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REVIEW PAPER

Pseudocereals in a gluten-free diet

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Abstract

Gluten-containing food products cause allergic reactions and intolerance in sensitive individuals, i.e., celiac disease or gluten enteropathy. Celiac disease is a disease of the immune system in which gluten is recognized as a harmful agent. The only therapy for people sensitive to gluten is a gluten-free diet. Due to their gluten-free status and suitability for a gluten-free diet, pseudocereals have played a significant role. Their grains enhance nutritional quality and are nutrient-dense. Iron, magnesium, fiber, protein, and other nutrients are abundant in them. Buckwheat, amaranth, millet, and quinoa are the most significant pseudocereals. Due to their high nutritional content and lack of gluten, pseudocereals have become a staple of the gluten-free diet for those with gluten-related illnesses in recent years.

Keywords: pseudocereals, quinoa, millet, amaranth, buckwheat, gluten-free diet

1. INTRODUCTION

Gluten proteins are found in wheat, barley, oats, and rye. In sensitive individuals, gluten causes an allergic reaction and intolerance, i.e., celiac disease or gluten enteropathy (Balakireva & Zamyatnin 2016; Sharma et al. 2020). After consuming gluten grains, the organism is sensitized and produces IgE antibodies. An allergic reaction is often manifested by itching of the skin and the appearance of urticaria, redness, swelling of the lips and the area around the eyes, nausea, vomiting, spasms, secretion, and irritation of the nasal mucosa (rhinitis), and asthma (Majsiak et al. 2023).

Another reaction to gluten is called celiac disease or gluten enteropathy, i.e. gluten intolerance (Sergi, Villanacci, & Carroccio 2021; Sestak 2013). Celiac disease is a hereditary disease of the immune system in which gluten is recognized as a harmful agent, so when it is introduced into the body, a series of reactions are stimulated in which IgA and IgG antibodies are formed, and inflammation occurs in the small intestine. As a result of these inflammatory processes, the intestinal mucosa cells are destroyed and the intestinal villi necessary for the absorption and use of nutrients disappear (Ailioaie, Ailioaie, Litscher, & Chiran 2022; Caio et al. 2019).

This is why the destruction of the intestinal epithelium results in malabsorption (reduced absorption of nutrients into the bloodstream) and malnutrition (resulting in malnutrition). When gluten enteropathy is diagnosed, it lasts a lifetime (Montoro-Huguet, Belloc, & Domínguez-Cajal 2021). Therefore, therapy should be started immediately. No medicine would reduce inflammation and alleviate complications, but the complete treatment is based exclusively on a gluten-free diet (Aljada, Zohni, & El-Matary 2021; Francavilla et al. 2014).

As a result of malabsorption, due to the lack of nutrients, vitamins, and minerals, several diseases occur. Diseases that accompany gluten enteropathy are malnutrition, anemia, adenocarcinomas of the intestine and esophagus, lymphomas, osteoporosis, osteomalacia, kidney stones, reduced fertility, miscarriages, premature birth, congenital malformations, epileptic seizures, pericarditis, cardiomyopathy, lactose intolerance, frequent in-

fections, ulcerative jejunoileitis (Lis et al. 2019; Lodhi et al. 2018). People following a gluten-free diet must continuously check product ingredients and be mindful of what they are putting into their bodies. During the first few weeks of a gluten-free diet, it is recommended to consumers to take additional vitamins, minerals, and proteins to replenish deficits and nutrient reserves (Jones 2017; Khoury, Balfour-Ducharme, & Joye 2018; Piec & Jancza-Smuga 2022).

An additional iron, folic acid, and vitamin B-complex intake is often recommended with a gluten-free diet. Fluid and electrolyte replacement is sometimes needed, including calcium, potassium, and magnesium. People who have lower bone density also require additional vitamin D supplementation.

Meat, fish, eggs, and substitutes (legumes) are rich in high-value proteins and B-complex vitamins and minerals (Dai & Koh 2015; Iolascon et al. 2017; Langyan et al. 2022). That is why the representation of foods from this group is important, and without meat, it would be difficult to ensure adequate intake of macro and micronutrients. Dry and young legumes and nuts, besides having a high nutritional value, are a source of non-nutritive ingredients that benefit health (Rawat et al. 2023). Due to its excellent nutritional content, gluten-free status, and suitability for a gluten-free diet, pseudocereals have recently gained popularity. In the continuation of this work, the most important pseudocereals will be presented.

1.1. GLUTEN-FREE DIET

A gluten-free diet is now advised solely for people whose use of gluten causes illness. Therefore, only after diagnosing a disease caused by gluten, is it necessary to introduce a diet that does not contain it (Sharma et al. 2020; Welstead 2015). It implies eliminating all food containing wheat, barley, rye, and their derivatives from the diet. However since even the lowest amount of gluten can reactivate the disease and harm the patient, extreme caution is needed when choosing foods (Lacorn, Weiss, Wehling, Arlinghaus, & Scherf 2019). Different foods naturally do not contain gluten, such as fruits, vegetables, eggs, meat, fish, corn, and rice. The food mentioned above has a high nutritional value, and because of the lack of gluten is safe for people with celiac disease and is a desirable part of their daily diet (Melini & Melini 2019). There are products intended for such patients, that have been factory-removed from gluten. Such products must have an internationally recognized symbol of the crossed wheat class that guarantees the absence of gluten, i.e. presence within permissible limits (Osorio, Mejías, & Rustgi 2019). Due to its positive properties, gluten is used as an additive in the production of many foods. Food produced in this way is considered risky because it may contain hidden gluten ingredients (Mumolo et al. 2020).

According to the *Codex Alimentarius* (2008), gluten-free foods are divided into three groups: foods that do not naturally contain gluten and their gluten content must not exceed 20 mg/kg; foods that contain gluten, but is a technological process removed and the amount of gluten must not exceed more than 200 mg/kg; a combination of foods, in which amount of gluten must not exceed more than 200 mg/kg.

1.2. PSEUDOCEREALS

Pseudocereals do not belong to the cereal group, but their seeds resemble cereals. Tef is considered pseudocereals, but the most important are quinoa, millet, amaranth, and buckwheat. These grains are rich in nutrients and therefore, including these gluten-free grains in a gluten-free diet not only affects the variety but also improves its nutritional quality (Petrova & Petrov 2020; Schoenlechner 2016; Schoenlechner, Siebenhandl, & Berghofer 2008).

Pseudocereals are grown all over the world and make up a large percentage of daily meals in all parts of the world. Various studies have shown that plants are rich in phytochemicals and help the body fight free radicals. In this way, they influence the prevention and treatment of many diseases (Samtiya, Aluko, Dhewa, & Moreno-Rojas 2021). The most pseudocereals in the last century were considered inferior food. In recent decades, more people have become aware of their nutritional benefits, leading to a resurgence in their presence in the diets of individuals globally who are aiming to adopt a healthier way of living. Pseudocereal grains are edible seeds that belong to dicotyledonous species and contain a high starch content, like real grains (Nandan et al. 2024). Pseudocereals are crops of the future, primarily due to their high adaptability to different environments. They represent a current trend in human nutrition, as they are gluten-free (GF) cereals with excellent nutritional value (Paucar-Menacho et al. 2022). The bioavailability of protein in pseudocereals is higher and superior compared to regular cereals. An important characteristic of pseudocereals is their lipid content, which is 2 to 3 times higher compared to common cereals (wheat). The mineral deficit that occurs in patients following a gluten-free diet (GFD) is overcome and improved by replacing processed foods of low nutritional value with pseudocereals of high nutritional value, or through mineral supplements. Pseudocereals are a relevant source of calcium, iron, and zinc (Krasina, Filippova, Kurakina, & Fedorova 2021).

By comparing the raw values of pseudocereals with the values of wheat, it can be seen that wheat has much

higher selenium values, compared to the values of pseudocereals (Agregán et al. 2023).

Phenolic compounds are the most studied phytochemicals found in pseudocereals. These compounds are responsible for the health benefits of this type of food.

Analysis of various types of gluten-free flour showed a wide variety of phenolic compounds, with flavonoids (anthocyanins, flavones, flavanones, isoflavonoids), phenolic acids (hydroxycinnamate, hydroxybenzoides, hydroxybenzoic acid derivatives, hydroxyl acid derivatives) (Jagadeeswaran, Mahendran, & Umadevi 2022).

Although pseudocereals are rich in nutrients and bioactive compounds, it is also relevant to mention the presence of anti-nutritional components, mainly phytic acid, saponins, and tannins. They can interfere with nutrients, preventing them from being properly digested, absorbed, or used. However, processing treatments such as sprouting, fermentation, and cooking improve the nutritional and sensory properties of pseudocereals and reduce these antinutrients, thereby increasing nutrient availability and digestibility (Czerwonka & Białek 2023).

Therefore, although a gluten-free diet can be restrictive, gluten-free cereals or pseudocereals that are high in protein, fiber, iron, magnesium, and other bioactive compounds, such as phenolics, lead to a balanced diet. If introduced into a gluten-free diet, pseudocereals reduce the most common nutritional deficiencies in ceiac disease patients. They also provide a wider variety of foods and a less monotonous diet for celiac disease patients (Alvarez-Jubete, Arendt, & Gallagher 2010; Czerwonka & Białek 2023).

1.2.1. *Quinoa*

Quinoa (*Chenopodium quinoa*) is a crop belonging to the *Chenopodiaceae* family. It is considered one of the oldest crops in America. From 2000 to 2018, world production of quinoa tripled (Casalvara et al. 2024; Gupta & Morya 2022; Li, Lietz, & Seal 2021). Due to its characteristic resistance, stress tolerance, and its nutritional and biological properties, quinoa has been described as one of the grains of the 21st century. The average protein content of quinoa is higher compared to other cereals, such as barley, rice, corn, and wheat. Quinoa contains high quality proteins. Albumins and globulins are represented, while prolamin is present in traces. It contains all essential amino acids in a concentration of 38.71 g/100 g of protein (Agarwal, Tripathi, Kumar, Sharma, & Patel 2023).

Proteins contain lysine and tyrosine, amino acids that are limiting in conventional grains. The two main classes of proteins in quinoa seeds are 11S globulin and 2S albumin (Tavano et al. 2022).

The fat content of quinoa seeds is on average 2-10%. It is considered an alternative oilseed because of its lipid composition. Quinoa fat is noted for its significant amount of unsaturated fatty acids, with linoleic acid constituting over 50%, palmitic acid around 20%, oleic acid approximately 8%, and linolenic acid about 6%. Quinoa oil boasts strong antioxidant properties, a high concentration of polyunsaturated fatty acids, which includes both omega-3 and omega-6 fatty acids, along with a notable level of tocopherols. Polar lipids account for roughly 25% of the total composition. They are composed mainly of phospholipids, neutral lipids, triglycerides make up 74%, and diglycerides 20%. They are stable during storage, due to their high vitamin E content (Graf et al. 2015; Malik & Singh 2022).

Quinoa contains a significant amount of carbohydrates, the most important of which is starch. Its granules have a polygonal shape with a diameter of 2 mm, smaller than those of ordinary cereals. Quinoa carbohydrates include amylose, monosaccharides, disaccharides, and crude fiber. Sucrose is present in significant amounts compared to other sugars. It contains a low proportion of glucose and fructose (Rao & Poonia 2023).

This pseudocereal is considered an important source of dietary fiber. About 78% of the amount of fiber in quinoa is insoluble, while 22% is in soluble form (Gonzalez, Konishi, Bruno, Valoy, & Prado 2012; Kyriakopoulou, Keppler, & Goot 2021).

Quinoa grain is a good source of minerals. It contains large amounts of potassium, calcium, magnesium, copper, iron, manganese, and zinc. It contains a high level of vitamin B6 and folate, the amounts of which can cover the daily needs of children and adults (Pathan & Siddiqui 2022).

The thiamin content in quinoa is less than that found in other grains like oats and barley, yet it contains greater amounts of niacin, riboflavin, vitamin B6, and total folate. Saponins are glycosidic substances located in the outer layer of the seed, known as the pericarp. They diminish the seed's taste and digestibility, which is why it's important to remove them prior to eating. There are two methods of removing saponins from quinoa: the wet method, that is, washing the seeds in cold alkaline water, and the dry method, i.e. frying and then scraping the grain to remove the outer layers (Agrawal, Singh, Gajbe, Kalambe, & Bankar 2023).

However, the mentioned methods do not achieve complete removal of saponins. It is necessary to develop new methods for removing saponins from quinoa seeds. Quinoa has different tannin contents. This difference is explained as a consequence of the difference in habitat diversity. The seeds contain flavonoids, such as quercetin

and kaempferol glycosides, ferulic acid, phytic acid, and tannins. Most of the phenols in quinoa have antioxidant activity. Apart from antioxidant properties, phenols also have anti-allergic, anti-inflammatory, anti-cancer (Hussain et al. 2021).

Quinoa is an excellent source of nutrients and bioactive phytochemicals that contribute to a healthy diet and provide quality proteins that have a large number of benefits for human health (Angeli et al. 2020).

1.2.2. *Millet*

Millet is an annual, small-seeded cereal grown worldwide. It is used in the food industry and the industry of animal feed production. It belongs to the *Poaceae* family. There are about 20 different types of millet. The most commonly cultivated species are millet (*Panicum miliaceum* L.), pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), foxtail millet (*Setaria*), and small millet (*Panicum sumatrens*). They differ in genome size, fertility levels, and breeding systems (Saini, Saxena, Samtiya, Puniya, & Dhewa 2021).

Millet is the sixth most important cereal grain in the world and is the main source of energy and protein for millions of people in India, Africa, and China, especially for people living in arid regions (Hassan, Sebola, & Mabelebele 2021).

The use of millet in human nutrition has been known since ancient times. However, during the 20th-century agricultural systems, millet was replaced by higher-yielding crops such as wheat, corn, and soybeans. It was most often used as bird food. In the last two decades, millets have regained attention in agriculture, thanks to the awareness of millets as s climate-smart crop and their benefits for human health.

Millet production is dominated by Asia and Africa, compared to Europe and America. Short duration and wide adaptability in different environmental conditions make millet one of the most suitable crops for sustainable agriculture and future food security (Das, Khound, Santra, & Santra 2019; Hassan et al. 2021).

Millet is one of the most suitable crops for areas where annual rainfall is ≤100 mm. The shallow root system and short growing season make it an ideal crop in dry climates. It is cultivated on acidic soil with a pH of 5.5-6.5, which is a great advantage, compared to wheat or rice, which need a pH of 6.0-7.0 and 6.5-8.5, respectively. It is usually planted in late May or early June, and harvested in late August or early September. The optimal temperature for its growth is 20-30 °C (Kheya et al. 2023).

Millet has many benefits for human health. It is characterized by high nutritional value. It is a good source of minerals, such as calcium, phosphorus, potassium, sodium, magnesium, manganese, iron, magnesium zinc, dietary fiber, polyphenols, and protein. It contains all essential amino acids (methionine, phenylalanine, tryptophan, valine, and only lysine is organizing). It was found that the index of essential amino acids is higher in millet, compared to wheat (Bellad & Belavadi 2023; Gahalawat, Lamba, & Chaudhary 2024)

Millet has a significantly lower glycemic index, compared to rice, wheat, and barley, which makes it an ideal food for people with type 2 diabetes and cardiovascular disease, as well as for people suffering from obesity (Agrawal et al. 2023)

It contains a large amount of lecithin, which plays an important role in the nervous system because it regenerates myelin fibers and improves the metabolism of brain cells. It also contains a significantly high amount of B-complex vitamins, folic acid, and niacin. The high fiber and antioxidant content of millet plays an important role in the prevention of cardiovascular diseases and cancer (Baltrusch 2021).

Millet can also be used as a prebiotic. Indigestible carbohydrates from millet help the growth of food microflora in the intestines. It prevents constipation and is therefore quite effective as a preventive food against colon cancer. Many countries have their traditional millet-based fermented alcoholic beverages. Gluten-free drinks have a growing trend in the European and American beverage industries, so this gluten-free cereal is often represented in that production. It is most often used in the beer industry, as it is an important material for malt due to its high amylase activity (Chen, Zhang, Xu, & Ren 2021).

The presence of all the necessary nutrients in millet makes it suitable for wide use in the production of food products, such as baby food, snacks, and diet food. More and more millet products enter people's daily lives in the form of millet porridge, millet alcoholic beverages, as well as various bakery products made from this pseudocereal (Hassan et al. 2021).

1.2.3. *Amaranth*

Amaranth belongs to the family *Amaranthaceae* of the order *Cariophyllales*. Among the people, in addition to the name amaranth, it is often called foxtail, which it got because of its specific appearance. The genus includes about 75 species, which are mostly annual plants and are distributed in temperate and tropical regions of the world. Most of the species are considered weeds, and ornamental plants, and only three of them, *Amaranthus caudatus*, *Amaranthus cruentus,* and *Amaranthus hypochondriacus* are consumed by humans as seeds or used as a functional ingredient in food (Hassan et al. 2021; Singh et al. 2024)

In the past, this plant was an integral part of many religious and ritual ceremonies. It originates from South America and is increasingly called the cereal of the 21st century. It is distributed on all continents, but under different names and for different purposes.

Amaranth has many favorable agronomic properties and is highly adaptable to different ecological zones, with better resistance to biotic and abiotic stresses than many other conventional food crops (Singh et al. 2024).

Amaranth, like corn and sugar cane, belongs to photosynthetic plants. The advantage of this type of plant is satisfactory yields achieved with low water consumption. This makes amaranth resistant to droughts and very well reduces greenhouse effects by sequestering atmospheric CO_2 (Sooriyapathirana et al. 2021).

Amaranth grains can be toasted, extruded, or ground into flour and can therefore be consumed as such or incorporated into other grain products, such as breads, cakes, muffins, pancakes, cookies, noodles, and crackers (Singh & Punia 2020).

The nutritional quality of amaranth seeds is higher than that of most cereals, due to the high protein content and balanced composition of essential amino acids (Jan, Hussain, Naseer, & Bhat 2023).

Protein content and amino acid composition depend on genotype and growth conditions. Proteins contained in amaranth seeds have a higher biological value than milk proteins, so they can be used to produce a milk substitute, useful for people who cannot tolerate lactose.

Amino acids include methionine, lysine, arginine, and tryptophan, as well as sulfur-containing amino acids. The fat content in amaranth is about 2-3 times higher than in other cereals. Amaranth oil contains more than 75% unsaturated fatty acids, namely: linoleic acid, palmitic acid, stearic acid, oleic acid, and linolenic acid (Manyelo, Sebola, Rensburg, & Mabelebele 2020; Rao & Poonia 2023).

Amaranth contains high levels of squalene, a highly unsaturated, open-chain triterpene, normally found only in the liver of deep-sea fish and other marine species. Squalene reduces cholesterol levels, inhibits chemically induced breast and colon cancer, reduces the frequency of heart diseases, supports the removal of toxins from the body, activates and prolongs the life of cells, and strengthens the functioning of the body. Squalene found in amaranth oil is one of the metabolites involved in the biosynthesis of cholesterol in the liver (Popa, Băbeanu, Popa, Niță, & Dinu-Pârvu 2015; Sayed-Ahmad et al. 2022).

Amaranth seeds, depending on the species, contain from 48% to 69% starch, with very small grains.The small portion size leads to a quick increase in blood sugar levels. For this reason, it is important to exercise caution when incorporating amaranth products into the diets of individuals with diabetes. Amaranth starch is several times easier to digest than millet starch. Compared to other cereals, amaranth starch exhibits excellent freeze-thaw and retrogradation stability, higher gelatinization temperature and viscosity, higher water-binding capacity, as well as higher solubility, swelling power, and enzyme sensitivity. This starch is resistant and not susceptible to human digestive enzymes (Capriles, Coelho, Guerra-Matias, & Arêas 2008; Różewicz 2021). It has beneficial physiological effects, such as lowering blood lipids or reducing the risk of colon cancer. Regarding the minerals found in amaranth, their levels are approximately double compared to those in other grains. It contains large amounts of calcium, magnesium, iron, potassium, and zinc. Amaranth seeds and leaves are rich in natural antioxidants. They are mainly polyphenols, flavonoids, anthocyanins, and beta-carotene. Due to the high nutritional value of amaranth, it is used more and more in human nutrition. It is used as a spice, but also as a vegetable, because the young plants can be prepared in a similar way as spinach and beetroot (Martinez-Lopez, Millan-Linares, Rodriguez-Martin, Millan, & de La Paz 2020). Flour, groats, porridge, flakes, sprouts, and other products are made from amaranth seeds. This is particularly advised for individuals with heart conditions who require a gluten-free diet, growing children, expectant mothers, athletes, and those who are at risk for disorders affecting the nervous, skeletal, and vascular systems. As a gluten-free cereal, it is a desirable crop for the nutrition of millions of people. Amaranth is also used in the pharmaceutical industry for the production of drugs, including drugs against atherosclerosis, stomach ulcers, and tuberculosis, as well as antiseptic, antifungal, and anti-inflammatory preparations. It is also used in the cosmetic industry, for the production of creams and masks for beautification, smoothing, skin protection, as well as anti-aging (Baraniak & Kania-Dobrowolska 2022).

1.2.4. *Buckwheat*

Buckwheat (*Fagopyrum esculentum*), it is used for eating in various ways in many cuisines from Asia to Europe. For years it was suppressed at the expense of wheat. However, as awareness of the problem of celiac disease and gluten grew over time, substitute grains for wheat became in demand. The search was"discovering" new gluten-free cereals. Buckwheat was among them (Skřivan, Chrpová, Klitschová, Švec, & Sluková 2023). The origin of buckwheat goes back thousands of years to the vast expanses of Central Asia. It began cultivating first in Asia, spreading to Europe and North America. It has become popular in Europe due to its resistance to climate and pests. The

hardy nature of the plant and its adaptability to the harsh climate secured it a place where other crops had difficulty or deceptive success. The main part of the plant that is used for food purposes is the seed. Buckwheat seeds are triangular, brown to greenish. Seed size varies, usually smaller than typical grains. Buckwheat grows quickly and has characteristic heart-shaped leaves. The flowers are small, white, or pink. The plant usually blooms in July and August. Other parts are also edible (Farooq et al. 2016; Wen et al. 2021).

Traditionally, buckwheat is used primarily as cooked cereal or porridge, then in processed foods. Buckwheat flour can be found more and more nowadays. The flour gives a nutty note and strong flavors. It is perfectly complemented with wheat for bread and dough. In East Asian countries, buckwheat is used to make tea. Cooking the cleaned and fried grain gives a sweet drink with a pleasant taste (Skřivan et al. 2023).

In meals, it is an excellent source of carbohydrates for energy. Recently, it has become somewhat more popular because it is sought after in dishes as an alternative to wheat. Today, it is widespread in the diet of many countries around the world (Sabença et al. 2021).

Buckwheat is rich in fiber which has a beneficial effect on digestion. Fiber also has additional benefits, primarily for regulating blood fats and cholesterol. Buckwheat is considered a good source of protein among cereals. It contains approximately 11-13% protein. Like other grains, buckwheat does not contain complete proteins. The main limiting amino acid is lysine, followed by leucine (Sofi et al. 2023).

Buckwheat has a low sugar content and a low glycemic index. Regarding the content of mineral substances, magnesium, and manganese stand out above all.Buckwheat is notable for its high content of rutin, a type of bioflavonoid that offers numerous health benefits. Research has associated it with positive effects on vascular health, particularly concerning veins, as it serves as an antihypertensive agent by reducing high blood pressure and preventing the hardening of blood vessels(Huda et al. 2021). Another flavonoid found in buckwheat is quercetin, which is recognized for its antioxidant properties and has been extensively studied for its various health benefits. These benefits include anti-inflammatory, antimicrobial, and anti-cancer effects.

Buckwheat also contains several other useful phytonutrients. In addition to rutin and quercetin, there are other flavonoids (vitexin, isoorientin) and polyphenols (fagopyrins, phenolic acids) (Aghababaei & Hadidi 2023; Shabir et al. 2022).

2. CONCLUSION

Based on the presented literature data, it is concluded that a gluten-free diet is the basic way of treating celiac disease and other diseases associated with gluten intake. Because such a diet is usually depleted in nutrients, the introduction of pseudocereals increases the level of nutritional value of food products, vitamins, minerals, and other important nutritional values in a gluten-free diet. Individuals with gluten-related disorders depend on a gluten-free diet that includes pseudocereals, whereas other individuals opt for them as a lifestyle choice and for preventative reasons.

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