/ml) meanwhile hulled barley and triticale have the lowest bulk density (0.35 and 0.25 g/ml, respectively). Bulk density is an indicator of flake flatness and it is used as an indication of the storage space required for a definite quantity of various flakes. The lower bulk density indicates the good flaking quality [24].

Water activity is a useful value to predict food safety and quality where it indicates the available amount of water to microorganisms. Water activity of the produced flake samples was varied from 0.31 to 0.43 indicating high storage and microbial stability. Abbas et al. [42] reported that, at a water activity of less than 0.6, the activity and the growth of all microorganisms could be inhibited. There is an increase in the possibility of lipids oxidation, at very low water activity (<0.25) [43].

The water absorption index at room temperature (RTWAI) measures the quantity of water absorbed by starch and is used as a starch gelatinization index as native starch does not absorb water at room temperature [44]. RTWAI of oat and triticale flakes was significantly higher compared to other samples (P ≤ 0.05) as shown in the Table 3. These results might be attributed to the higher content of protein and crude fiber [45]. Significant differences were found in water absorption index at high temperature (HTWAI) of flake samples and ranged from 313.05 to 498.81% for soft wheat and triticale flakes, respectively. The different water absorption index could be attributed to the surface of flakes, which can absorb water into the matrix, differently [46].

Rehydration ratio of flake samples is presented in the Table 3. Results showed no significant differences in rehydration ratio between hulled barley, triticale and millet flakes and they have the highest ratios. On the other hand, soft wheat and durum wheat flakes have the lowest rehydration values among the flake samples. Depending on the physical characteristics of produced flakes from various cereal grains, it could be concluded that durum wheat, sorghum and triticale were the cereal flakes with nearest values to the control sample (commercial oat).

The chemical composition of cereals mainly influences their quality as well as the derived products. The chemical composition of the produced flakes is presented in the Table 4. It could be noticed that commercial oat and triticale flakes had higher protein contents (13.89 and 13.46%, respectively), meanwhile sorghum and hull-less barley had the lowest contents (10.23 and 10.20%, respectively) among all flake samples. Fat content of flakes ranged between 1.55% for hulled barley and 6.22% for commercial oat. Concerning the ash content, it ranged from 1.53% in soft wheat flakes to 2.26% in triticale. Among all flake samples, triticale has the highest fiber content (3.36%). Noticeably, there were no significant differences in the fiber content of commercial oat, hull-less barley and hulled barley and they have lower content compared to other samples. Carbohydrates, as the major components of cereals, were more than 76%

Table 3. **Physical and functional characteristics of the produced cereal flakes**

Таблица 3. **Физические и функциональные характеристики произведенных злаковых хлопьев**

Flake samples	Color			Density (g/ml)		Water activity (a_w)	RTWAI (%)	HTWAI (%)	Rehydration Ratio
	L*	a*	b*	True	Bulk				
Commercial oat	82.58 ± 1.96^{a}	3.22 ± 0.03^{b}	21.23 ± 0.41^{a}	1.16 ± 0.12^{a}	0.44 ± 0.01^{b}	0.52 ± 0.02	112.72 ± 0.62^{f}	351.33 ± 5.83^{g}	1.97 ± 0.08^{c}
Oat	58.09 ± 2.23^{c}	3.09 ± 0.15^{bc}	12.77 ± 0.39^{d}	1.20 ± 0.09^{a}	0.40 ± 0.01^{c}	0.43 ± 0.05	216.49 ± 0.12^{a}	382.05 ± 2.26^{f}	1.98 ± 0.01^{c}
Soft wheat	57.81 ± 2.40^{c}	3.27 ± 0.27^{b}	13.10 ± 0.33^{d}	1.26 ± 0.02^{a}	0.43 ± 0.01^{b}	0.36 ± 0.01	106.60 ± 2.03^{g}	313.05 ± 0.47^{h}	1.66 ± 0.06^{d}
Durum wheat	59.71 ± 0.83^{bc}	3.12 ± 0.21^{bc}	16.20 ± 0.16^{b}	1.26 ± 0.01^{a}	0.40 ± 0.01^{c}	0.37 ± 0.03	122.36 ± 3.97^{e}	351.44 ± 4.09^{g}	1.38 ± 0.16^{d}
Hull-less barley	52.53 ± 1.18^{de}	2.44 ± 0.10^{d}	10.85 ± 0.54^{f}	1.18 ± 0.09^{a}	0.40 ± 0.01^{c}	0.40 ± 0.01	175.03 ± 1.46^{c}	422.94 ± 0.37^{d}	2.43 ± 0.01^{b}
Hulled barley	48.68 ± 1.37^{e}	2.86 ± 0.05^{c}	6.68 ± 0.02^{g}	1.10 ± 0.02^{a}	0.35 ± 0.01^{d}	0.35 ± 0.04	179.44 ± 0.96^{b}	466.33 ± 5.55^{b}	3.43 ± 0.04^{a}
Triticale	56.28 ± 6.64^{cd}	2.46 ± 0.02^{d}	12.97 ± 0.07^{d}	1.19 ± 0.10^{a}	0.25 ± 0.01^{e}	0.34 ± 0.01	215.22 ± 0.67^{a}	498.81 ± 3.58^{a}	3.41 ± 0.26^{a}
Millet	56.15 ± 1.41^{cd}	2.10 ± 0.06^{e}	11.70 ± 0.36^{e}	1.27 ± 0.01^{a}	0.51 ± 0.01^{a}	0.31 ± 0.03	125.50 ± 0.37^{e}	409.68 ± 4.81^{e}	3.23 ± 0.17^{a}
Sorghum	64.02 ± 1.77^{b}	3.62 ± 0.27^{a}	13.78 ± 0.28^{c}	1.19 ± 0.10^{a}	0.40 ± 0.01^{c}	0.39 ± 0.02	164.85 ± 3.61^{d}	443.38 ± 5.59^{c}	2.71 ± 0.06^{b}

Values are means of three replicates ± standard deviation. Values in the same column followed by different superscripts are significantly different (P ≤ 0.05). RTWAI: room temperature water absorption index; HTWAI: high temperature water absorption index.

Table 4. **Chemical composition of the flakes produced from various cereal grains**

Таблица 4. **Химический состав различных цельнозерновых хлопьев**

Flake samples	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Crude fiber (%)	Carbohydrate content (%)	Energy (Kcal)
Commercial oat	8.53 ± 0.23^{a}	13.89 ± 0.02^{a}	6.22 ± 0.03^{a}	2.13 ± 0.01^{a}	1.70 ± 0.02^{e}	76.06 ± 0.63^{h}	416.43 ± 1.13^{b}
Oat	7.88 ± 0.08^{b}	12.98 ± 0.09^{c}	5.45 ± 0.06^{c}	1.78 ± 0.06^{b}	2.41 ± 0.03^{bc}	77.38 ± 0.04^{g}	408.53 ± 0.73^{c}
Soft wheat	5.39 ± 0.19^{d}	10.46 ± 0.10^{f}	1.84 ± 0.04^{e}	1.53 ± 0.06^{c}	2.17 ± 0.07^{d}	84.01 ± 0.05^{b}	393.75 ± 0.80^{e}
Durum wheat	5.28 ± 0.09^{d}	11.92 ± 0.20^{d}	1.77 ± 0.09^{ef}	1.64 ± 0.09^{bc}	2.24 ± 0.02^{cd}	82.42 ± 0.05^{d}	393.09 ± 0.11^{e}
Hull-less barley	4.97 ± 0.04^{e}	10.20 ± 0.12^{f}	1.55 ± 0.08^{g}	1.78 ± 0.04^{b}	1.69 ± 0.11^{e}	84.78 ± 0.10^{a}	394.31 ± 0.04^{e}
Hulled barley	5.29 ± 0.05^{c}	11.67 ± 0.05^{d}	1.75 ± 0.01^{ef}	2.08 ± 0.15^{a}	1.83 ± 0.02^{e}	82.67 ± 0.11^{c}	394.41 ± 0.61^{e}
Triticale	4.87 ± 0.14^{e}	13.46 ± 0.04^{b}	1.70 ± 0.03^{f}	2.26 ± 0.13^{a}	3.36 ± 0.23^{a}	79.22 ± 0.16^{f}	386.43 ± 1.15^{f}
Millet	4.36 ± 0.01^{f}	10.73 ± 0.18^{e}	5.81 ± 0.04^{b}	1.76 ± 0.07^{b}	2.33 ± 0.02^{cd}	79.37 ± 0.18^{f}	418.33 ± 0.07^{a}
Sorghum	4.57 ± 0.08^{f}	10.23 ± 0.11^{f}	3.52 ± 0.10^{d}	1.60 ± 0.03^{bc}	2.56 ± 0.07^{b}	82.09 ± 0.11^{e}	399.92 ± 0.55^{d}

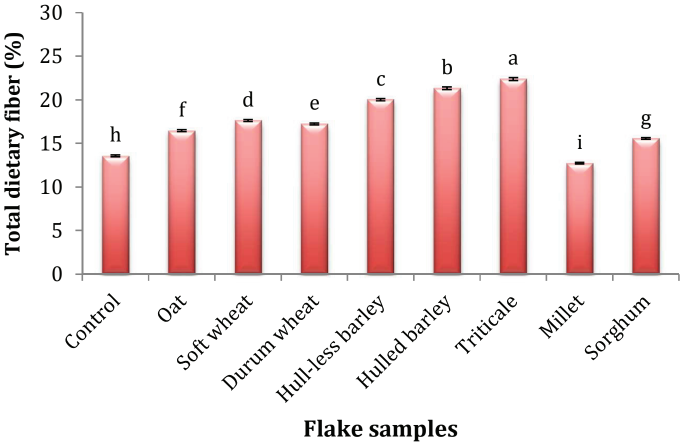
Values are means of three replicates ± standard deviation, values in the same column followed by different superscripts are significantly different (p ≤ 0.05). Carbohydrates content was calculated by difference.

and ranged from 76.06% in commercial oat flakes to 84.78% in hull-less barley flakes. It was observed that all the flake samples exhibited significantly lower protein, fat, ash and crude fiber (Table 4) than the native grains (Table 1) which could be due to the processing treatment used for flakes production [47,48]. The lower fat content of flakes compared to grains was attributed to the amylose-lipid complex formation which has lower extractability [49].

The calculated energy values of flakes are shown in the Table 4 and they ranged from (418.33 kcal) in millet to (386.43 kcal) in triticale. From the above results, it could be concluded that triticale, durum wheat, and hulled barley are the good cereals to prepare the flakes of high characteristics, as they have high protein and ash contents, low fat and low calories content.

The content of total dietary fiber in the flake samples is shown in the Figure 2. Previous studies indicated that ready-to-eat cereal consumption may increase fiber intake and lead to a high nutritional quality of the whole diet [50]. The obtained results indicated that triticale, hulled barley and hull-less barley flakes have higher contents of TDF among all flake samples (22.38, 21.33 and 20.01%, respectively). Meanwhile, millet, commercial oat and sorghum flakes have less TDF contents (12.72, 13.57 and 15.55%, respectively) compared to other flake samples. These results were in agreement with the reported result of Prasad and Joye [9].

The mineral contents of flakes from various cereal grains were determined and are shown in the Table 5. There was a wide range of mineral contents in various cereal flakes.



Data are expressed as means ± standard deviation and the different letters are significantly different at 0.05 level.

Figure 2. **The total dietary fiber content of the produced cereal flakes. Control: commercial oat flakes**

Рисунок 2. **Общее содержание пищевых волокон в произведенных зерновых хлопьях. Контрольный образец: покупной овес**

Table 5. **Mineral contents (mg/100g) and RDA* (mg/day) of the produced cereal flakes**

Таблица 5. **Содержание минеральных веществ (мг/100 г) и рекомендуемая суточная норма потребления* (мг/день) в произведенных зерновых хлопьях**

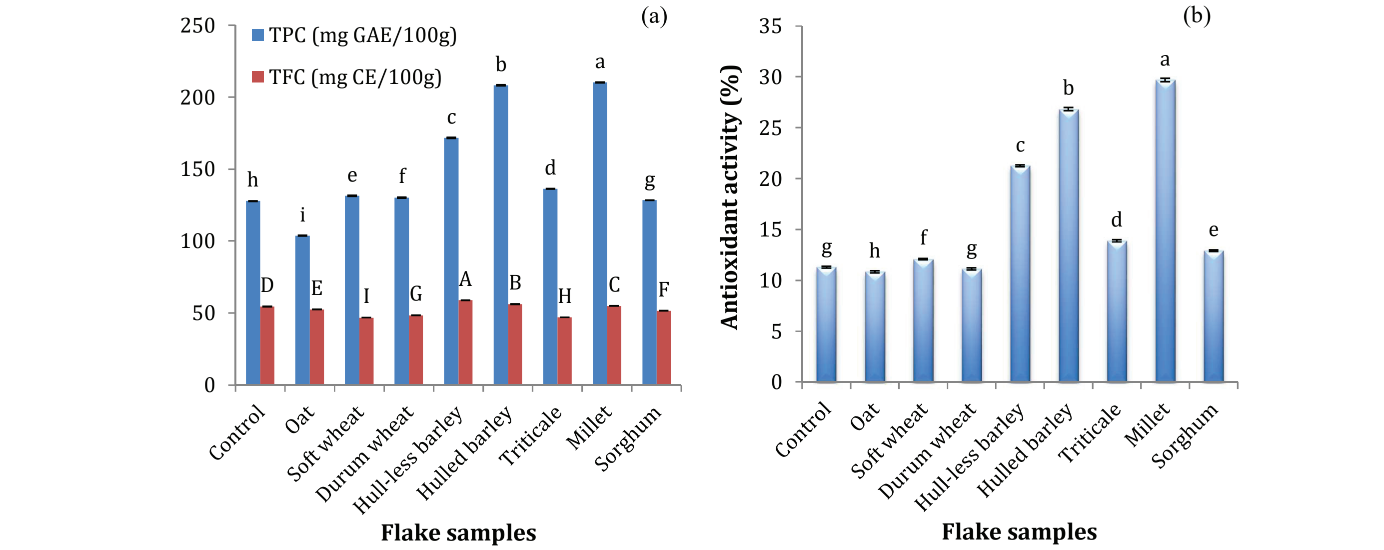
Flake samples	Mineral contents (mg/100g)						
	Macroelements				Microelements		
	Mg	K	P	Ca	Mn	Zn	Fe
Commercial oat	118	210	370	48	3.5	2.1	3.9
Oat	138	196	380	49	3.62	1.8	3.8
Soft wheat	85	365	290	39	3.2	3.1	2.9
Durum wheat	95	220	185	27	4.32	2.7	2.6
Hull-less barley	96	380	260	41	2.0	2.26	4.7
Hulled barley	102	330	275	45	2.2	2.17	5.1
Triticale	93	390	360	64	2.4	2.9	3.4
Millet	128	260	286	37	2.80	4.8	5.7
Sorghum	120	370	352	16	1.50	2.7	4.2
RDA*	320^{f}-420^{m}	---	$700^{f,m}$	$1000^{f,m}$	---	8^{f}-11^{m}	8^{m}-18^{f}

*RDA: Recommended Dietary Allowance (mg/day) according to DGA (2020–2025) [51]. The superscripts (^{f} and ^{m}) is the RDA for females and males, respectively.

Among all flake samples, oat had the highest Mg and P content, durum wheat showed highest Mn content, triticale had the highest K and Ca content, and millet had the highest level of Zn and Fe. The results of the present study are consistent with other previous works [10,22].

Dietary intakes of minerals in flakes were estimated and compared with the Recommended Dietary Allowance of daily (RDA) values for adult females and males aged 31–50 (Table 5). Comparing the RDA macroelements and microelements, it could be concluded that most cereal flakes (100 g) contribute more than 24–43% for males and females, respectively of the Mg RDA. Furthermore, all the produced flakes except durum wheat can supply around 40–55% of the phosphorous RDA. Additionally, about 44–60% (for males and females, respectively) of the Zn RDA can be obtained by 100 g of millet flakes. Concerning the iron content, 100 g of millet, hulled and hull-less barley could provide about 50% of RDA of iron.

Generally, whole grains contain various phytochemicals depending on the cereal type and how the grains have been processed [7]. Phytochemical properties such as total phenolic content (TPC), total flavonoid content (TFC) and antioxidant activity (DPPH) of flake samples are shown in the Figure 3. According to Nani et al. [52], phenolic compounds (phenolic acids and flavonoids) in whole grains have an immunosuppressive effect that can be used as dietary supplements for autoimmune disease treatment. Beneficially, it is better to consume whole grains or



Data are expressed as means ± standard deviation and the different letters are significantly different at 0.05 level.

Figure 3. **Phytochemical properties of the produced cereal flakes. Control: commercial oat flakes. (a): TPC and TFC and (b): Antioxidant activity of flake samples**

Рисунок 3. **Фитохимические свойства произведенных зерновых хлопьев. Контрольный образец: покупной овес. (a): TPC (общее содержание фенолов) и TFC (общее содержание флавоноидов), и (b): Антиоксидантная активность образцов хлопьев** bran because phenolic compounds are not equally distributed in the grain but are mainly found in the pericarp [53]. Concerning the TPC, there was differentiation among all flake samples and it varied from 103.77 mg GAE/100g for oat flakes to 210.20 mg GAE/100 g for millet flakes. Hull-less barley flakes contained the highest value (58.86 mg CE/100 g) of TFC while the soft wheat had the lowest value (46.81 mg CE/100 g).

The DPPH method is efficiently used to determine the antioxidant activity [54]. The antioxidant activity of the flake samples was detected by the evaluation of the free radical scavenging effect on the 1.1-diphenyl-2-picrylhydrazyl (DPPH) radical. The results revealed that the antioxidant activity of various flakes was ranged from 10.83% for oat flakes to 29.70% for millet. Also, the results showed that all flake samples except durum wheat had higher antioxidant activity values compared to both commercial oat and oat flakes as control samples.

4. Conclusion

Whole grain products are considered as health-beneficial ingredients that should be consumed regularly. They contain flavor-active compounds and cell wall structures which may affect the flavor and texture attributes as well as the consumers' acceptance. Concerning the nutritional quality of the produced cereal flakes, they have various contents of minerals and phytochemicals. Oat flakes have higher Mg and P content, durum wheat show higher Mn content, triticale has the highest K and Ca content, and millet has the highest level of Zn and Fe. Triticale flakes has significantly higher dietary fibers and water absorption index compared with the other flakes. The sensory characteristics of all the produced flake samples in the present study are favorably accepted with more than 87% acceptability index. Wheat, barley, triticale, millet and sorghum grains could be used as oat alternatives to produce promoting, functional and ready-to-eat cereal flakes with various characteristics. Fortunately, millet and sorghum flakes are functionally gluten-free alternatives to the oat flakes.

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