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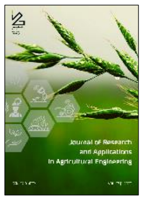

# Cultivation and Technological Value of Pseudocereals – Nutritional and Functional Aspect in the Context of a Gluten-free Diet

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Nowadays, consumers are more aware of what they eat and therefore start demanding from the food market. Paying attention to gluten-free products. For this reason, pseudocereals such as buckwheat, quinoa, amaranth or chia seeds have been noticed. They have good nutritional value and nutraceutical properties. Among other things, they are a good source of starch, fiber, proteins, minerals, vitamins, and phytochemicals such as saponins, polyphenols, phytosterols, phytosteroids, and betalains with potential health benefits. The plant is said to have a beneficial effect on improving health and supporting treatment in the case of disorders of the blood lipid profile, as well as hypoglycemic and anti-cancer effects. This review aims to characterize, in terms of nutritional and functional, three pseudocereals, i.e. buckwheat, quinoa and chia seeds.



## 1. Introduction

For many years, cereals have been an essential and basic element of the human diet [1]. Over time, attention began to be paid to the pseudocereals. They include: common buckwheat Fagopyrum esculetum Moench, Tartary buckwheat Fagopyrum tataricum (L.) Gaertin, horse amaranth Amaranthus hypochondriacus, quinoa Chenopodium quinoa, Spanish sage Salvia hispanica, Celosia argentea silver celosia [2].

Buckwheat (Fagopyrum esculentum Moench) has been cultivated for centuries because of its grains and greens, which are to be used, inter alia, in as food, feed. The origin of buckwheat is Central Asia. In the 13th century, it was transferred to Europe (Austria, Germany, Italy) through nomadic peoples. Although in the 20th century it was neglected in Western countries due to the increased wheat harvest during the Green Revolution. In the case of amaranth and quinoa, they were the two main crops in Latin America in pre-Columbian cultures. By contrast, cultivation and consumption were suppressed after the Spanish rebound. It was only in the mid-90s that the nutritional properties of pseudocereals were appreciated. Suitability for gluten-free products in particular [1, 3].

Pseudocereals are not grasses (Poaceae) and do not have to be closely related to each other, and which share the production of grain-like, starch-rich seeds [4]. They are described in the literature as "21st century grains" because of their excellent nutritional value. The interest in this raw material on the market is increasing for several reasons. First of all, they are not a source of

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gluten, but are rich in starch, protein and fiber. The amino acid profile is characterized by a high content of sulfur-rich amino acids. They are a good source of vitamins, minerals (i.e. calcium, zinc, iron) as well as phytochemicals (saponins, polyphenols, phytosteroids, phytosterols, betalain), i.e. compounds with potentially beneficial health-promoting properties [5]. The content of minerals in pseudocereals is about twice as high as in other grains, which have great potential to solve the hidden problem of hunger. In addition, pseudocereals are also rich in fatty acids, compared to cereals. This is especially related to unsaturated fatty acids, namely linolenic acid [3].

In addition to these health-related motivations, consumers also pay attention to environmental aspects. Climate change is an incentive for many people to reconsider their behavior and food choices. Nutrition, and to be more precise agricultural production, has a big impact on climate change. However, they can also be viewed in another way: the effects of climate change on agricultural production are becoming increasingly apparent in many regions around the world. One of the elements helping to address some of these disadvantages is the increase in biodiversity in agriculture [6].

In Western countries, there is a growing interest in sprouts, and thus in the process of seed germination. Because soaking and germination of seeds are traditional and the most effective treatments enhancing the bioactive and nutritional potential. As well as reducing the content of anti-nutrients in the raw material. This is because consumers are demanding minimally processed, additive-free, more natural, nutritious foods [7, 8].

This review focuses on the nutritional and functional characterization of the three pseudocereals, i.e. buckwheat, quinoa and chia seeds.

## 2. Botanical characteristics

From a botanical point of view, pseudocereals are dicotyledons. The high content of starch and the lack of gluten in the seeds influenced their use similarly to traditional cereals. Most of them give a high yield and have the ability to adapt to demanding environmental conditions [1, 9, 10]. Table 1 presents the botanical classification of selected pseudocereals.

Tab. 1. Botanical classification of selected pseudocereals [11,14,16]

| **Class** | Dicotyledoneae | | | | |
|---|---|---|---|---|---|
| **Subclass** | Caryophyllidae | | | | Asteridae |
| **Order** | Caryophyllales | | | Polygonales | Lamiales |
| **Family** | Amaranthaceae | | Chenopodiaceae | Polygonaceae | Lamiaceae |
| **Genus** | Amaranthus | Celosia | Chenopodium | Fagopyrum | *Salvia* |
| **Species** | at least 60 species, e.g.:<br>*A. caudatus*<br>*A. cruentus*<br>*A. hypochondriacus* | *C. argentea* | more than 250 species, e.g.:<br>*Ch. quinoa* WILLD. (quinoa)<br>*Ch. pallidicaule* AELLEN<br>(kanigua, canihua)<br>*Ch. nuttalia* SAFFORD | *F. tartaricum*<br>(bitter buckwheat)<br>*F. esculentum* Moench<br>(sweet buckwheat) | *S. hispanica* |

### 2.1. Buckwheat (Fagopyrum)

Buckwheat belongs to the knotweed family, or Polygonaceae; dicotyledonous class. It is included in the so-called secondary plants. This means that it was extracted from weeds found in other crops (such as oats). It includes 15 species growing in the temperate climate of Europe and Asia. On the other hand, there are mainly two species grown in the world, namely Fagopyrum esculentum Moench (common buckwheat) and Fagopyrum tataricum (L.) Gaertin (Tartary buckwheat) [11, 12].

The root system of the aforementioned pseudocereal is formed by a tap root that reaches 1 meter into the soil and lateral roots of the second and third row. It is worth noting that the buckwheat roots begin to brown quickly, which is a symptom of their aging. The reason for this is limited nutrient uptake. It may also indirectly influence the Fagopyrum yield. The buckwheat stalk is branched and can reach 60 to 100 cm in height. Its color is influenced by the anthocyanins contained in the raw material. Leaves are heart-sagittate, upper sessile, lower petiole. The flowers, on the other hand, are white, pale pink or red. Collected in loose clusters or umbels. One plant is capable of producing 500–2000 flowers. However, only 4–10% develop seeds. The buckwheat fruit is a dark brown, triangular nut with sharp edges [11, 12].

### 2.2. Quinoa (Chenopodium quinoa Willd.)

Quinoa (Chenopodium quinoa Willd.) also known as Peruvian rice or quinoa. It is a plant belonging to the Chenopodiaceae (quinoa) or Amaranthaceae family [13]. The Chenopodiaceae family includes over 100 diverse species. It is an annual, green plant. However, we distinguish 300 of its cultivation forms, which differ in the colour of the seeds and the plant itself. It can have various shades of green, but it can be red or purple. It depends, inter alia, on environmental conditions (humidity) and species characteristics. It can be described as steppe and / or desert flora, or it can cover sea coasts. This pseudo-cereal can be grown at high altitudes. In difficult soil and climatic conditions. Peruvian rice plants show a high tolerance to salinity, frost, drought and have the ability to grow in marginal soils [14, 15].

The root of Peruvian rice reaches a depth of up to 60 cm. It is a tap root with numerous side roots. The stem is cylindrical in shape. As it matures, the stem becomes hollow. This is especially true of the lower parts on the ground. It should be noted that the number of above-ground shoots depends, inter alia, on the growing conditions. It is also believed to be a varietal trait. The plant can reach a height of 20 cm to 2 m. The lower leaves are usually larger and coarsely serrated, and those higher up are usually smaller, finer, lanceolate in shape. The fruit is the so-called nut. It is a disc-shaped, flattened ball. The seeds, as well as the leaves, may have different colors (white, red, black) [14].

### 2.3. Chia (Salvia hispanica)

Chia grows naturally in tropical and subtropical environments. The optimal height above sea level for this raw material to grow is 400 to 2500 m. However, the conditions below 200 m above sea level are not conducive to its cultivation. The optimal temperature range for the growth of this raw material is 16–26 °C. And the minimum and maximum temperatures are 11 °C and 36 °C respectively. It is considered a short-day plant and its growth and fruiting period depends on the latitude it grows at. For this reason, it begins flowering in the southern hemisphere in April and in the northern hemisphere in October. At latitudes such as 39° 11'S, 32° 14'N, the plant cannot produce seeds because it is being killed by frost (even before flowering). Chia thrives well in sandy loam and loamy loam soils with good drainage conditions [16–18].

Salvia hispanica can reach 1 meter in height. The leaves are serrated and arranged opposite to each other. They are 3–5 centimeters wide and 4–8 centimeters long. The flowers, on the other hand, are two-sexed; size 3–4 mm, they are located at the ends of the shoots, growing in whorls. After flowering, chia forms round fruits, which consist of oval seeds 1 mm wide and 2 mm long. Their surface is shiny and smooth. The color, on the other hand, ranges from white through gray to brown (with irregularly arranged black spots) [16].

## 3. Growing conditions

### 3.1. Buckwheat (Fagopyrum)

Fagopyrum tataricum (L.) Gaertin and Fagopyrum esculentum Moench are the most cultivated and consumed species in the world. In 2020, the global production of buckwheat amounted to over 1.8 million tonnes. The leading countries in the production of this pseudo-camp are China, Russia, France, Ukraine, Poland, USA, Kazakhstan [19–21].

One plant is capable of producing 500–2000 flowers. However, only 4–10% develop seeds. It is mainly influenced by the correctness of agrotechnics, weather conditions during vegetation (especially during flowering), as well as varietal properties. Fagopyrum esculentum Moench, i.e. common buckwheat, is particularly sensitive to climatic factors, sunlight, sowing date, local agrotechnical practices (which affects the seed yield). Buckwheat is pollinated mainly by bees (only partially by the wind). It is a thermophilic plant that prefers sunny positions. The optimal temperature for germination is 15 °C, while 20 °C is the temperature for growth. It should be mentioned here that it is sensitive to frost. It reacts unfavourably to prolonged droughts as well as strong winds. It yields best on wheat complex soils with regulated air-water ratios, as well as with a pH of 5.6-7 [11, 12].

It is sown when the soil is properly warmed up. It is important that the likelihood of frost is no longer present. Sowing is done at a depth of 2–3 cm, on better and moist soils. On weak and very dry soils, however, 4–5 cm. Rows should be in the range of 15–45 cm. The amount of sowing depends, among other things, on the quality of the soil. On better soils, the sowing rate per area is 70 kg/ha. On the other hand, on worse soils, 80 kg/ha. When sowing takes place at a delayed date, the amount of sown seeds should be increased by 10 kg/ha. The most favorable time for this process is May 15–25. Flowering time is from July to August [11].

There are several objectives that are important in the case of the common cultivation of this raw material: the highest quality of seeds, stable yield, easy hulling, resistance to lodging, low seed grinding, high content of rutin, resistance to excess water in the environment, low content of allergenic proteins, resistance to pre-harvest germination and beneficial sensory values [22].

### 3.2. Quinoa (Chenopodium quinoa Willd.)

It has been cultivated in South America for almost 5,000 years. Quinoa is also referred to as "the sacred grain of the Incas, the golden grain of the Incas and the mother of the grains." It was the staple food of the Inca who inhabited the mountain areas [13]. From the 20th century it began to be cultivated in Europe, Africa, Asia and North America. In 2020, world production amounted to 175,188 thousand tonnes [19, 23].

Interest in the cultivation of Peruvian rice has increased due to its ability to adapt to various environmental conditions. The consequence of such flexibility are response mechanisms and adaptive strategies created by quinoa, such as physiological (growth regulation), morphological (phenotypic flexibility), molecular (activating stress proteins), which in turn lead to changes in the compounds contained in the raw material [15, 24]

The growing season does not exceed 150 days (between late spring and early autumn frosts). Yields can reach 1.5 t / ha. The indicated amount is the yield size without fertilization [14].

### 3.3. Chia (Salvia hispanica)

Chia is currently grown in countries such as Australia, Bolivia, Guatemala, Colombia, Mexico, Argentina and Peru. It is worth noting that its largest production center is in Mexico, and the seeds are transported to the USA, Japan and European countries. In European countries it is also grown in greenhouses [16, 17].

The reported yield of seeds from selected commercial fields located in Argentina and Colombia ranges from 450 to 1250 kg/ha. However, the yield can be even greater than 2000 kg/ha, provided favorable experimental conditions [16].

## 4. Nutritional value

Pseudocereals are attracting more and more attention as raw materials that improve the nutritional value of, for example, a gluten-free diet [25]. Table 2 presents information related to the nutritional value of buckwheat, quinoa and chia seeds.

Tab. 2. Nutritional value of selected pesudoceral grains based on USDA [52–54]

| Nutrient | Pseudoceral | | |
|---|---|---|---|
| | Buckwheat | Quinoa | Chia |
| **Energy** | 335 kcal / 1440kJ | 368 kcal/ 1540kJ | 486mkcal / 2030 kJ |
| **Protein** | 12.6 g | 14.1 g | 16.5 g |
| **Total lipid** | 3.1 g | 6.07 g | 30.7 g |
| **Ash** | 2.54 g | 2.38 g | 4.8 g |
| **Carbohydrate** | 70.6 g | 64.2 g | 42.1 g |
| **Dietary fibre** | 10g | 7 g | 34.4 g |
| **Calcium** | 41 mg | 47 mg | 631 mg |
| **Iron** | 4.06 mg | 4.57 mg | 7.72 mg |
| **Magnesium** | 251 mg | 197 mg | 335 mg |
| **Phosphorus** | 337 mg | 457 mg | 860 mg |
| **Potassium** | 577 mg | 563 mg | 407 mg |
| **Zinc** | 3.12 mg | 3.1 mg | 407 mg |
| **Copper** | 0.515 mg | 0.59 mg | 4.58 mg |
| **Manganese** | 2.03 mg | 2.03 mg | 2.72 mg |
| **Vitamin C** | 0 mg | n.e. | 1.6 mg |
| **Thiamine** | 0.417 mg | 0.36 mg | 0.62 mg |
| **Riboflavin** | 0.19 mg | 0.318 mg | 0.17 mg |
| **Niacin** | 6.15 mg | 1.52 mg | 8.83 mg |
| **Vitamin E (alpha-tocopherol)** | 0.32 mg | 0 mg | 0.5 mg |
| **Folate** | 54 µg | 184 µg | 49 µg |

Among the presented pseudocereals, differences in the content of individual ingredients can be noticed. Chia seeds had the highest energy value, while buckwheat had the lowest. Differences are also noticed in the content of macronutrients. In the case of protein and fat, chia seeds also have the highest content among the seeds presented. The opposite situation is noticed in the case of carbohydrates, of which buckwheat is the largest.

The content of individual minerals and vitamins varies between pseudocereals. However, it should be noted that chia seeds are high in calcium. The publication by Niro et al. 2019 on gluten-free grain alternatives evaluated the nutritional value and bioactive compounds. In nine types of cereals and pseudo-cereals, the content of compounds, i.e. riboflavin, thiamine, and tocols (tocopherols and tocotrienols) was determined. It was shown that the analyzed samples were characterized by a high content of bioactive compounds. Particularly noteworthy were amaranth and quinoa, which are good sources of vitamin E. Chia seeds had a content of approx. 14 mg/100 g, and quinoa, on average 9.1 mg/100g DM. On the other hand, amaranth showed the lowest content of tocols, 6 mg/100 mg. In the case of chia and quinoa, the dominant isomer was γ-tocopherol (94%, 69% and 64% of all tocols). And in the case of amaranth, the dominant isomer is β-tocopherol, which makes up 54% of all tocols [26].

## 5. Bioactive ingredients

Bioactive compounds are non-nutritional plant components with health benefits. In pseudocereal grains, they include saponins, phytosterols, polysaccharides, betalains, bioactive proteins and peptides [27].

### 5.1. Fatty acids

The content of individual fatty acids is presented in Table 3. Chia seeds had the lowest content of saturated acids and the highest polyenic acids. Among the presented cereal grains, buckwheat seeds contained the highest content of monoenoic acids. Chia seeds are higher in omega-3 than flaxseeds [16].

Tab. 3. A comparison of fatty acid profile of selected pesudoceral grains [29, 55, 56]

| Fatty acids | Pseudoceral | | |
|---|---|---|---|
| | **Buckwheat** *Fagoopyrum esculentum* **Moench** | **Quinoa** | **Chia** |
| **Saturated** | | | |
| **12:0** | n.e. | n.e. | n.e. |
| **14:0** | 0.14±0.01 | 0.13±0.01 | 0.06±0.01 |
| **15:0** | n.e. | n.e. | 0.04±0.01 |
| **16:0** | 16.56±0.03 | 8.25±0.12 | 7.1±0.05 |
| **17:0** | 0.31±0.01 | n.e. | 0.06±0.01 |
| **18:0** | 2.24±0.02 | 0.64±0.03 | 3.24±0.08 |
| **20:0** | 1.87±0.01 | 0.56±0.01 | 0.24±0.06 |
| **22:0** | n.e. | 0.98±0.01 | 0.08±0.01 |
| **24:0** | n.e. | 0.46±0.01 | 0.10±0.01 |
| **Monoenoic** | | | |
| **16:1** | 0.40±0.02 | n.e. | 0.20±0.01 |
| **17:1** | 0.09±0.01 | n.e. | n.e. |
| **18:1** | 39.95±0.1 | 23.15±0.07 | 10.53±0.17 |
| **20:1** | 4.18±0.02 | 1.75±0.02 | 0.16±0.01 |
| **24:1** | n.e. | 0.22±0.12 | n.e. |
| **Polyenic** | | | |
| **18:2** | 32.16±0.11 | 51.88±0.1 | 20.37±0.19 |
| **18:3 n-6** | n.e. | n.e. | 0.27±0.02 |
| **18:3 n-3** | 1.64±0.05 | 8.35±0.7 | 59.76±0.13 |
| **20:2** | n.e. | 0.16±0.01 | 0.07±0.01 |
| **Summary** | | | |
| **Saturated** | 21.12 | 11.02 | 10.92 |
| **Monoenoic** | 44.62 | 25.12 | 10.89 |
| **Polyenic** | 33.8 | 60.39 | 80.47 |

*The values in the table are given as a percentage; "±" means standard deviation; (n.e., not evaluated)*

### 5.2. Amino acids

Pseudocereals, like cereals, are the source of a number of amino acids, which are listed in Table 4. Chia seeds were characterized by the highest content of amino acids among the pseudocereals presented.

The analysis of the amino acid composition indicated that chia, buckwheat and quinoa seeds are the source of 10 exogenous amino acids. Among which, in the case of chia, the highest content was leucine, arginine, phenylalanine, valine and lysine. It is worth mentioning that chia seeds, as well as buckwheat and quinoa, are a source of endogenous amino acids. Buckwheat has a balanced amino acid profile. Buckwheat protein is one of the richest in the amino acid lysine and arginine. Buckwheat protein amino acid score is 100, which is the highest among plant sources. Quinoa grain is also considered a complete protein. This is because it contains all nine essential amino acids that the human body cannot produce on its own. As well as high in lysine compared to other grains [3, 16].

Tab. 4. A comparison of amino acid profile of selected pesudoceral grains based on USDA [52–54]

| *Amino acids* | *Pseudoceral* | | |
|---|---|---|---|
| | **Buckwheat** *Fagoopyrum esculentum* **Moench** | **Quinoa** | **Chia** |
| **Tryptophan** | 0.183g | 0.167g | 0.436g |
| **Theronine** | 0.482g | 0.421g | 0.709g |
| **Isoleucine** | 0.474g | 0.504g | 0.801g |
| **Leucine** | 0,792 | 0.84g | 1.37g |
| **Lysine** | 0.64g | 0.766g | 0.97g |
| **Methionine + Cysteine** | 0.382g | 0.512g | 0.995g |
| **Phenylalanine + Tyrosine** | 0.725g | 0.86g | 1.583g |
| **Valine** | 0.646g | 0.594g | 0.95g |
| **Arginine** | 0.935g | 1.09g | 2.14g |
| **Histidine** | 0.294g | 0.407g | 0.531g |
| **Alanine** | 0.712g | 0.588g | 1.04g |
| **Aspartic acid** | 1.08g | 1.13g | 1.69g |
| **Glutamic acid** | 1.95g | 1.86g | 3.5g |
| **Glycine** | 0.981g | 0.694g | 0.943g |
| **Proline** | 0.482g | 0.773g | 0.776g |
| **Serine** | 0.652g | 0.567g | 1.05g |
| **Sum of amino acids** | 11.41 | 11.77g | 19.48g |

### 5.3. Phytosterols

Phytosterols belong to the triterpenoids family, which is similar in structure to cholesterol. The 27–30 carbon ring with hydroxyl groups includes the chemical structure. They can be found in four different forms: free sterols, steryl esters of fatty and phenolic acids, steryl glycosides, and acylated steryl glycosides. Quinoa and buckwheat are rich in Δ5-sterols, i.e. beta-sitosterol, stigmasterol and campesterol. It is worth noting that the first compound accounts for 60–70% of the total phytosterol content. Referring to the health benefits resulting from the presence of the indicated compounds, in a study by Rideout et al. 2015 they confirmed the effect of phytosterols in reducing triglycerides in healthy patients. But also with hypertriglyceridemia and in this case the effect was stronger [5, 28]. On the other hand, a study on chia seeds showed the presence of campesterol, stigmaterol, Δ5-avenasterol and beta sitosterol in them [29].

### 5.4. Polyphenols

Phenolic compounds have attracted a lot of attention in recent years, mainly due to their health benefits. Buckwheat is considered to be the best source of phenolic compounds among pseudocereals (275.5-532.0 mg gallic acid equivalent/100 g DM). Nutraceutical properties of buckwheat are identified with the presence of flavonoids, i.e. rutin, quercetin, quercitrin, orientin, homoorientin, vitexin and isovitexin. It is worth mentioning that the common buckwheat showed a lower concentration of rutin (0.2 mg / g dm) compared to Tartary buckwheat (8.1 mg/g dm). In the case of phenolic compounds from Peruvian rice, it is in the range 167.2 to 308.3 mg gallic acid equivalents/100 g DM, in free form. Flavonoids are the second most abundant phenolic group in quinoa seeds are rutin, quercetin, kaempferol derivatives present mainly in the free fraction [5, 30–32].

Salvia hispanica seeds are also a rich source of phytochemicals characterized by high biological activity. We can distinguish here, in particular, polyphenols, i.e. gallic acid, chlorogenic acid, cinnamic acid, ferulic acid. quercetin, kaempferol, epicatechin, rutin, apigenin, and p-coumaric acid. Isoflavones such as daidzein, glycitein, genistein, and genistin are present in small amounts [16].

## 6. Functional properties

Celiac disease is a chronic systemic autoimmune disorder. It occurs in genetically predisposed people. It can be triggered by gluten exposure in the diet and, consequently, lead to the disappearance of the villi and the growth of the intestinal crypts. Celiac disease affects about 1% of the world's population. It is worth noting, however, that it often goes undiagnosed. This disorder is characterized by an abnormal immune response. It consists in an excessive response of the immune system to the group of cereal proteins, prolamines (gliadin, secalin, avenin, hordein). It has been shown that following a gluten-free diet can lead to nutritional imbalance, as well as a deficiency of certain vitamins and minerals. Deficiencies can result from malabsorption (at the intestinal level) and a diet that relies heavily on rice and corn [33–36]. This creates a field for enriching the gluten-free diet with pseudocereals. A study by Alvarez-Jubete et al. evaluated pseudocereals and gluten-free breads containing pseudocereals for protein, fat, dietary fiber, total starch, ash, minerals and fatty acid composition. The results indicated that the bread containing pseudocereals showed a significantly higher level of protein, fat, fiber, as well as minerals than the control bread. It has been shown that buckwheat and quinoa can be an alternative to traditional gluten-free products [9].

The consumption of pseudocereals is associated with benefits in the fight against obesity, complications related to diabetes and prediabetes. In a study by Mithil et al. 2015 a diet based on amaranth protein was found to reduce food intake and body weight. By lowering the level of ghrelin in rat plasma. However, an increase in the postprandial levels of cholecystokinin and leptin was also noticed. Additionally, in the study by Olguín Calderón et al. 2019 indicated that the diet with amaranth proteins changed the microbiota in obese mice. The results indicate that this action may be one of the mechanisms of the beneficial effects of amaranth on health [37, 38].

In a study by Marineli et al. 2015 the influence of consumed chia seeds on selected indicators of carbohydrate metabolism was assessed. The rats in the experiment ate a high-fat and high-fructose diet. In which soybean oil was replaced with 13.3% addition of chia seeds (w/w), which, compared to the control diet, were characterized by greater insulin and glucose tolerance. Reduced levels of non-esterified fatty acids (NEFA) in the blood were noted in the group of animals consuming chia seeds. It is worth mentioning that these are not the only benefits that were observed in the group consuming chia seeds. There was a decrease in the level of markers of liver cell damage (aspartate transaminase and alanine transaminase). The high concentration of liver markers was due to the use of a high-fructose and high-fat diet [39].

Buckwheat is a source of antioxidant compounds (such as orientin, rutin, quercitin, vitexin, isoorientin, isovitexin, vitamins. Most of the ingredients have proved to be effective as active oxygen scavengers. It is worth noting that more and more attention is being paid to the therapeutic effect of diseases such as cancer, neurodegenerative diseases, diabetes. It is associated with bioactive compounds and with a well-balanced amino acid pattern [40]. It can also contribute significantly to the diet of people with cardiovascular problems. Because an increase in cholesterol consumption can increase oxidative stress and cholesterol levels. Such a condition may contribute to the development of chronic diseases, e.g. atherosclerosis. In a study in mice with hypercholesterolaemia, the effect of buckwheat protein was investigated. Plasma cholesterol levels were reduced to a greater extent than other grains. It also helped regulate the activity of liver cells responsible for high cholesterol [41, 42].

It has been shown that, in addition to the nutritional role of pseudocereal proteins, they exert their own biological properties and/or as a source of bioactive peptides, contributing to the reduction of LDL cholesterol in the plasma [43]. Bioactive peptides are inactive in the sequence of the parent protein from e.g. plants. Peptides may be released in the digestive tract after enzymatic or chemical hydrolysis, fermentation, or digestion. It is worth noting that peptides formed as a result of digestion in the gastrointestinal tract can act as regulatory compounds with a similar effect to hormones [44–47].

The number of studies using peptides isolated from chia is limited. It is noted that they show beneficial health effects. Chia seeds protein hydrolyzate produced in the enzymatic hydrolysis process with alcalase and/or flavourzyme, showed antibacterial activity. Rate-slowing enzyme of and 3 hydroxy-3-methylglutaryl coenzyme A reductase (HMG-CoA reductase) [47–49].

In the case of buckwheat, the effect associated with bioactive peptides is also noted. Mice fed a high-fat diet containing buckwheat proteins had significantly less cholesterol and triglycerides, lipopolysaccharides, interleukin 6, and tumor necrosis factor α than those fed a high-fat casein diet [50, 51].

## 7. Future perspectives

The development of methods to improve pseudocereal varieties through various breeding, biotechnology and agronomic practices to improve yields and climate resilience is making significant progress.It is worth noting that the formulas and technological processes improving the nutritional and technological properties of pseudocereals, without worsening the bioavailability of bioactive molecules, are necessary to increase them to gluten-free diets. Research on this topic could contribute to increasing the cultivation of pseudocereals in developed countries [5].

## 8. Summary

Quinoa, chia and buckwheat are pseudo-cereals that are gaining popularity among consumers and the scientific community around the world. In addition to their excellent nutritional profile, the lack of gluten in these pseudocereals has made them a good alternative to the development of gluten-free products that ensure adequate nutrient intake in celiac patients, whose numbers are increasing day by day.

Pseudocereals are the source of, among others bioactive compounds including saponins, phenolic compounds, phytosterols, bioactive proteins and peptides. These compounds are considered to be the main ones responsible for the beneficial effects of the human body. These compounds help promote human health and reduce the risk of various chronic disorders, including diabetes, cancer, cardiovascular disease and aging.

In addition, technological processes improving the technological and nutritional properties of pseudocereals, without worsening the bioavailability of bioactive molecules, are necessary to increase their incorporation into gluten-free foods. There are more and more publications and recipes regarding gluten-free cereals. What gives sick people the opportunity to learn new tastes and diversify their diet.

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