Gluten-Free Diet in Celiac Disease: Nutrient Imbalances and Alternative Grain Sources

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Abstract

Celiac disease (CD) is a chronic autoimmune disorder of the small intestine that develops through the immune system in genetically predisposed individuals in response to gluten intake. This disease is triggered by the consumption of gluten found in cereals such as wheat, barley, and rye, and continued gluten intake leads to damage of the intestinal mucosa, villous atrophy, impaired nutrient absorption, and various symptoms. Currently, the only known effective treatment for CD is a strict gluten-free diet (GFD) that must be maintained lifelong. However, complete elimination of gluten from the diet can lead to deficiencies in energy, fiber, vitamins, and minerals if appropriate alternative foods are not selected. In particular, gluten-free (GF) cereals and pseudocereals with functional properties have significant potential to improve the nutritional quality of a GFD. The aim of this study is to evaluate nutrient imbalances in patients with CD and, by examining the nutrient contents and health benefits of GF cereals, to provide guidance for achieving a balanced and adequate diet in the application of a GFD.

Çölyak Hastalığında Glutensiz Diyet: Besin Dengesizlikleri ve Alternatif Tahıl Kaynakları

Özet

Çölyak hastalığı, genetik yatkınlığı olan bireylerde gluten alımına bağlı olarak bağışıklık sistemi aracılığıyla gelişen kronik ve otoimmün bir ince bağırsak bozukluğudur. Bu hastalık, buğday, arpa ve çavdar gibi tahıllarda bulunan glutenin tüketilmesiyle tetiklenir ve gluten alımı sürdükçe bağırsak mukozasında villusların zarar görmesine, besin emiliminde bozulmalara ve çeşitli semptomlara neden olur. Günümüzde çölyak hastalığının bilinen tek etkili tedavisi, ömür boyu sürdürülmesi gereken katı bir glutensiz diyettir. Ancak glutenin diyetten tamamen çıkarılması, doğru besin alternatiflerinin seçilmemesi nedeniyle enerji, posa, vitamin ve mineral eksikliklerine yol açabilir. Özellikle fonksiyonel özelliklere sahip glutensiz tahıllar ve psödotahıllar, glutensiz beslenmenin besin kalitesini artırmada önemli potansiyel taşımaktadır. Bu çalışmanın amacı, çölyak hastalarında besin ögesi dengesizliklerini değerlendirmek ve glutensiz tahılların besin ögesi içerikleri ile sağlık faydalarını inceleyerek, glutensiz diyet uygulamalarında dengeli ve yeterli beslenme sağlanmasına rehberlik etmektir.

1. INTRODUCTION

CD is an autoimmune disorder that manifests in genetically predisposed individuals and is defined by characteristic serological and histopathological findings resulting from the ingestion of gluten. Gluten is a group of alcohol soluble proteins naturally found in grains such as wheat, rye, spelt, barley and kamut (Caio et al., 2019). Adhering to a lifelong GF diet may potentially result in the occurrence of nutrient deficiencies, primarily attributable to the restricted range of GF grain and dietary alternatives available (Aljada et al., 2021). Adding pseudocereals can improve diet quality, while regular nutrient monitoring helps detect deficiencies early (Özkaya & Özkaya, 2018). The aim of this review is to identify potential nutrient deficiencies in individuals following a GFD, evaluate strategies and recommendations to prevent these deficiencies, and examine alternative GF cereal sources that can enhance diet quality.

2. CELİAC DİSEASE

2.1. Epidemiology and Symptoms of Celiac Disease

A recent meta-analysis indicates that CD is a global condition, with an estimated prevalence of 0.6% to 1.0% overall, specifically measured at 1.4% based on serologic tests and 0.7% based on biopsy results (Singh et al., 2018). The disease can occur at any age and is more common in women than in men (Caio et al., 2019). With the growing recognition of a wider range of diseases associated with gluten intake, a collaborative effort towards a comprehensive literature review on definitions was published in 2013 as the Oslo definitions (Ludvigsson et al., 2013). According to theese definitions, the types of CD are given in Table 1.

Table 1. Oslo definitions for CD

Type	Description
Classical CD	Characterized by symptoms and signs of malabsorption. Diarrhea, steatorrhea, weight loss, or growth failure are required for diagnosis.
Non-classical CD	Refers to patients with confirmed CD who do not exhibit signs related to malabsorption. Symptoms may include constipation, abdominal discomfort, or others not typically linked to malabsorption.
Silent CD	No clinical symptoms are present; however, positive serology and mucosal damage (villous atrophy) are detected through screening. Often found in at risk groups (e.g., individuals with type 1 diabetes).
Potential CD	Positive serological markers (e.g., anti-TTG IgA) are present, but the mucosal structure is normal or only mildly affected (no villous atrophy). It is possible for these individuals to develop CD in the future.
Refractory CD	Diagnosed when symptoms and mucosal damage persist despite strict adherence to a GFD.

According to the Oslo definitions, CD is categorized based on the severity of intestinal mucosal damage and the resulting clinical extent of nutrient malabsorption; in this context, Classical CD is characterized by overt signs of malabsorption such as diarrhea, steatorrhea, and weight loss which are essential for its diagnosis, whereas Non-classical CD presents with atypical symptoms like constipation or abdominal pain that are not traditionally linked to malabsorption. Furthermore, Silent CD involves an asymptomatic yet active malabsorptive process due to significant villous atrophy detected through screening, while Potential CD shows no active malabsorption as the mucosal architecture remains preserved; conversely, Refractory CD represents the most severe and persistent form of malabsorption, characterized by intestinal damage that fails to heal despite strict adherence to a GFD (Caio et al., 2019; Ludvigsson et al., 2013).

2.2. Pathophysiology of Celiac Disease

Gliadin, a natural component of wheat gluten, can trigger an immune response in individuals with CD leading to damage of the intestinal mucosa. Gliadin leads to the destruction of epithelial cells and increases the expression of interleukin-15 (IL-15), which plays a central role in activating cytotoxic intraepithelial lymphocytes. In addition to IL-15, proinflammatory cytokines such as interferon-γ (IFN-γ) and tumor necrosis factor-α (TNF-α) contribute to the amplification of the Th1-mediated immune response and mucosal inflammation. During infections or when intestinal permeability is altered, gliadin is deaminated by tissue transglutaminase in the lamina propria and interacts with human leukocyte antigen (HLA-DQ2) (or HLA-DQ8) molecules on antigen-presenting cells. Gliadin peptides are then presented to $CD4^+$ T cells via the T-cell receptor, triggering cytokine release through signaling pathways such as Janus kinase/signal transducer and activator of transcription (JAK/STAT) and nuclear factor kappa-B (NF-κB), which ultimately leads to epithelial damage, villous atrophy, and crypt hyperplasia (Aboulaghras et al., 2022).

Beyond the mere reduction of the intestinal absorptive surface, the inflammatory cascade in CD profoundly disrupts the biochemical and functional integrity of the enterocyte brush border. Elevated levels of proinflammatory cytokines, particularly IFN-γ and TNF-α, have been shown to downregulate the expression and activity of critical micronutrient transporter proteins within the intestinal epithelium (Caio et al., 2019; Calder et al., 2009). In this context, the impaired expression of Divalent Metal Transporter 1 (DMT1) and ferroportinvresponsible for apical iron uptake and basolateral iron export, respectively provides a mechanistic explanation for the frequent occurrence of iron-deficiency anemia in celiac patients, even prior to the development of complete villous atrophy (Halfdanarson et al., 2007). Moreover, inflammation induced disruption of brush border integrity is associated with reduced expression of zinc transporters such as ZIP4 and calcium binding proteins including calbindin-D9k, indicating that micronutrient malabsorption in CD arises not only from structural mucosal damage but also from functional downregulation of the molecular transport machinery (Fleet, 2017; James Freeman, 2022).

2.3. Diagnosis of Celiac Disease

Due to the frequent presentation of extraintestinal or atypical symptoms, establishing a diagnosis of CD requires a high index of clinical suspicion. The diagnosis is typically confirmed through a combination of serological assays and histological evaluation of duodenal biopsies. The cornerstone of management is a strict lifelong GFD, to which the majority of patients exhibit a favorable clinical response (Al-Bawardy et al., 2017).

2.4. *Updated Diagnostic and Management Guidelines*

The 2023 American College of Gastroenterology (ACG) guidelines present notable updates in the diagnosis and management of CD compared to the 2013 recommendations. While duodenal biopsy was previously essential, it may now be omitted in children with anti–tissue transglutaminase immunoglobulin A (TG2 IgA) levels >10× upper limit of normal and positive endomysial antibodies (EMA). In specific cases, children can now be diagnosed with CD without the need for a biopsy. While this 'no-biopsy' approach may appear to present challenges for dietitians in terms of follow-up due to the absence of a baseline tissue report, recent evidence suggests that it does not adversely affect patient adherence to their diet or the speed of recovery, provided that antibody levels are closely monitored (Kori et al., 2024).

TG2 IgA remains the preferred serologic test, but deamidated gliadin peptide immunoglobulin G (DGP IgG) is recommended for IgA-deficient patients. HLA-DQ2 or DQ8 typing, once rarely used, is now helpful for ruling out the disease when negative. GFD management now strongly emphasizes lifelong follow-up with a dietitian, replacing the earlier symptom-based monitoring with regular assessments using antibody levels and clinical status. Refractory CD is better defined, often resulting from non-adherence to GFD, and alternative conditions must be excluded. Greater focus is also placed on preventing complications such as lymphoma and osteoporosis through structured follow-up (Bai et al., 2013; Rubio-Tapia et al., 2023).

3. NUTRITIONAL MANAGEMENT IN CELIAC DISEASE

A lifelong GFD is the only effective treatment for individuals with CD. Therefore, strict elimination of gluten containing grains including wheat (gliadin), barley (hordein), rye (secalin), oats (avenin), and related cereals is essential for effective disease management and long-term health outcomes (Aljada et al., 2021). This treatment usually reduces symptoms and improves health (Kelly et al., 2015). A GFD excludes all food products containing wheat, barley, rye, oats, and spelt. This includes all types of flour, bread, pasta, beer, baked goods, and cakes made from these grains. According to the Food and Drug Administration (FDA) foods labeled “gluten-free” must be naturally GF or meet the requirement that components derived from processed grains contain no more than 20 ppm (parts per million) of gluten (FDA, 2013). The diet should consist of natural, unprocessed foods. Patients should be referred to a dietitian for proper guidance, ensuring their nutritional needs are met and they receive balanced intake of nutrients. Any deficient nutrients should be supplemented prior to starting the diet. Blood tests should be monitored throughout the diet. In the first month, dairy products may be restricted in some patients due to temporary lactose intolerance, which typically resolves as intestinal mucosal healing occurs and does not affect all individuals with CD. Appropriate supplements (electrolytes, calcium, magnesium, iron, folate, B12) may be necessary in cases of severe diarrhea and malabsorption. Approximately one-third of patients experience dyspepsia or reflux; enteral nutrition may rarely be required. Daily gluten intake below 20 mg leads to symptomatic improvement, serological recovery, and histological remission in the majority of patients (García-Manzanares & Lucendo, 2011). Daily gluten intake below 20 mg leads to symptomatic improvement, serological recovery, and histological remission in the majority of patients. Approximately 70% of patients experience symptom relief within the first two weeks of starting a GFD. In children, adherence to a GFD restores normal growth and development and prevents many disease-related complications. Strict dietary compliance also results in normalization of CD specific antibody levels (García-Manzanares & Lucendo, 2011). In a large pediatric cohort, IgA anti-transglutaminase antibodies normalized in nearly 90% of children within 24 months of initiating a GFD (Sbravati et al., 2022). Although villous atrophy begins to improve within months, complete histological recovery may take years and may not occur in every patient, primarily due to ongoing gluten exposure. However, patients who do not adhere to the diet or switch to a GFD may experience various adverse outcomes, including growth retardation, short stature, micro and macro nutrient deficiencies, anemia, elevated aminotransferase levels, joint and muscle pain, osteoporosis, dental enamel disorders, and various autoimmune diseases (Özkaya & Özkaya, 2018). It is important to educate patients on a healthy and balanced GFD with the help of dietitians to prevent malnutrition and monitor blood values over the years. To improve diet quality, it is beneficial to encourage the consumption of natural GF foods such as vegetables, fruits, legumes, nuts, and pseudocereals, carefully select the source and amount of complex carbohydrates and proteins, and always choose GF products fortified with micronutrients and vitamins (Mazzola et al., 2024). According to Academy of Nutrition and Dietetics (AND) and World Gastroenterology Organisation (WGO) guidelines, patients should ideally be followed by a dietitian every 3–6 months until clinical normalization, and thereafter every 1–2 years. An expert dietitian should assess the patient's nutritional status and evaluate macro and micronutrient intake (McDermid et al., 2023; WGO Global Guidelines, 2016).

3.1. Nutrient Imbalances Associated With the Gluten Free Diet in Celiac Disease

GFDs frequently lack nutritional balance. Studies show that GFD can cause nutritional deficiencies compared to a gluten containing diet. Such dietary habits can cause imbalances in both macro and micronutrient intake. Typically, GFDs are low in complex carbohydrates, dietary fiber and protein, while being high in fats and simple carbohydrates (Herrera-Quintana et al., 2025; Miranda et al., 2014; Simón et al., 2023). Moreover, deficiencies in micronutrients such as zinc, folate, iron, calcium, vitamin B12, and vitamin D are commonly observed (Abdi et al., 2023) A recent meta-analysis reported that celiac patients on a GFD had an average energy intake of 1995 kcal/day, with 47.8% of calories from carbohydrates, 15.5% from protein, and 35.8% from fat, and with high saturated fat content (13.2%) and increased total fat intake, especially among adolescents (GFD cohort). These values can be contextualized against general population recommendations (50–60% carbohydrate, 10–20% protein, and ≤20 g saturated fat as part of a balanced diet). Fiber intake in adults on a GFD averaged 18.9 g/day, below the 25 g/day recommended intake for healthy adults, and intakes of calcium, magnesium, iron, and vitamin D were reported as inadequate relative to standard dietary reference values. These comparisons suggest that GFD should be carefully planned and supplemented with nutrient-dense GF foods (Gessaroli et al., 2023). Common nutritional imbalances in GFD are summarized in Figure 1.

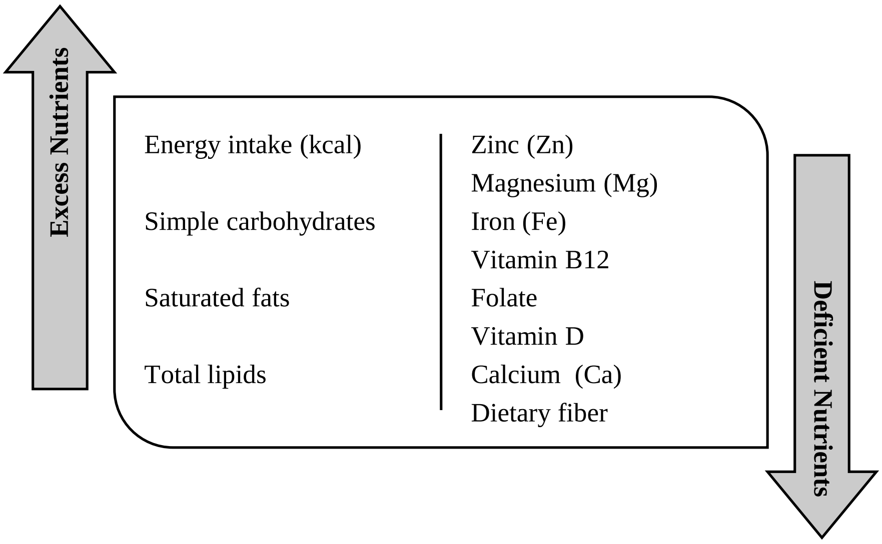

Figure 1. Common Nutritional Imbalances in GFD (Vici et al., 2016)

3.1.1. Carbohydrates

Numerous studies indicate that a GFD is typically associated with reduced consumption of complex carbohydrates and dietary fiber. Individuals with CD tend to consume higher amounts of sugar compared to healthy individuals (Kreutz et al., 2020; Wild et al., 2010). Additionally, GF bread and flour products often contain a lot of sugar, and GF crackers tend to be high in fat and sugar compared to regular foods Pasta has a comparable sugar content; however, GF cake mixes exhibit a considerably higher total sugar level in comparison to cakes containing wheat (Rinninella et al., 2021). Some studies suggest that GFDs are may be associated with lower intake of legumes and other fiber-rich plant foods, as well as higher consumption of processed foods with a high glycemic index, which contributes to generally low dietary fiber intake in these patients (Cardo et al., 2021; Jamieson & Neufeld, 2020; Wild et al., 2010). These dietary patterns may contribute to insulin resistance, impaired glucose tolerance, and increased risk of diabetes. A recent meta-analysis highlighted a significant occurrence of non-alcoholic fatty liver disease and metabolic syndrome in individuals with CD adhering to a GFD, which may be associated with the nutritional imbalances characteristic of this dietary pattern (Aggarwal et al., 2024). In a prospective intervention study by Suárez-González et al. (2021) nutrition education led by a registered dietitian significantly improved eating patterns and bowel habits in pediatric patients with CD resulting in increased compliance with dietary recommendations, reduced consumption of ultra processed foods, higher intake of fruits and vegetables, and improvement of constipation symptoms; therefore dietitian involvement is crucial in GFD planning.

Bread wheat contains the most proteins that trigger CD, while some diploid wheat species are less toxic. Although these diploid wheats are not commonly eaten, this information may help guide future research into safer wheat varieties. Although oats contain lower levels of prolamins compared to other gluten-containing cereals, they may still trigger immune reactions in some individuals with CD. Only uncontaminated, certified GF oats are considered potentially safe for certain patients. Conversely, naturally GF cereals such as maize, rice, and sorghum, along with pseudocereals including quinoa, amaranth, and buckwheat, offer nutritionally valuable and safe alternatives for individuals adhering to a GFD (Comino et al., 2013).

3.1.2. Proteins

GF products typically have less protein than conventional wheat based products. This is because gluten is a protein, and GF products typically use rice and corn-based flours, which are naturally lower in protein (Abdi et al., 2023; Cornicelli et al., 2018; Newberry et al., 2017). In a study population of women in patients with CD, the average protein intake after diagnosis was found to be significantly lower after 12 months on a GFD. (Shepherd & Gibson, 2013) Additionally, one study reported that the mean protein content of GF products was 5.8 g/100 g, compared with 8.6 g/100 g in gluten-containing products, indicating that the protein content of GF products was approximately 33% lower. Furthermore, in 57% of the seven food categories examined, GF products exhibited significantly lower protein levels than their gluten-containing counterparts (Missbach et al., 2015).

3.1.3. Fats

Numerous studies have demonstrated that adults with CD often exhibit imbalanced fat intake on a GFD, with some cohorts reporting high total fat consumption and others noting excessive saturated fatty acid and cholesterol intake; similar patterns have been observed in children, including an increased ratio of saturated to polyunsaturated fatty acids (Ferrara et al., 2009; Gessaroli et al., 2023) These imbalances may stem from low consumption of plant-based foods and the frequent intake of processed GF products which tend to contain higher amounts of total and saturated fats compared to their gluten containing counterparts. Such diets rich in saturated fats may increase the risk of cardiovascular disease and contribute to insulin resistance (Cardo et al., 2021). A previous study provides valuable insights into the nutritional differences between GF and gluten containing products, particularly concerning fat content. González et al., (2025) analyzed 30 different flours and 24 types of bread, revealing that GF flours, especially those derived from cereals, contain more fat than their gluten containing counterparts. Similarly, GF breads were found to have almost twice the fat content compared to gluten containing breads. This elevated fat content in GF products is attributed to both the inherent properties of the raw materials and the frequent addition of fat based ingredients, such as sunflower oil and margarine, to improve texture and palatability. These findings align with previous observations that GF diets often involve higher fat intake, particularly saturated fats, due to the consumption of processed GF products. Beyond caloric density, the use of saturated fats like palm oil and high Omega-6 vegetable oils in these products is a major concern. Such lipid profiles can trigger a pro-inflammatory cascade by shifting the Omega-6 to Omega-3 ratio, potentially sustaining subclinical inflammation and delaying mucosal healing (Simopoulos, 2016).

3.1.4. Dietary Fiber

GFD is typically lower in dietary fiber compared to gluten containing diets. Fiber deficiency may occur both at diagnosis due to villous atrophy and during the GF diet, often because of low fiber product choices, poor quality GF foods, and the exclusion of fiber rich grains. Most GF products are made from starches or refined flours, and the refining process removes the fiber rich outer layers of grains, further reducing fiber content (Khairuddin

& Lasekan, 2021). To support adequate fiber intake in individuals with CD, the consumption of fiber rich GF grains such as brown rice, wild rice, quinoa, oats, amaranth, millet, sorghum, and teff is recommended. Oats included in the GFD of patients with CD should be free from contamination with wheat, barley, or rye gluten (Pinto-Sánchez et al., 2017). General dietary recommendations from bodies such as the Dietary Guidelines for Americans advise that at least half of daily grain intake should come from whole grain sources to improve dietary fiber and micronutrient intake.Celiac patients should aim to meet the general population's recommended dietary fiber intake levels, using the Recommended Dietary Allowance (RDA) as a guideline. According to the RDA, the suggested daily fiber intake varies by age group: 19 g/day for children aged 1-3 years, 25 g/day for those aged 4-8 years, and 26-38 g/day for individuals aged 9-18 years (Özkaya & Özkaya, 2018).

3.1.5. Folate and Vitamin B12

Folic acid is a vitamin that is absorbed mainly in the jejunum and this is often affected in CD (Theethira et al., 2014). Folate deficiency has been reported in about 10–85% of adults at the time of CD diagnosis, and in roughly 0-20% of those adhering to a GFD (Tunçer & Yabancı Ayhan, 2021). A single center retrospective study reported that folate deficiency was observed in 4.3% and vitamin B12 deficiency in 2.4% of children following a GFD. These findings suggest that deficiencies in water soluble vitamins may persist when dietary intake is insufficient. Moreover, the limited nutritional content of GF products and the lack of dietary variety may contribute to the continuation of these deficiencies (Kreutz et al., 2023a). In the treatment of folate deficiency in CD, folic acid supplementation at a dose of 1 mg/day for 3 months is generally recommended, followed by maintenance supplementation of 400–800 µg/day, with the exact dose adjusted according to serum folate levels and clinical status (e.g., presence of diarrhea) (Rondanelli et al., 2019; Tunçer & Yabancı Ayhan, 2021). In children, even when following a GFD, folate intake and serum folate levels may be insufficient, which can lead to elevated homocysteine levels. Therefore, it is recommended that folate levels in children with CD be regularly monitored, and appropriate dietary adjustments or supplementation be provided if deficiencies are detected (Di Nardo et al., 2019)

Folate requires vitamin B12 activation; therefore, low intracellular folate levels may result from vitamin B12 deficiency (Lamjadli et al., 2025). Vitamin B12 is absorbed in the ileum. In CD, villous atrophy and mucosal damage in the small intestine may impair vitamin B12 absorption. Vitamin B12 deficiency causes fatigue, weakness, numbness, tingling, pain in the tongue, and hematological abnormalities (Dahele & Ghosh, 2001). Vitamin B12 deficiency can be observed at the time of diagnosis in CD, but it generally improves with strict adherence to a GFD. If B12 deficiency persists despite a GFD, accidental gluten intake or other coexisting conditions should be investigated (Scarampi et al., 2025). According to a 2 year follow up study on anemia in untreated, newly diagnosed celiac patients, about 11% had vitamin B12 deficiency at diagnosis, and anemia was often multifactorial, involving iron, folate, and vitamin B12 deficiencies. Following the initiation of a GFD accompanied by proper supplementation, hemoglobin levels returned to normal in 81% of patients within the first year and in 89% by the end of the second year. These findings highlight the importance of monitoring and supplementing vitamin B12 alongside a GFD to effectively manage anemia in CD (Roldan et al., 2022). In adults with CD, vitamin B12 levels may normalize after strict adherence to a GFD, but supplementation is recommended if deficiency related symptoms persist. In such cases, a daily dose of 1000 µg of vitamin B12 is commonly suggested (Dahele & Ghosh, 2001; Rondanelli et al., 2019). In the literature, particularly in children, hemoglobin, blood parameters, and homocysteine levels have been shown to normalize and micronutrient deficiencies to be corrected with a GFD and appropriate supplementation; therefore, monitoring vitamin B12 and folate levels and providing supplementation when deficiencies are detected is recommended in clinical practice for individuals with CD (Beker Sanli et al., 2015; Comba et al., 2018; Kreutz et al., 2023)

3.1.6. Vitamin D and Calcium

A GFD is essential for the management of CD; however, it may not always fully prevent vitamin D and calcium deficiencies. These deficiencies may not be directly attributable to gluten exclusion itself, as major dietary sources of calcium are generally permitted in a GFD and vitamin D is not derived from gluten-containing foods. Instead, they may be related to factors such as malabsorption, incomplete mucosal recovery, limited dietary diversity, or suboptimal dietary planning. Vitamin D intake may be insufficient in some patients with CD, and calcium intake may fall below recommended levels, particularly among adolescents and older adults (Di Stefano et al., 2023). Calcium is the mineral that highlights the complex causal processes involved in the development of nutrient deficiencies in CD. The potential mechanisms include the loss of villus surface area, the binding of calcium to unabsorbed fatty acids in the intestinal lumen, the disruption of active intestinal calcium transport due to vitamin D depletion in enterocytes, and a secondary decrease in dietary calcium and vitamin D intake related to associated lactase deficiency. These mechanisms result in hypocalcemia, which can trigger secondary hyperparathyroidism, leading to increased mobilization of calcium from bone and subsequent reductions in bone mineral density. Thus, calcium deficiency in CD is not a simple isolated event but rather the outcome of interacting, multi-step processes involving intestinal damage, vitamin D metabolism, and hormonal adaptation. This finding also suggests that vitamin D deficiency may induce or directly contribute to other nutrient deficiencies, including calcium and magnesium (Di Stefano et al., 2013; Grace-Farfaglia, 2015; Micic et al., 2020) . A meta-analysis reported that calcium and magnesium intakes associated with a GFD were particularly inadequate among adolescents, whereas vitamin D intake was insufficient in both children and adults (Gessaroli et al., 2023). Vitamin D deficiency occurs in 8-88% of untreated adult celiac patients and 0-25% of those following a GFD (Rondanelli et al., 2019). While lactose intolerance may lead some celiac patients to avoid dairy, this does not necessarily result in vitamin D deficiency, particularly in regions where dairy is not routinely fortified. A strict GFD can normalize Vitamin D and calcium levels within a year, potentially reversing bone loss. Calcium and vitamin D supplementation is recommended for patients with low levels, reduced bone density, or inadequate intake (Al-Toma et al., 2019). Research shows that 800 IU of vitamin D per day increases serum levels after six to 12 months. Calcium supplementation of 1000–1500 mg/day in divided doses is recommended for adults and adolescents, with additional supplements if dietary intake is inadequate. Since more than half of celiac patients may consume less than these recommended levels, regular dietitian monitoring is suggested (Wierdsma et al., 2013).

3.1.7. Iron (Fe)

CD primarily impairs iron absorption due to villous atrophy and inflammation in the small intestine, which reduces the surface area available for nutrient uptake (Theethira et al., 2014). Iron is primarily absorbed in the duodenum, and damage to this region markedly reduces absorption; this has been shown to be the main mechanism underlying iron deficiency in CD. In addition, increased inflammation affects hepcidin production, disrupting the systemic distribution of iron, and this metabolic dysregulation has been suggested to contribute to the development of iron deficiency (Stefanelli et al., 2020; Talarico et al., 2021).

A meta-analysis of studies conducted up to 2017 revealed that 3.2% of patients diagnosed with iron deficiency anemia also had biopsy-confirmed CD (Mahadev et al., 2018). According to the European Society for the Study of Coeliac Disease, many patients have low iron levels when they are diagnosed, and between 2% and 5% of these patients have CD. Strict adherence to a GFD has been shown to improve iron levels, but it is still important to include iron-rich foods in one's diet. In cases where patients have very low levels of iron or cannot tolerate oral iron supplements, intravenous iron treatment may be necessary (Al-Toma et al., 2019). Persistent iron deficiency in patients on a GFD may result from several factors, including poor dietary adherence, accidental gluten exposure, naturally low iron content in GF products, or ongoing intestinal pathology affecting absorption (Stefanelli et al., 2020).

3.1.8. Zinc (Zn)

Zinc is an essential trace mineral that plays a key role in numerous biochemical functions. Its deficiency can impair protein production and cause growth delay (Vici et al., 2016). Zinc is absorbed predominantly in the proximal duodenum, its level may be low in untreated celiac patients. Zinc deficiency in particular is well documented in patients with CD (Theethira et al., 2014). Zinc deficiency may impair protein synthesis, stunting growth. However, strict adherence to a GFD generally normalizes zinc levels, eliminating the need for long term supplementation. These micronutrient deficiencies are more common in children than adults with CD (Li et al., 2023). A study of National Health and Nutrition Examination Survey (NHANES) 2011–2014 data (398 children and 3334 adults) found lower zinc levels in children 6-19 with CD, confirming previous findings. However, adults over 20 with CD did not have low zinc levels. So, zinc supplementation could be beneficial in children at risk for CD (Li et al., 2023). Children have a high metabolic demand for zinc to support rapid growth and skeletal development, leaving them more vulnerable to malabsorption. In contrast, adults, who lack growth-related stress, primarily utilize zinc for mucosal repair, which may explain their more stable levels despite the disease (Chao, 2023). Consequently, targeted zinc supplementation is particularly vital in pediatric management to prevent irreversible growth delays during critical developmental windows.

3.1.9. Magnesium (Mg)

Approximately 21.4% of patients with CD had magnesium deficiency at diagnosis, and 19.6% of those on a GFD had it. Magnesium deficiency in CD is not directly caused by the GFD itself. Instead, it may result from a combination of malabsorption due to intestinal damage and the overall dietary intake and quality, similar to other minerals (Rondanelli et al., 2019). In a study, both male and female participants in the German population were found to have insufficient daily magnesium intake (Martin et al., 2013). Studies examining nutrients obtained from a GFD in adult and adolescent populations, magnesium intake has been reported to be insufficient in adolescents (Gessaroli et al., 2023; Kreutz et al., 2020). According Rondanelli et al. (2019) certain individuals with CD may benefit from magnesium supplements specifically 200-300 mg per day of magnesium oxide or magnesium chloride whereas others can enhance their magnesium status through dietary intake alone.

4. ALTERNATIVE GLUTEN FREE GRAINS AND PSEUDOCEREALS

In recent years, interest in GF grains has increased substantially. A GFD should primarily consist of naturally GF foods that are balanced in both macro and micronutrients (Rinninella et al., 2021). GF grains such as corn, rice, sorghum, and teff, along with pseudocereals such as amaranth, buckwheat, and quinoa, offer potential health benefits by supplementing nutritional deficiencies in existing GF products (Khairuddin & Lasekan, 2021).

4.1. Gluten Free Grains

GF grains have been used for centuries in traditional cooking techniques in the regions where they are grown. In recent times, GF grains have also been used to develop functional GF foods due to the increase in the prevelance of gluten intolerance and gluten sensitivity (Woomer & Adedeji, 2021).

Sorghum is a small, round grain that belongs to the Poaceae (Panicoideae) family. It is a common ingredient in GF products. The substance is primarily composed of prolamin proteins. Sorghum has a high carbohydrate content which is largely starch-based (Agregán et al., 2023). Sorghum is known as the fifth most widely cultivated grain crop in the world. Sorghum is used in foods, has high nutritional potential, and can be safely consumed by celiac patients. A recent study has revealed that coloured rice, corn and sorghum varieties contain higher levels of essential nutrients, dietary fiber and essential amino acids compared to white rice and corn (Winarti et al., 2023).

Rice is the seed of a monocotyledonous plant belonging to the genus Oryza and is classified in the Poaceae family. It is one of the most important staple foods in human nutrition. Due to its hypoallergenic properties, rice flour is widely used in GF products (Agregán et al., 2023). Rice consists of mostly carbohydrates (80%), protein (7-8%), fat (3%) and fiber (3%). Starch is the main component of rice. White rice is the most common type but there are also coloured varieties such as black, red and brown rice. As seen in Table 2, white rice has the lowest fiber (0.23 g/100 g) and fat (0.23 g/100 g) content among rice varieties, whereas black rice offers significantly higher fiber (6.99 g/100 g) and protein (9.28 g/100 g). The colour of these varieties comes from anthocyanins found in the pericarp, seed coat and aleurone layer (Raghuvanshi et al., 2017). Black rice is rich in carbohydrates and micronutrients, as well as phenolic compounds and anthocyanins. It also stands out with a very high folate content (270 µg/100 g) compared to red rice (20 µg/100 g) (Table 2). These compounds have been shown to exhibit potent antioxidant effects Black rice is considered a functional food because it provides high-quality protein, minerals, vitamins, fiber, and has a low fat content (Abouel-Yazeed et al., 2019). A pilot study evaluated the effects of different cooking methods (boiling or risotto-style) of black and white rice on the glycemic index and postprandial glucose response in children and adolescents with CD and type 1 diabetes. According to the results, black rice, being richer in fiber and lower in starch, provided better glycemic control when boiled compared to white rice (Colasanto et al., 2023).

Corn is an important agricultural product worldwide and contains zein, a storage protein that can be used as a substitute for gluten in baking. Nutritionally, corn contains 8.80 g/100 g of protein and a relatively high fiber content of 9.80 g/100 g, although it is lower in calcium (2.48 mg/100 g) and iron (0.38 mg/100 g) compared to other GF grains (Table 2). A study was conducted to compare the phenolic compound content and antioxidant capacity of pigmented and yellow corn varieties. The study found that pigmented varieties have significantly higher antioxidant potential. Due to its high phenolic compound and anthocyanin content, pigmented corn has been identified as a potentially important antioxidant and anti-inflammatory food component, particularly for individuals with CD following a GFD (Colombo et al., 2021).

Teff stands out as an ancient grain with high nutritional value and versatile application potential. It is rich in nutrients and antioxidants, offering technological and nutritional advantages for use in various food products. Its high fiber content (8 g/100 g), nutritional value, and prebiotic properties make teff stand out as a superior grain compared to many other common cereals. Specifically, teff is exceptionally rich in calcium (180 mg/100 g), which is significantly higher than white rice (7.94 mg/100 g), and it provides a strong protein profile of 13.3 g/100 g (Table 2). As a naturally GF grain, teff is suitable for individuals with CD and gluten sensitivity (Abebe et al., 2025). Teff is rich in lysine, an essential amino acid that is limited in other grains. Teff has a low fat content and consists largely of unsaturated fats. It supports gut health due to its soluble and insoluble fiber profile. In modern applications, its lack of gluten and high water retention capacity make it suitable for use in the production of functional products such as bread, muffins, cookies, and breakfast cereals (Abebe et al., 2025).

Hairless canary seed (Phalaris canariensis L.) belongs to the Gramineae family, like wheat, rice, and corn. It is highly distinguished by its protein content, which is the highest among the listed grains at 23.70 g/100 g (Table 2). It is GF and rich in protein, tryptophan, and bioactive peptides, and also contains carotenoids, polyphenols, and healthy unsaturated fats. Furthermore, it is a significant source of magnesium (216 mg/100 g) and folate (100 µg/100 g) (Table 2). Due to these properties, it is considered a functional food ingredient for oxidative stress, diabetes, and celiac patients (Abdel-Aal & Gamel, 2025).

Fonio (Digitaria exilis), a small-grained cereal native to West Africa. Although fonio has a relatively low total protein content, it is comparatively rich in essential sulfur-containing amino acids, methionine and cysteine, compared to other GF grains. This characteristic may be important for preventing deficiencies of sulfur-containing amino acids that can arise during GFDs in individuals with CD. Methionine plays a key role in methylation and homocysteine metabolism, while cysteine is a critical precursor for glutathione synthesis; these metabolic pathways are directly linked to B-vitamin cofactors. Fonio, despite its low protein and fiber content, can be a valuable source of minerals and amino acids for GFDs due to its high magnesium and sulfur-containing amino acid) content. (Cruz, J 2004; Yiğit & Güneş, 2018) (Table 2).

Table 2. Nutrient Content of Different Gluten-Free Grains (per 100 g uncooked)

Cereal Type	Protein (g)	Fat (g)	Carbohydrate (g)	Dietary Fiber (g)	Calcium (mg)	Iron (mg)	Magnesium (mg)	Folate (µg)	Reference
GF Grains									
White Rice	7.60	0.23	78.34	0.23	7.94	7.65	46.45	70	(Raghuvanshi et al., 2017)
Red Rice	7.70	2.20	73.70	2.20	9.26	13.5	192.27	20	(Raghuvanshi et al., 2017)
Black Rice	9.28	3.06	75.59	6.99	7.50	8.20	79.1	270	(Abouel-Yazeed et al., 2019; Winarti et al., 2023)
Corn	8.80	3.80	65.00	9.80	2.48	0.38	144.57	80	(Winarti et al., 2023)
Teff	13.30	2.38	73.13	8	180	7.63	184	25	(Rinninella et al., 2021)
Sorghum	10.40	1.90	72.60	6.23	12.52	2.39	73.07	50	(Winarti et al., 2023)
Glabrous Canary Seed	23.70	7.90	60.93	6.20	32	6.60	216	100	(The Canary Seed Development Commission of Saskatchewan, 2016)
Fonio	2.20	2.20	89.5	0.90	1.03	2	148	4.5	(Bassey et al., 2023; Koreissi-Dembélé et al., 2013)

Pseudocereals										
Buckwheat	13.25	3.40	71.50	10	18	2.20	231	30	(USDA, 2020)
Quinoa	14.12	6.07	64.16	7	47	4.6	197	184	(USDA, 2020)
Amaranth	13.56	7.02	65.25	6.7	159	7.61	248	82	(USDA, 2020)

Note: All nutrient values presented in the table correspond to 100 g of raw (unprocessed, non-fortified) products.

4.2. Pseudocereals

Pseudocereals are similar to cereals and most of their seeds are consist of endosperm, aleurone, testa, and husk. Amaranth, quinoa and buckwheat are not true cereals; they are dicotyledonous plants. In contrast, common cereals such as wheat, maize, and barley are classified as monocotyledons. Consequently, these plants are classified as pseudocereals, as their seeds bear a resemblance to those of true cereals in terms of function and composition (Alvarez-Jubete et al., 2010).

In the formulation of GFD, highly nutritious pseudocereals such as amaranth, quinoa, and buckwheat play a significant role. For example, replacing corn starch with amaranth flour increased the protein and fiber content in GF breads without affecting sensory properties (Nandan et al., 2024; Rai et al., 2018). According to the results of a randomized crossover study, the consumption of buckwheat products in patients with gluten sensitivity has been shown to reduce gastrointestinal and related symptoms, primarily abdominal pain and bloating, increase serum magnesium levels, and improve the inflammatory profile by lowering pro-inflammatory cytokines (Dinu et al., 2017). For individuals adhering to a GFD, pseudocereals offer a more balanced nutrient composition and may help prevent common deficiencies (Caeiro et al., 2022).

Amaranth and quinoa have a higher protein content than common grains such as wheat: specifically, amaranth contains approximately 13.6 g/100 g, quinoa 14.1 g/100 g, and buckwheat 13.25 g/100 g, which are notably higher than white rice (7.6 g/100 g) and corn (8.8 g/100 g) (Table 2). The proteins are mostly composed of globulins and albumins, which differ from the prolamins found in grains. (Alvarez-Jubete et al., 2009). Pseudocereals are rich in lysine, an amino acid that is limited in cereals. In addition, their protein digestibility and quality (NPU/PER values) are close to those of casein (milk protein)(Abdel-Aal & Hucl, 2002)

A GFD is generally low in dietary fiber. For individuals with celiac disease, a daily fiber intake of 20–35 g is recommended. Pseudocereals have a much higher fiber content compared with cereals such as rice and maize (Saturni et al., 2010). Buckwheat has the highest fiber content at 10.0 g/100 g, followed by quinoa (7.0 g/100 g) and amaranth (6.7 g/100 g), compared to only 0.23 g/100 g in white rice (Table 2). Amaranth is also rich in calcium (159 mg/100 g), magnesium (248 mg/100 g), and iron (7.61 mg/100 g) (Table 2), which are especially important for CD patients at risk of osteoporosis and anemia, particularly when compared to the lower mineral levels in corn (Table 2).

Although pseudocereals have a higher fat content, this fat mainly consists of healthy unsaturated fatty acids, particularly alpha-linolenic acid. Amaranth is notable for its high content of squalene, a compound also found in fish liver oil (Saturni et al., 2010). The lipid content of amaranth (7.0 g/100 g) and quinoa (6.1 g/100 g) is higher than that of buckwheat (3.4 g/100 g) and other grains such as white rice (0.23 g/100 g) (Table 2), and consists mostly of unsaturated fatty acids (linoleic and oleic acids). Pseudocereals have a low glycemic index potential: quinoa, buckwheat, and amaranth are important for blood sugar regulation (Alvarez-Jubete et al., 2010; Caeiro et al., 2022; Nandan et al., 2024).

CONCLUSION

The GFD is an essential component of a comprehensive management strategy for individuals diagnosed with CD. However, if not implemented in accordance with the established guidelines, it can potentially result in significant nutrient imbalances. Nutritional deficiencies that are prevalent in the population include dietary fiber, B vitamins, iron, calcium, and vitamin D. These deficiencies can often be attributed to a GFD or to nutrient absorption problems associated with CD. Including nutrient rich alternatives such as pseudocereals and GF grains in the diet can help reduce nutritional imbalances. It is therefore recommended that GFD be supported by pseudocereals such as quinoa, amaranth, and buckwheat, as well as GF grains such as teff, sorghum, black rice, and red rice. A balanced and carefully planned GFD is essential to ensure long term health and nutritional adequacy in individuals with CD. To improve the quality of a GFD, it is necessary to reduce total fat and saturated fat intake, increase fiber intake, and choose grains and GF products rich in deficient vitamins and minerals. Furthermore, future research should prioritize modern processing techniques, such as fermentation and germination, to reduce anti-nutritional factors (e.g., phytates) in pseudocereals and enhance the bioavailability of essential minerals. Additionally, there is a need to evaluate the long-term health outcomes of individuals adhering to a GFD.

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