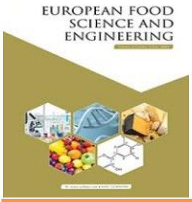

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Teff: Its role in gluten-free food formulations and potential applications - An overview of existing literature research

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ABSTRACT

Teff, an ancient Ethiopian grain, is renowned for its gluten-free nature and nutrient density, offering protein, fiber, iron, and calcium-ideal for individuals with celiac disease or gluten sensitivity. Its unique functional properties, including moisture retention, texture enhancement, and extended shelf life, make it valuable in gluten-free food production. This review covers the nutritional content of teff, including its carbohydrate, protein, fat, mineral, and vitamin compositions, as well as its functional properties such as water absorption capacity, water holding capacity, and rheological characteristics. In addition, the bioactive and probiotic potential of fermented teff products and their role in enhancing gut health are discussed. The utilization of teff in the development of gluten-free food products is explored, emphasizing its ability to improve the nutritional and sensory qualities of gluten-free alternatives. Teff has shown significant potential as a gluten-free ingredient, improving both the sensory appeal and the nutritional value of gluten-free products. Its mild flavour and diverse application potential across various food categories make it a promising alternative to traditional grains. Ongoing research and innovation in teff-based product development will be key in advancing the gluten-free food sector and meeting the growing demand for high-quality and nutritious alternatives.

1. Introduction

Gluten is a protein mixture composed of gliadins and glutenins in wheat, with similar proteins in barley and rye, accounting for 80% of total grain proteins. In barley, this protein is known as hordein, in rye as secalin, and in oats as avenin (Biesiekierski, 2017; Shewry, 2017). Although these proteins share similar properties, they can trigger adverse reactions in individuals with celiac disease or gluten sensitivity due to their structural similarities to wheat gluten proteins (Biesiekierski, 2017; Demir et al., 2017; Cabanillas et al., 2020). Gluten proteins, especially gliadin and glutenin, are known to cause negative effects in those with gluten allergy, celiac disease, or non-celiac gluten sensitivity (Scherf et al., 2016). The European Commission defines gluten in the context of gluten intolerance as "gluten derived from wheat, rye, barley, oats, or their hybrid varieties and derivatives, to which some individuals are intolerant and which is insoluble in water and 0.5 M sodium chloride solution" (Arendt & Dal Bello, 2008; Šmídová, & Rysová, 2022). Celiac disease is characterized by a permanent sensitivity to certain sequences of amino acids found in the prolamin fraction of the wheat, barley, and rye (Wieser & Koehler, 2008). Individuals with celiac disease must follow a gluten-free diet, avoiding proteins from grains like amaranth, corn, quinoa, buckwheat, sorghum, millet, teff, rice, and oats (Figure 1) (Thompson et al., 2009; Tsatsaragkou et al., 2017). Replacing gluten-containing foods, such as bread, pasta, and cereals, with gluten-free options can be challenging (Thompson, 2009; Zoumpopoulou & Tsakalidou, 2019). A gluten-free diet includes naturally gluten-free foods like seafood, poultry, meat, vegetables, fruits, legumes, and most dairy products. It is crucial to carefully check food labels for hidden gluten and avoid cross-contamination in food preparation (Hasselbeck, 2009; Bower & Sharrett, 2014; Jnawali et al., 2016; El Khoury, 2018).

Gluten-free flours, including rice, corn, chickpea, almond, coconut, buckwheat, potato, and teff, provide nutritious alternatives for individuals with celiac disease, wheat allergy, and non-celiac gluten sensitivity (Hager et al., 2012a; Ahmad et al., 2019). Teff (*Eragrostis tef*) (Figure 2) is a gluten-free cereal grain native to the Horn of Africa, particularly Ethiopia and Eritrea, where it plays a vital role in traditional diets (Zeid et al., 2012; Woldeyohannes et al., 2022). Teff is Ethiopia's second-most important cash crop after coffee, generating about $500 million annually and significantly

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Figure 1. Foods that trigger and foods safe for celiac disease symptoms.

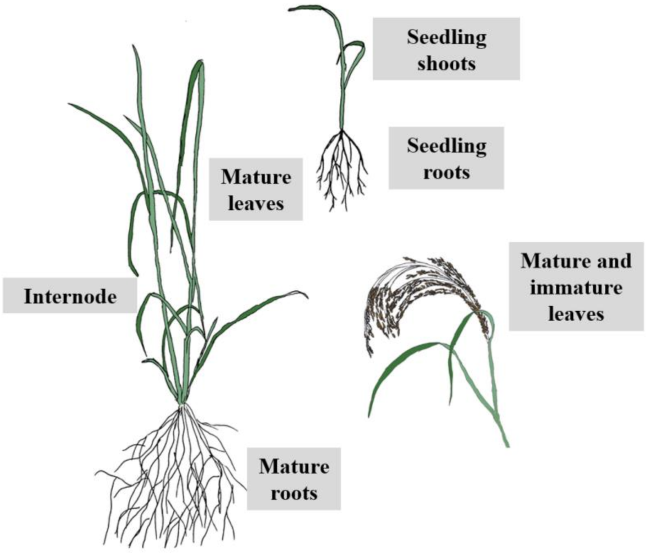

Figure 2. Representation of different parts of the teff plant (VanBuren et al., 2020)

surpassing the price of other cereal crops (Awol et al., 2023).

Due to its small, nutrient-dense grains and adaptability to various agroecological conditions, teff has gained global attention for its resilience and potential as a nutrient-rich gluten-free grain (Gebremariam et al., 2014). Teff is recognized for its rich nutritional profile, including essential minerals like iron and calcium, dietary fiber, and bioactive compounds such as phenolic acids and flavonoids, making it a valuable component for health promotion (Figure 3) (Zhu, 2018). It is increasingly incorporated into gluten-free products, including baked goods, porridge, and fermented foods such as injera, a staple in Ethiopian cuisine (Tess et al., 2015; Awulachew, 2020). As the demand for gluten-free and nutrient-dense foods rises, teff continues to gain popularity globally (Gebru et al., 2020). Teff-based fermented cereals also play a vital role in promoting food security, dietary diversity, and preserving cultural heritage in Ethiopia and beyond (Baye, 2018; Tadele & Hibistu, 2021; Tadele & Hibistu, 2022; Risitha & Vani, 2023).

Teff cultivation has expanded to countries like the Netherlands, Uganda, South Africa, the UK, Canada, China, India, Cameroon, and the United States due to its adaptability to diverse environments (Di Ghionno et al., 2017). Teff's small size, high density, and water absorption capacity make it suitable for various food and beverage applications, such as malting, brewing, and gluten-free products (Bultosa, 2007; Gebremariam et al., 2014; Callejo et al., 2019). Additionally, teff fermentation promotes probiotic properties, enhancing gut health and overall digestive well-being (Mezemir, 2015; Alemneh et al., 2021).

Teff is rich in bioactive compounds like flavonoids, phenolic acids, phytic acid, and lignans, which exhibit antioxidant properties that neutralize free radicals. Its fibers promote digestive health, while the proteins provide essential nutrients. Industrial processes like milling and fermentation may alter teff's phenolic profile, influencing its nutritional benefits (Bultosa, 2007; Gebremariam et al., 2014; Dueñas et al., 2021; Awol et al, 2023). Teff is also beneficial for athletes and weight management due to its low glycemic index and sustained energy release (Figure 4) (Do Nascimento et al., 2018; Sridhara et al., 2021). Furthermore, teff extracts have demonstrated *in vitro* anti-proliferative and anti-metastatic effects, particularly when subjected to heat treatment Moreover, its small size, high density, and water absorption capacity make it ideal for brewing, malting, and gluten-free products (Gebremariam et al., 2014). Teff, through its fermentation process, contributes to the development of probiotic properties, promoting beneficial bacteria growth that supports gut health and overall digestive well-being (Mezemir, 2015; Carboni et al., 2020; Alemneh et al., 2021).

Teff grains are rich in bioactive compounds such as flavonoids, phenolic acids, phytic acid, and lignans, which have antioxidant properties that combat cellular damage by neutralizing free radicals. The fibers in teff aid digestive health, while its proteins are a valuable nutritional source. Industrial processes like milling and fermentation can alter teff's phenolic profile, potentially affecting its nutritional benefits (Dueñas et al., 2021). Additionally, teff is high in essential minerals like iron and calcium and various vitamins, contributing to overall health. Its gluten-free nature and low glycemic index offer sustained energy release, making it beneficial for athletes and weight management (Gamboa & Ekris, 2008; Do Nascimento et al., 2018; Sridhara et al., 2021).

This article aims to comprehensively examine the research findings related to teff, including its nutritional content, health benefits, bioactive properties, and its role as a gluten-free alternative in various food applications. Additionally, it seeks to provide insights for future research to further explore teff's potential within the gluten-free market.

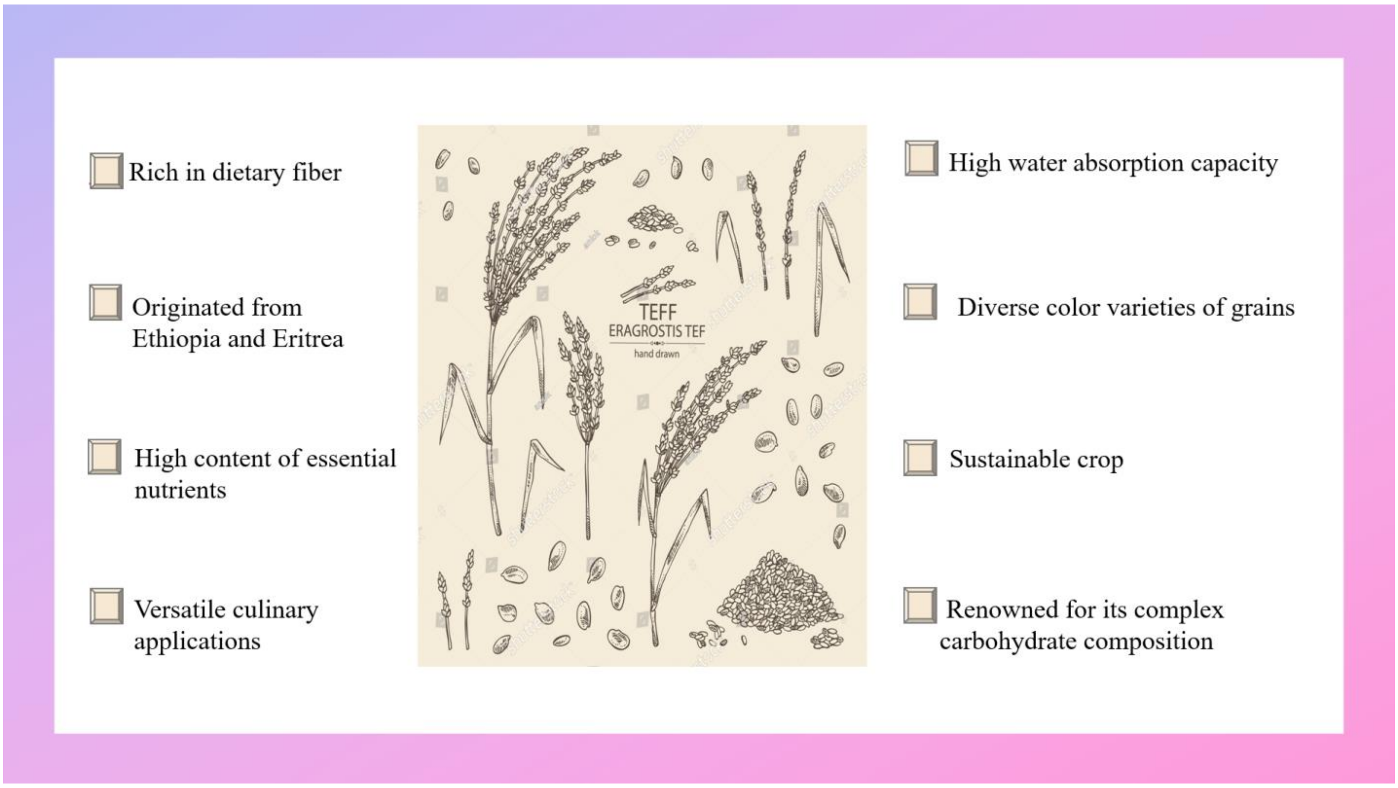

Figure 3: A general overview for teff.

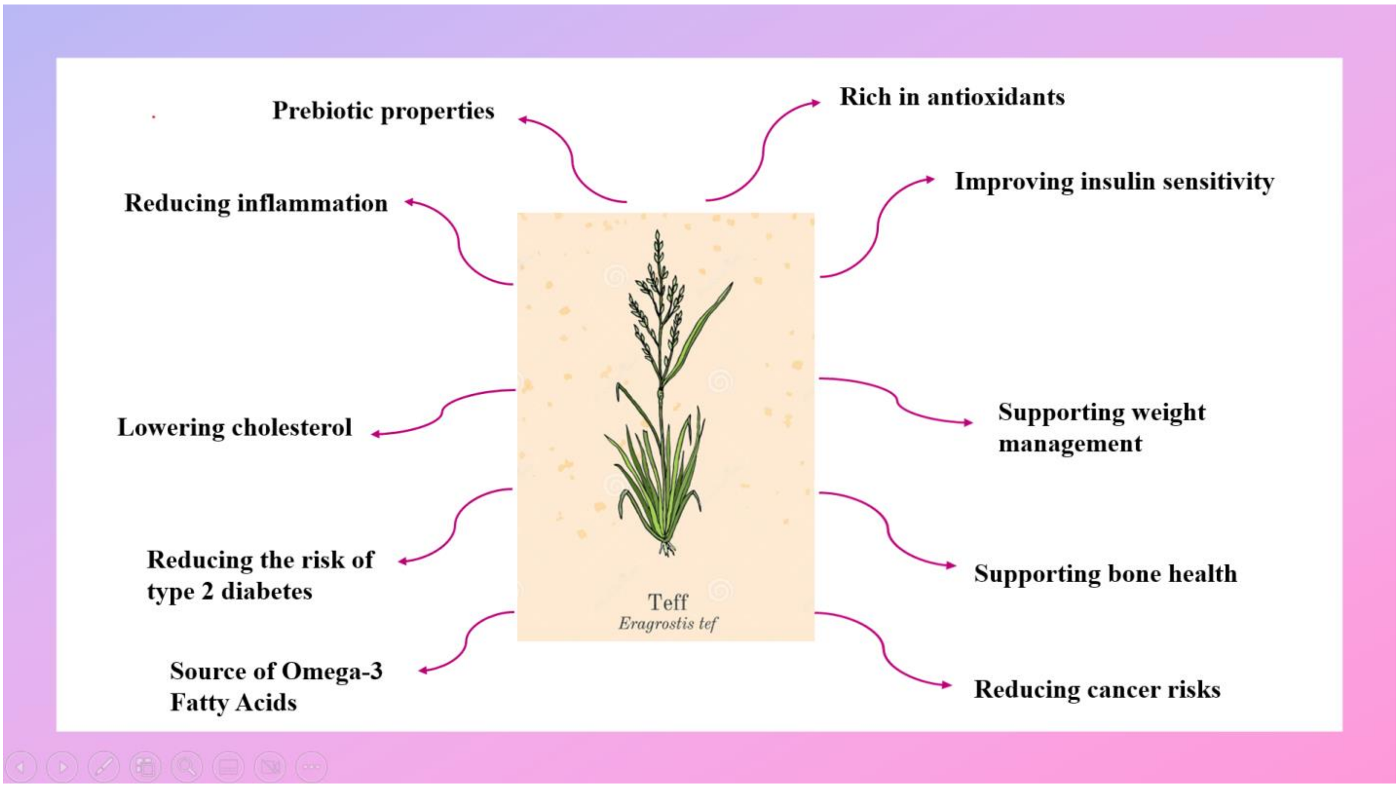

Figure 4. Health benefits of teff.

2. Nutrient Content of Teff

2.1. Carbohydrate content of teff

Carbohydrates serve as the primary source of energy for the human body, fueling metabolic processes and daily activities. Among carbohydrate-rich foods, teff stands out for its unique nutritional profile. The carbohydrate content of teff, predominantly starch, contributes significantly to its dietary significance and functional versatility (Gamboa & Ekris, 2008). The nutritional composition of teff is presented in Figure 5 in the form of a pie chart. Accordingly, teff's carbohydrate content ranges from 70% to 80% of its dry weight, making it a staple in many diets, particularly in Ethiopia, where it is used in traditional foods like injera (Dijkstra et al., 2008; Gebru et al., 2020; Sridhara et al., 2021). Starch (73-78%), the primary component of teff, contains both amylose and amylopectin, the lower amylose content (20-32%) improves digestibility and culinary applications (Dijkstra et al., 2008; Gebremariam et al., 2014; Yılmaz & Arslan, 2018; Zhu, 2018; Sridhara et al., 2021). The water-soluble total sugar content in white and brown teff grain extracts was found to range between 2.69-4.56 g GE/100 g and 2.22-4.74 g GE/100 g, respectively, indicating that both varieties are rich in total water-soluble sugars (Yisak et al., 2023).

In addition to its unique carbohydrate composition, teff offers health benefits due to its high dietary fiber content, which aids in digestive health and blood sugar management (Yilmaz & Arslan, 2018; Gebru et al., 2020). Researches by Bultosa (2007), Gebremariam et al. (2014), Baye (2018), Alemneh et al. (2021), and Barretto et al. (2021) highlighted the fiber content of teff, typically ranging from 2% to 10% in TF. Comparative analyses with grains like barley, rye, and maize revealed variations in fiber content, with teff often showing comparable or higher levels. For instance, Bultosa (2007) compared teff's fiber content with that of barley, rye, and maize, underscoring teff's favorable fiber content among these grains. The relatively high fiber content of teff supported satiety, aiding in weight management and promoting digestive health. Furthermore, teff could be a promising ingredient for developing food formulations tailored specifically for diabetic individuals, given its low glycemic index as demonstrated in studies on both healthy humans and mice (Habte et al., 2022).

Teff's high carbohydrate content, especially its slow-digesting starch, is beneficial for stable blood sugar levels, making it a good option for diabetics (Gamboa & Ekris, 2008). Non-starch polysaccharides in teff contribute to its high dietary fiber content, which is linked to reduced chronic disease risk (Gebru et al., 2020). This combination of high starch and fiber content supports its role as a staple food in Ethiopian cuisine and highlights its potential in global health nutrition.

The gelatinization of starch in teff, characterized by the swelling and rupture of starch granules upon heating, significantly influences its digestibility and physiological effects. Compared to other cereal grains, teff starch exhibits unique gelatinization properties. While wheat starch typically gelatinizes at temperatures ranging from 52 °C to 66 °C (Ubwa et al., 2012), teff starch gelatinizes at higher temperatures, typically between 68 °C to 80 °C (Bultosa et al., 2002).

2.2. Protein content of teff

Proteins are essential macronutrients that play diverse and vital roles in the human body, serving as the building blocks for tissues, enzymes, hormones, and immune molecules. Among cereal grains, teff stands out for its noteworthy protein content and unique amino acid composition, contributing to its nutritional value and functional versatility (Gebremariam et al., 2014). In this sense, Dijkstra et al. (2008), Gebremariam et al. (2014), Sharma & Chauhan (2018), and Zhu (2018) highlighted the protein content of teff, which typically ranged from 8% to 15% in TF. Moreover, teff protein was distinguished by its balanced amino acid profile, encompassing all essential amino acids in adequate proportions.

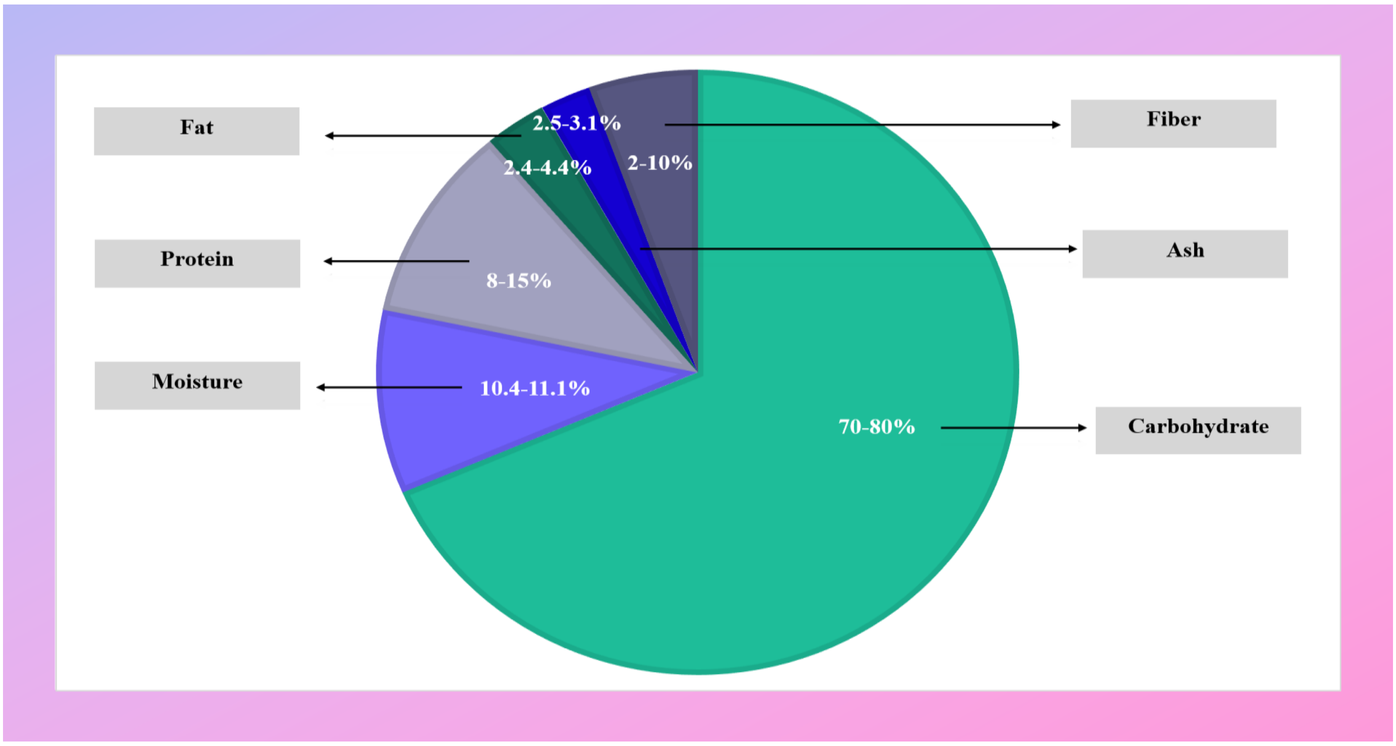

Figure 5. Nutritional composition of teff.

Additionally, Dijkstra et al. (2008) suggested that this protein content makes teff a valuable source of essential amino acids, including methionine and lysine, which are often restricted in other cereal grains. Bultosa (2007) and Barretto et al (2021) further underscored the variations in protein content among different teff grain varieties, emphasizing the importance of considering the variety differences in nutritional assessments. In this context, studies comparing white and brown teff seeds revealed that white teff seeds had higher total amino acid content (Gebru et al., 2019). Furthermore, Kahlon & Chiu (2015) and Sridhara et al. (2021) emphasized the importance of teff as a protein-rich food, particularly for vegetarian and vegan diets. The protein composition of teff also played a crucial role in promoting muscle growth and repair, as well as supporting overall immune function and hormone production (Dijkstra et al., 2008; Barretto et al., 2021). Additionally, teff's protein content contributed to its satiety-inducing properties, making it a suitable option for weight management and appetite control (Awulachew, 2020; Sridhara et al., 2021). Furthermore, Barretto (2020) reported that teff protein contained higher levels of lysine (3.7%), an essential amino acid often limited in grains like wheat. This unique amino acid profile enhanced teff's nutritional value, making it a valuable dietary source of essential amino acids, especially for those on plant-based diets or facing lysine deficiency (Gebremariam et al., 2014; Shumoy et al., 2018; Gebru et al., 2020).

Teff's gluten-free nature is a significant advantage for those with gluten intolerance or celiac disease. Unlike wheat, barley, and rye, which contain gluten proteins that can provoke adverse reactions in sensitive individuals, teff is naturally gluten-free (Baye, 2018; Satheesh & Fanta, 2018). This characteristic not only broadens dietary choices for those with gluten-related disorders but also positions teff as a valuable ingredient in gluten-free food products (Baye, 2018; Quan et al., 2023).

The protein content and amino acid composition of teff are further influenced by various processing methods, including fermentation, malting, and brewing. Fermentation, for instance, has been shown to enhance the digestibility and bioavailability of teff protein by promoting the breakdown of complex protein structures into more readily absorbable forms. During the fermentation process of teff, proteins play a crucial role in enzymatic activities and microbial growth, influencing the overall quality and characteristics of fermented products such as injera (Gebremariam et al., 2014; Barretto et al., 2020). Overall, teff's protein-rich, gluten-free composition and high lysine content highlight its unique nutritional benefits compared to other grains.

2.3. Fat content of teff

Fats and fatty acids play essential roles in the human body, serving as concentrated sources of energy, facilitating the absorption of fat-soluble vitamins, and contributing to cell structure and function. Among cereal grains, teff exhibits a distinctive fat content, comprising both saturated and unsaturated fatty acids, which contributes to its nutritional profile and health benefits. In this regard, studies by Hager et al. (2012a), Yılmaz & Arslan (2018), Zhu (2018), and Amare et al. (2021) sheded light on the fat content of teff, which typically ranged from 2.4% to 4.4% in TF. According to Hager et al. (2012a), a comparative study found that teff has a higher lipid content (4.4%) than rice (0.9%), sorghum (3.5%), maize (2.5%), and wheat (3.6%) flours, but a lower lipid content compared to oat (6.7%) and quinoa (8.6%). Moreover, Amare et al. (2021) examined the fatty acid profile of various teff varieties from Ethiopia and found significant differences in lipid composition. Teff grains were notable for their content of unsaturated fatty acids, such as oleic acid (a monounsaturated fatty acid), linoleic acid (an omega-6 polyunsaturated fatty acid), and linolenic acid, all essential for human health. The study revealed oleic acid levels ranging from 23.59% to 26.65%, linoleic acid levels from 41.91% to 43.33%, and alpha-linolenic acid (ALA) levels from 6.09% to 7.18% across different teff varieties. These fatty acids possess various health benefits, including cardiovascular protection, anti-cancer and anti-inflammatory effects (Barretto et al., 2021). Moreover, El-Alfy et al. (2012) reported that teff had more unsaturated fatty acids like oleic and linoleic acid compared to other cereals, making it nutritionally superior due to its lower saturated fat content. In summary, although teff may not be a major source of dietary fat, its distinctive fatty acid composition, which includes unsaturated fatty acids, enhances its nutritional value and health-promoting properties. By incorporating teff into a balanced diet, individuals can benefit from its advantageous fatty acid profile, thus supporting overall health and well-being.

2.4. Mineral and vitamin content of teff

Minerals are vital micronutrients essential for numerous physiological functions, including bone formation, nerve function, enzyme activation, and oxygen transport. Sufficient mineral intake is necessary to support overall health and prevent deficiency-related disorders (Godswill et al., 2020). Teff, a highly nutritious cereal grain, contains a range of minerals that enhance its nutritional value and health benefits. Studies by Bultosa (2007), Gebremariam et al. (2014), Baye (2018), and Barretto et al. (2021) had explored teff's mineral content, emphasizing its importance as a substantial source of essential minerals like iron, calcium, zinc, copper and magnesium.

Iron is vital for blood oxygen transport and energy metabolism (Figure 6), and teff is a key dietary source of this mineral. Iron deficiency anemia is a major global health concern, particularly in areas with limited access to iron-rich foods (Saini et al., 2016). Consuming teff has been linked to lower rates of iron deficiency anemia, particularly in Ethiopia, where teff is a staple food (Gebru et al., 2020; Awulachew, 2020a). In this context, Mohammed et al. (2019) conducted a study on the relationship between teff injera consumption and anemia. They reported that consuming teff was linked to lower chances of anemia in pregnant women. In addition, a daily intake of approximately 200 g of 30% teff-enriched bread would meet 76% of the Dietary Reference Intakes for iron in women and 129% for iron in men. It also provided 39% of the protein requirement for men and 48% for women, as well as 50% of the required fiber intake for adults (Alaunyte et al., 2012). Furthermore, calcium, crucial for bone health, muscle function, and nerve transmission (Figure 6), is abundant in teff. Deficiency in calcium is widespread, increasing the risk of osteoporosis and fractures. Incorporation of teff into the diet can alleviate calcium deficiency and promote bone health, especially in populations with restricted access to dairy products (Gebremariam et al., 2014; Erol et al., 202;). Daily iron, calcium, and zinc needs can be supplied by consuming suitable food products made from teff (Baye, 2014; Gebremariam et al., 2014; Awulachew, 2020a). Additionally, zinc, essential for immune function, wound healing, and DNA synthesis (Figure 6), is abundant in teff. Zinc deficiency compromises immune response and increases susceptibility to infections.

Figure 6. Mineral composition of teff.

Adding teff to the diet boosts zinc intake, aiding immune function, especially in areas where zinc deficiency is common (Figure 6) (Barretto et al., 2021). Also, magnesium, crucial for numerous enzymatic reactions, muscle and nerve function, blood sugar regulation, and blood pressure control, is abundant in teff (Gröber et al., 2015). Consuming teff may lower the risk of hypertension, type 2 diabetes, and cardiovascular diseases due to its magnesium content by enhancing cellular defenses against oxidation damage and potentially improving insulin sensitivity and secretion (Habte et al., 2022).

Experimental research on the vitamin composition and contents revealed that vitamin B1 (0.30-0.83 mg/ 100 g), vitamin B2 (0.11-0.30 mg/ 100 g), vitamin B3 (0.20-3.36 mg/ 100 g), vitamin B6 (0.48 mg/100 g), thiamin (0.39 mg/100 g), riboflavin (0.27 mg/100 g), vitamin K (1.9 µg/100 g), vitamin A (9 IU), and α-tocopherol (0.08 mg/100 g) are present in raw teff (Gebru et al., 2020). When compared to wheat (0.43 mg/100 g) and barley (0.37 mg/100 g), teff usually had less thiamin (Sridhara et al., 2021). In summary, teff's mineral and vitamin content enriches its nutritional profile and health benefits, making it a valuable component of a balanced diet. Including teff in daily meals helps to increase mineral and vitamin intake and promotes overall health and well-being, especially in areas where mineral deficiencies are common.

3. Functional Properties of Teff

3.1. Bioactive properties of teff

Teff is abundant in both macronutrients and micronutrients, and it also contains a range of bioactive nonessential metabolites like phenolic compounds and saponins, with its high phenolic content being largely attributed to significant levels of phenolic acids and flavonoids (Ananth et al., 2023). Research on teff's phytochemistry often highlights phenolic compounds due to their potential in lowering the risk of chronic diseases (Gebru et al., 2020; Dueñas et al., 2021; Sliwinski et al., 2021; Yisak et al., 2022). In this sense, Kataria et al. (2022) examined the effects of various thermal processing treatments on brown teff. Specifically, thermal processing had varied effects on teff grains, improving antioxidant activities and reducing antinutritional components. Microwave treatment was the most effective, enhancing both antioxidant potency and achieving a balance in reducing antinutrients (tannins, saponins, and phytic acid). Similarly, Ahmed et al. (2021) reported that roasting treatments, particularly microwave roasting, significantly improved the biochemical composition, antioxidant activity, and bioactive properties of teff grains, including their phenolic compounds and fatty acids. They concluded that roasting enhanced teff's nutritional value, making it a promising ingredient for functional foods. Additionally, Kotásková et al. (2016) reported that free phenolic fractions of teff grains, particularly in brown teff, exhibited higher flavonoid and polyphenol content, along with stronger antioxidant activity. They also found that boiling significantly improved the digestibility of teff, with cooked samples showing a 20% higher digestibility compared to uncooked teff. Furthermore, Gebru et al. (2021) reported that teff grains contain higher phenolic content and antioxidant activity compared to commonly consumed grains. Using UPLC-qTOF-MS, they tentatively identified 61 bioactive compounds in teff, providing a comprehensive profile of its phytochemicals and supporting its potential application in functional foods. Also, Kotásková et al. (2016) reported that the sous-vide method was the most effective heat treatment for preserving the phenolic content and antioxidant activity in teff grains, with minimal decreases observed compared to other thermal processes. They also found that heat-treated teff showed higher digestibility than raw grains, with the sous-vide process leading to the lowest reduction in antioxidant activity and improved phenolic acid concentration. Moreover, Viell et al. (2020a) reported that the simplex–centroid mixture design effectively optimized solvent composition for extracting phenolic compounds from brown teff grains, with the ternary mixture of water, ethanol, and methanol being the most efficient. Both ultrasound-assisted extraction techniques and homogenizer-assisted extraction successfully extracted key polyphenols such as rutin, p-coumaric acid, protocatechuic acid, and quercetin, highlighting teff's potential as a rich source of antioxidants. Additionally, Yisak et al. (2020) reported on the optimal extraction procedures and antioxidant capacity of phenolics in white and brown teff varieties, finding that brown teff had significantly higher total phenolic and flavonoid content. They determined that the extraction times varied, with 60 min being optimal for bound polyphenolics in brown teff and 40 min for free polyphenolics in white teff and noted that antioxidant activity was influenced not only by total phenolic content but also by the structure of individual phenolics. In addition, Dueñas et al. (2021) identified 59 phenolic compounds in teff, with flavones accounting for 97-99% of the total phenolic content, where C-glycosyl flavones were more abundant than O-glycosyl flavones. Processing methods such as flaking and extrusion were found to significantly affect flavone content, with a decrease observed in white teff, while brown teff showed higher flavone content after processing.

3.2. Probiotic characteristics of fermented teff products and their prebiotic potential

The growing awareness among consumers regarding the link between food and health is driving an increased interest in healthy diets. As a result, there is a rising demand for probiotic fermented food products, particularly those based on cereals. This trend is driven by consumers seeking alternative dietary options, including non-dairy probiotic fermented foods. The popularity of such products is fueled by the growing number of individuals adopting vegetarianism for medical or personal reasons, as well as concerns associated with dairy-based products. Additionally, the inclusion of prebiotics, which are non-digestible fibers that promote the growth of beneficial bacteria in the gut, further enhanced the appeal of these probiotic fermented foods among health-conscious consumers (Alemneh et al., 2023). In Ethiopia, teff is not only a staple in food production but also plays a significant role in the creation of traditional alcoholic beverages like tela, arake, gluten-free beer, and shamita. Moreover, injera, a popular Ethiopian flatbread, is predominantly made from teff rather than other grains. The fermentation process of injera, crucial for its characteristic texture and flavor, is heavily influenced by factors such as pH, substrate concentration, temperature, and aeration (Mengesha et al., 2022). In this sense, Alemneh et al. (2021) investigated the fermentation of *Lactobacillus plantarum* A6 (LA6) and *Lactobacillus rhamnosus* GG in TFs. In the study comparing single-strain and mixed-strain fermentations, it was found that mixed cultures exhibited higher microbial growth rates and pH reduction. The pH drop during fermentation was observed to create a harsh environment for spoilage bacteria, while incomplete consumption of maltose and glucose was noted. The results indicated that mixed cultures enhanced fermentation outcomes. The study was suggested to provide foundational knowledge for future research on probiotic food products based on teff. Moreover, Mezemir (2015) highlighted the association of *Lactobacillus plantarum* with lactic acid fermented plant-based foods, particularly Ethiopian sourdough made from teff. Injera, a staple food in Ethiopia, is a main dietary source of lactic acid bacteria (LAB) fermentation, with *Lactobacillus plantarum, Lactobacillus brevis,* and *Lactobacillus fermentum* being the predominant species at the end of teff fermentation, with *L. plantarum* being the most dominant. Studies on teff dough have shown that lactic acid bacteria proliferate during fermentation, reaching high concentrations and demonstrating survival in the acidic gastric environment. Optimizing teff fermentation could enhance its probiotic potential, offering health benefits for consumers in Ethiopia. Moreover, Gebru & Sbhatu (2020) focused on isolating LAB from Korean kimchi and spontaneously fermented Ethiopian TF batter, screening them for probiotic characteristics. A significant portion of the isolates demonstrated notable acid and bile tolerance, with many also exhibiting antimicrobial activity against *S. enteritidis* indicator strains. Isolates with strong protease activity were selected for teff fermentation to assess the impact on phenolic contents. The fermentation process led to a significant increase in total phenolic content in teff, while the total flavonoid content decreased with the majority of isolates. Tadesse et al. (2018) aimed to isolate and identify dominant bacteria from fermenting teff dough. The bacterial isolates were identified as *Lactobacillus paracasei, Lactobacillus brevis, Enterococcus durans, Enterococcus hirae, Enterococcus avium,* and *Enterococcus faecium.* All lactic acid bacteria identified could produce acid within 12 h of incubation. This research confirmed the presence of diverse bacterial species in fermenting teff dough and suggested the involvement of various bacterial groups throughout the fermentation process. Additionally, Habtu et al. (2024) focused on improving the consistency and reducing the fermentation time of traditional Ethiopian teff injera by identifying and molecularly characterizing the key microorganisms involved in the process. Dominant species isolated during fermentation included *Lactobacillus plantarum*, *Lactobacillus fermentum*, and yeast species such as *Saccharomyces cerevisiae* and *Pichia kudriavsevii*. These findings provided an insight for developing standardized starter cultures to enhance the efficiency and quality of injera production. Additionally, Mulaw et al. (2019) reported that four Lactobacillus isolates from teff dough were found to exhibit potentially probiotic characteristics. The four effective probiotic LAB isolates belonging to Lactobacillus species were identified at the strain level using 16S rDNA gene sequence comparisons. They were identified as, *Lactobacillus paracasei* subsp. *tolerans* strain NBRC 15906, *Lactobacillus plantarum* strain JCM 1149, *Lactobacillus paracasei* strain NBRC 15889, and *Lactobacillus plantarum* strain CIP 103151. It was suggested that these strains can be good candidates for food industries as prospective probiotic cultures with additional human health benefits. In addition, Muche et al. (2023) stated that probiotic yeasts isolated from Ethiopian fermented injera sourdough demonstrated the ability to thrive at 37 °C, withstand low gastric pH, and tolerate bile salts, indicating their potential as probiotics. The study highlights the nutritional bioavailability and health benefits of these yeasts in fermented foods, recommending further whole genome sequencing for detailed characterization. Yeast species such as *Saccharomyces cerevisiae*, *Candida humilis*, and *Pichia kudriavzevii* were identified as promising probiotic candidates. Moreover, Bonger et al. (2023) stated that the study aimed to optimize the traditional fermentation process of teff injera by identifying the dominant lactic acid bacteria (LAB) and yeast species involved. Through morphological, physiological, and biochemical characterization, the primary LAB and yeast strains were identified, including *Lactobacillus fermentum*, *Lactobacillus brevis*, *Bacillus subtilis*, *Enterococcus casseliflavus*, *Saccharomyces cerevisiae*, and *Pichia kudriavzevii*. The study demonstrated that using a single starter culture reduced fermentation time by 75%, from 96 h to

24 h, with further molecular characterization recommended to confirm these findings. Additionally, Mezemir (2015) highlighted teff's small grain size and the corresponding whole-grain flour, emphasizing its high fiber and nutrient content, which underscores its potential as a prebiotic. Prebiotic carbohydrates, when metabolized by probiotic strains, foster the growth and proliferation of beneficial gut bacteria, enhancing gut health.

3.3. Water absorption capacity

The water absorption capacity of TF is a critical parameter that influences its hydration properties and dough-handling characteristics (Föste et al., 2020). It is crucial to assess the flavor and consistency of flour and dough as they undergo proofing and baking processes (Tsegaye, 2020). Studies have indicated that TF exhibited high water absorption capacity and starch retrogradation occurs at a slow pace slowly, potentially benefiting the shelf life of cereal-based products (Bultosa, 2007; Bultosa et al., 2008). In this regard, Tsegaye (2020) conducted a study to assess the water absorption capacities of various teff varieties, including Quncho, Felagot, Tesfa, Kora, Dukem, and Dagme. Results indicated variations in water absorption capacity among these varieties, with Kora exhibiting the lowest value at 0.89 g/g while Quncho displayed the highest value at 0.99 g/g. Moreover, Alemneh et al. (2022a) suggested that water absorption capacity played a crucial role in gluten-free formulations, influencing the processing and quality of various food products. Ethiopian TF stood out as a preferred ingredient due to its superior water absorption capacity, making it well-suited for developing gluten-free bakery items and other viscous foods. Additionally, Boka et al. (2023) explored how different teff varieties and flour particle sizes impact functional properties. They found that as the particle size of TF decreased, the water absorption capacity significantly increased. These studies indicated that the water absorption capacity of TF can vary depending on various factors such as growing conditions, particle size, and geographical sources. Understanding and utilizing this attribute could contribute to creating gluten-free products with optimal texture, consistency, and sensory attributes.

3.4. Water holding capacity

Water-holding capacity refers to the protein matrix's ability within food systems to absorb and retain water through various interactions, including bound, hydrodynamic, capillary, and physically entrapped mechanisms, regardless of gravity (Traynham et al., 2007). According to Inglett et al. (2016), teff-oat composites possess superior water-holding capacity compared to WF alone. This characteristic enhanced their suitability for a wide range of applications within the food industry. These composites were particularly valued for their thickening properties, ability to control syneresis, and capacity to stabilize emulsions, in addition to their nutritional advantages.

3.5. Rheological properties of teff-based blends

As teff becomes an important ingredient in gluten-free products, understanding teff-based blends' viscosity and rheological properties is crucial for optimizing their functionality in food formulations. In this context, insights into the viscosity of TF gels and its relationship to textural properties were provided by studies conducted by Abebe & Ronda (2014) and Tsegaye (2020). These studies revealed that the viscosity of TF gels was influenced by factors such as flour particle size, hydration level, and processing conditions. Comparisons with other grains, such as wheat, hemp, and chia, demonstrated the unique viscosity profile of TF and its potential applications in gluten-free formulations (Hrušková et al., 2013). Moreover, the viscosity properties of teff-oat composites were investigated to understand their suitability for various food applications. The study found that incorporating oat products into TF did not significantly alter the pasting properties, with pasting viscosities of teff-oat bran concentrate and teff-whole oat flour composites being comparable to TF alone but higher than WF. This suggested that the addition of oat products maintained the desirable viscosity characteristics of TF, making the composites potentially valuable ingredients for food formulation (Inglett et al., 2015). Likewise, in a chemometric study investigating the rheological features of wheat composites with teff, hemp, and chia, a substantial 30% increase in viscosity was observed in wheat composites containing teff compared to pure wheat formulations (Hrušková et al., 2013). This suggested that the addition of TF contributed to the overall viscosity of composite systems, thereby influencing their functional properties. Furthermore, Alemneh et al. (2021) compared whole grain TF from Ethiopia (ETF) and South Africa (STF) regarding their pasting properties. The study discussed the final viscosity and setback viscosity of these starches, emphasizing their effects on gel structure formation and product texture. STF demonstrated a higher final viscosity, suggesting its potential to form a firm gel structure upon cooling in comparison to ETF. Setback viscosity, indicating paste gel-building capability, was influenced by amylose entanglement, with STF displaying greater recrystallization during cooling due to the slower retrogradation of amylopectin. Consequently, products made with STF exhibited slower staling and softer textures than those made with ETF. Furthermore, Yasin (2021) demonstrated that blending ratio and varieties significantly affected the pasting properties of Quality Protein Maize (QPM)-teff composite flours. Higher values of peak viscosity, through viscosity, breakdown viscosity, final viscosity, and setback viscosity were observed for the Melkassa-1Q variety compared to Melkassa-6Q. This suggested a notable disparity in pasting characteristics between the two QPM varieties, where Melkassa-1Q, characterized by yellow color and flint texture, exhibited superior properties over Melkassa-6Q, which was white in color and had a semi-flint texture.

Gelation refers to the formation of a gel-like structure in a substance, which impacts its texture, stability, and functionality (Yang et al., 2020). In a related study, the gel formation properties of three varieties of TF (one brown and two white) were investigated, revealing that a minimum flour concentration of 6-8% was required, similar to WF. TF suspensions heated to 95 °C produced gels exhibiting solid-like behavior at both 25 °C and 90 °C, with higher consistency than wheat gels at the same concentration. The relationship between viscoelastic moduli and concentration followed a power law, and the Avrami model effectively described the textural changes in teff gels. Differences observed among teff, rice, and wheat flour were attributed to variations in their protein, starch, lipid, and fiber content. These findings suggested that TF could serve as a suitable ingredient in gel food formulations (Abebe & Ronda, 2014). Furthermore, Abebe et al. (2015) conducted a series of tests, including oscillatory, creep-recovery, and assessments of dough stickiness, to explore the impact of incorporating TF into the dough. Their findings revealed visible changes in the structure of dough matrices, characterized by reduced viscoelastic moduli and increased maximum stress tolerance before structural breakdown. The study observed that the effect of TF dose wasn't consistently significant across measured parameters. However, incorporating teff grain flour up to a 30% level resulted in bread with enhanced loaf volume compared to the control, attributed to optimal consistency and increased deformability of doughs. Nevertheless, higher doses of teff led to increased dough stickiness, potentially affecting dough handling and shaping processes necessary for achieving continuous strands or thin sheets. Additionally, Calix-Rivera et al. (2023) found that rheological analysis of gels made from treated samples showed microwave radiation (MW) had a positive effect. It resulted in higher viscoelastic moduli (*G'* and *G")* and increased maximum stress of the gels could withstand before breaking. The moisture content during MW treatment influenced the techno-functional properties, rheological, and thermal characteristics of TF. These findings suggested that MW-treated TF can be valuable ingredients for enhancing the technological, nutritional, and sensory qualities of food products. In conclusion, the pasting properties and gelation behavior of TF play pivotal roles in determining its functionality in various food applications. Studies have highlighted the unique viscosity profile of TF, its compatibility with oat products in composite-type flours, and its potential to enhance the overall viscosity of composite systems. Additionally, the gelation properties of TF have been investigated, showcasing its suitability as a key ingredient in gel-like behavior in food formulations. Overall, these findings underscore the versatility and functional significance of TF in food processing and product development.

3.6. Utilization of teff in the production of gluten-free food products

Between 2012 and 2024, numerous studies have investigated the incorporation of TF into a wide array of gluten-free food products-ranging from cakes, gruel, and injera to macaroni, muffins, breakfast cereals, complementary foods, cookies, biscuits, beverages, pasta, noodles, and breads-evaluating its potential and its impact on overall product quality. The key findings from these studies are summarized in Table 1. In this context, Haas et al. (2021) contribute to this body of research by manufacturing gluten-free cakes incorporated with TF. The results showed that higher proportions of teff led to increased total ash content. Among apparent and specific volumes, the cakes, including 25% TF, 37.5% rice flour, and 37.5% cassava starch, exhibited the highest average. In sensory evaluation, appearance, color, and odor showed no significant differences across treatments. Moreover, Joung et al. (2017a) emphasized that pound cakes, including 20% of TF, had the lowest hardness, springiness, and chewiness, indicating improved texture and flavor retention. The addition of 20% TF was believed to enhance the quality attributes and slow down the retrogradation process of pound cake. In addition, Minarovičová et al. (2019) reported that of using TF provided satisfactory results up to 50%. However, the most acceptable ratio for assessors was 25%. Incorporating 75% TF negatively affected the quality and texture of rice muffins; they became harder, more prone to crumbling, and less elastic. Subsequently, Coleman et al (2013) reported that increasing the teff percentage in the formulation led to reduced bread and cake volume. There were noticeable differences in biscuit height and color across the various teff treatments. Their study indicated that TF was most suitable for use in cookies and biscuits. Moreover, Oliveira et al. (2020) suggested that the highest concentrations of teff (100%) in the physical studies had no effect on the yield, color, and luminosity of the cake crumb, or the height at which the cake was baked. Furthermore, Awulachew (2020b) stated that the composite flour blend of teff with sorghum and maize improved the nutritional profile of injera by increasing protein, fat, and fiber content while lowering carbohydrates in some formulations. As well, de Souza Nespeca et al. (2023) revealed that while TF can be included in formulations, its excessive presence had a negative impact on product acceptance, suggesting a need for moderation in its usage. Additionally, Tess et al. (2015) specified that a decrease in the height of baked muffins was observed with an increase in the percentage of TF. Muffins with TF had a more viscous batter than reference rice muffins, with lower springiness and specific gravity. According to Joeng et al. (2017b), the TF-incorporated cookie had a considerably larger spread factor, $a*$ value, and flavonoid and polyphenol content than the control. Compared to the control, the teff-incorporated cookies had reduced $L*$ value, hardness, and $b*$ value. In various studies, the incorporation of TF in composite form with different flours has been explored, revealing promising results in diverse applications. Teff, renowned for its nutritional richness and gluten-free properties, has emerged as a versatile ingredient in food formulations. In this regard, adding both okara and red TF to the cookie flours enhanced the overall nutritional quality of the product, effectively utilizing okara in cookie production (Hawa et al., 2018). Furthermore, Caporizzi et al. (2023) stated that the study explored the use of TF in developing gluten-free breakfast cereals, revealing its impact on both the sensory and nutritional properties of extrudates. The addition of TF significantly enhanced the fiber content, antioxidant activity, and total phenolic content of the products, though it reduced lightness, porosity, and crispness. Moreover, Pelinson Tridapalli et al. (2023) proposed that the descriptive sensory analysis of the formulations emphasized features that supported the incorporation of sorghum, teff, and yacon in gluten-free bread preparation. They noted that the combination of these three ingredients in the optimized formulation positively impacted the sensory attributes of the product, enhancing its flavor, taste, and texture. Inglett et al. (2016) also reported that TF and its blends exhibited greater water retention capabilities than WF. Moreover, Naumenko et al. (2023) investigated the impact of incorporating TF into wheat bread on its technological process and quality. Results showed that while TF enhances the nutritional value of bread, especially when used with a sourdough starter, adding 10-20%, TF reduces gluten elasticity and dough springiness. However, using 10% TF and sourdough improved bread quality, including a 4.0% increase in specific volume and a pleasant "nutty" taste. Furthermore, the study by Attuquayefio (2015) emphasized the importance of elasticity and eye formation in injera and stated that these attributes were very important to Ethiopian consumers. In this context, it was of great importance to investigate the viscosity and fermentation time of teff paste. The results of the study showed that both viscosity and fermentation time had a significant effect on the elasticity of injera and eye formation. Therefore, controlling these factors during the production process was essential to ensure the manufacturing of high-quality injera that met consumer expectations in Ethiopia.

Recognized for its nutritional richness and gluten-free properties, teff has garnered attention as a valuable ingredient in food formulations. Building on this notion, of incorporating gums alongside TF throughout the bread-making process presented an opportunity to further enhance the texture and expansion qualities of the dough. It was suggested that for breads, incorporating teff, xanthan gum or guar gum may serve as suitable additives to improve qualitative attributes (Joung et al., 2017a).

Cereals serve as significant reservoirs of protein, carbohydrates, vitamins, minerals, and fiber worldwide. Specifically, whole grain cereals played a vital role in fostering the development of probiotics, while their indigestible carbohydrates function as prebiotics (Slavin, 2010; Sudheesh et al., 2022). In this context, Alemneh et al. (2021) reported that utilizing whole-grain TF as the sole substrate could result in the production of useful probiotic beverages. The exploration of alternative grains like teff in gluten-free bread production has prompted researchers, such as Chochkov et al. (2022), to underscore the critical role of starter culture selection. Their study illuminated the substantial influence of strain specificity on dough rheology and baking characteristics. This highlighted the necessity of meticulous starter culture selection to attain the desired bread quality in gluten-free baking processes, particularly when utilizing grains such as teff. In conclusion, the integration of teff into gluten-free food products offers substantial potential for improving the nutritional, sensory, and functional properties of a wide range of formulations. However, careful consideration of teff's proportion and the addition of suitable ingredients, such as gums or complementary flours, is crucial to optimize product quality, ensuring desirable texture, flavor, and consumer acceptance.

Table 1. Summary of scientific studies carried out in 2012-2024 on teff integration in gluten-free food products

Food type	Aim of study	Formulation	Results	References
A novel complementary food	To explore the potential of incorporating dabi teff, an underutilized crop, into pre-processed local food crops to develop an optimized complementary food that is energy and protein-dense with improved sensory qualities.	***Variable ingredients:** Dabi teff (20–35%), field pea (0–30%), maize (5–20%) ***Fixed ingredients:** Barley (25%), oats (15%), linseed (5%)	This study successfully formulated a complementary food combining dabi teff with other local ingredients, yielding a product with significantly higher protein and energy density compared to the control. The optimized mixture was identified with 15.34% field pea, 34.66% dabi teff, 5% maize flour, 25% barley, 15% oats, and 5% linseed, showing potential to combat protein-energy malnutrition in children.	Tura et al. (2023)
An adai (a dosa-like crepe from South India) ready mix	To provide an adai ready mix that is both time-efficient and has enough nutrition for people with celiac disease.	***A1:** Buckwheat (BWF, 60%) and Brown TF (40%) ***A2:** BWF (40%) and TF (60%)	A2 formulation was the most preferred formulation at the end of both 1st and 14th day storage.	Rebeiro & Thatheyus (2023)
An extruded complementary food	To evaluate how bulla, teff, and haricot bean, combined with extrusion processing, affect the composition, physical traits, functional properties, and sensory acceptance of a complementary food product.	***A1:** TF & bulla powder blend (3:1) (90%), haricot bean flour (10%) ***A2:** TF & bulla powder blend (3:1) (80%), haricot bean flour (20%) ***A3:** TF & bulla powder blend (3:1) (70%), haricot bean flour (30%)	A complementary food made from teff, bulla, and haricot bean flour is a nutritious and affordable alternative to commercial options for infant and child feeding. The blend improved nutrient composition, including protein, iron, calcium, and zinc, while reducing antinutritional factors. The porridge made from this instant flour received positive sensory feedback from mothers and caregivers.	Chewicha et al. (2024)
Biscuits	To investigate the impact of incorporating TF on the nutritional and physical properties of biscuits.	**B1:** 100% TF **B2:** 75% TF, 25% WF **B3:** 50% TF, 50% WF **B4:** 25% TF, 75% WF **B5:** 0% TF, 100% WF **B6:** 87.5% TF, 12.5% WF **B7:** 62.5% TF, 37.5% WF **B8:** 37.5% TF, 62.5% WF **B9:** 12.5% TF, 87.5% WF	Increasing the proportion of TF significantly enhanced the biscuits' nutritional value (protein, fiber, and minerals) and functional properties, such as water absorption capacity, but negatively affected their color and overall acceptability. A blend containing 12.5% TF with WF was identified as the optimal formulation for producing nutrient-rich biscuits with good sensory properties.	Seifu et al. (2022)
Bread	To specify the teff breads' nutritional characteristics and the effect of enzymes on their quality.	*Varying levels of replacement of 0%, 10%, 20%, and 30% WF *Enzyme combinations (used for high-level TF incorporated breads) *Amylase and glucose oxidase *Glucose oxidase and xylanase *Lipase and amylase *Xylanase and amylase	It is possible to enhance the quality of teff-enriched breads by using a mixture of enzymes. During the shelf-life, notable advancements were noted in the loaf volume and crumb hardness. Significant gains in iron content, overall antioxidant capacity, and sufficient amounts of protein, fat, and fiber were observed when TF was incorporated.	Alaunyte et al. (2012)
Bread	To examine the effects of blending TF with sorghum and maize on nutritional composition and sensory acceptability.	***B1:** 100% TF ***B2:** 55.4% TF, 37.3% sorghum, and 7.3% maize ***B3:** 50% (TF), 31% sorghum, and 19% maize	Although injera made from 100% TF was preferred in sensory acceptability, all formulations, particularly B2 (with decreased energy and increased fiber), were well-received. B2 is	Awulachew (2020b)

			recommended as a healthier option, especially for individuals with a sedentary lifestyle, and its sensory qualities could be further enhanced by shortening the fermentation period.	
Bread	To investigate the nutritional, rheological, and baking characteristics of blends made with two different teff cultivars mixed to two different WF with varying gluten strengths in amounts of 15% and 30%.	*Flour (600 g) *Yeast (3.6 g) *Salt (10.8 g) *Water (450 g)	The red TF exhibited stronger α-amylase activity, higher protein, Fe, and Zn contents, and lower sedimentation volume, peak viscosity, and setback values than the white TF.	Callejo et al. (2016)
Bread	To find out how different dried (buckwheat or rice) or fresh (with *Lactobacillus helveticus*) sourdoughs affect the sensory appeal and consumer preference of gluten-free loaves	***B1:**60% Rice flour (RF): 40% Maize flour (MF) ***B2:**57% RF, 38% MF, 5% TF ***B3:**54%RF, 36% MF, 10% TF ***B4:** %48 RF, 32% MF, 20% TF ***B5:** %51 RF, 34% MF, 15% rice sourdough (RSD) ***B6:** %51 RF, 34% MF, 15% buckwheat sourdough (BSD) ***B7:** %51RF, 34% MF, 15% *L. bulgaricus* sourdough ***B8:** %45 RF, 30% MF, 10% TF, 15% RSD ***B9:** %45 RF, 30% MF, 10% TF, 15% BSD ***B10:** %45 RF, 30% MF, 10% TF, 15% *L. helveticus* sourdough	A 10% TF addition to cereal sourdough (rice or buckwheat) increased the aroma of the bread and brought out the tastes of the fruit, cereal, and toast. Elevated TF (20%) and *Lb. helveticus* sourdough levels resulted in a reduction of the loaf area. Though physically appealing, customers thought loaves with 20% teff had a better flavor-breads with 10% teff coupled with rice sourdough had a better flavor.	Campo et al. (2016)
Bread	To ascertain how sourdoughs (*Enteroccocus durans, Pediococcus pentosaceus*, and *Pediococcus acidilactici)* affect the quality characteristics of gluten-free bread and dough.	***B1:** TF (40%), RF (40%), sorghum flour (SF), 10%, corn flour (CF, 10%), yeast (3%) ***B2:** TF (40%), RF (40%), SF (10%), CF (10%), carboxymethyl cellulose (CMS, 1%), yeast (3%) ***B3:** TF (40%), RF (40%), SF (10%), CF (10%), CMS (3%), yeast (3%) ***B4:** TF (32.8%), RF (40%), SF (10%), CF (10%), CMS (1%), sourdough (21.5%)	*E. durans* was the strain that produced the maximum level of softness during storage and guaranteed the best baking qualities. The strain *P. pentosaceus* exhibited the strongest favorable impact on flavor and taste.	Chochkov et al. (2022)
Bread	To examine the sensory qualities and qualitative attributes of gluten-free bread with TF and different gums (xanthan gum (XG) and guar gum (GG)).	***B1:** WF (100%) ***B2:** TF (85%), corn starch (CS,15%) ***B3**: TF (85%), CS (15%), GG (3%) ***B4:** TF (85), CS (15%), XG (3%) ***B5:** TF (85%), CS (15%), GG (3%), XG (3%)	The control samples exhibited the lowest pH and hardness, along with the highest dough expansion rate, crumb *L** value, moisture, and salinity. The highest pH, chewiness, and the lowest Brix were determined in B4, while the highest hardness was observed in B5.	Joung et al. (2017c)
Bread	To assess the variations in TF-made loaves in relation to other ingredients by identifying their chemical and physical properties.	***T1:** WF 100% ***T2:** TF 100% ***T3:** TF 75% Cassava starch (CS,12.5%) ***T4:** TF 50% TF, RF (25%), CS (25%)	There were no variations observed in the height, weight loss, yield, and apparent volume of the breads when TF was incorporated. However, TF resulted in reduced weight, increased specific volume, and diminished crust luminosity. Firmness showed a direct correlation with the amount of TF utilized.	Homem et al. (2020)
Bread	To assess the bioactive compounds and vitamins in gluten-free breads made with teff and other flours	***B1:** WF (100%) ***B2:** TF (100%), XG (2%) ***B3:** TF (75%), RF (12.5%), cassava starch (12.5%), XG (2%) ***B4:** TF (50%), RF (25%), cassava starch (25%), XG (2%)	Higher amounts of TF in breads led to increased antioxidant capacity and higher levels of vitamins such as thiamine, pantothenic acid, and pyridoxine, along with greater phenolic compounds. In contrast, breads made with wheat flour exhibited lower antioxidant capacity across various methods.	Homem et al. (2022)

Bread	To characterize gluten-free breads formulated with alternative flours, including brown rice, lupine, millet, quinoa, sorghum, teff, buckwheat, rice bran, and carob, while assessing their technological and sensory properties to understand the impact of these variables on consumer preferences and product quality.	***B1:** White rice flour (WRF, 22.5%), Cornstarch (CNS, 57.5%), buckwheat (20%) ***B2:** WRF (22.5%), CNS (57.5%), millet (20%) ***B3**: WRF (22.5%), CNS (57.5%), sorghum (20%) ***B4:** WRF (22.5%), CNS (57.5%), teff (20%) ***B5:** WRF (22.5%), CNS (57.5%), rice bran (20%) ***B6:** WRF (22.5%), CNS (57.5%), brown rice (20%) ***B7:** WRF (22.5%), CNS (57.5%), quinoa (20%) ***B8:** WRF (22.5%), CNS (57.5%), lupin (20%) ***B9:** WRF (22.5%), CNS (57.5%), carob (20%)	All gluten-free bread samples were generally well-received, although the carob flour version was less favored due to its flavor and color. Significant correlations between physicochemical properties and sensory descriptors indicated that factors like hardness and moisture influenced consumer preferences, with GFB samples made from sorghum, brown rice, and teff showing the highest specific volumes.	Irigoytia et al. (2024)
Bread	To evaluate the sensory characteristics of various gluten-free bread formulations using sorghum, teff, and yacon flours, employing CATA and JAR methodologies to describe their sensory profiles.	***B1:** Sorghum flour (100%) ***B2:** TF (100%) ***B3:** Yacon flour (100%) ***B4:** Sorghum flour (33%), TF (33%), Yacon flour (33%)	The sorghum flour formulation was associated with attributes like porosity, reddish color, and unpleasant consistency, while the teff flour formulation was characterized by a floury flavor and salty taste. The yacon flour formulation had ideal texture attributes but negatively affected flavor, whereas the mixed flour formulation showed a pleasant aroma and ideal taste characteristics, suggesting that a combination of these flours can yield gluten-free bread with favorable sensory qualities.	Iwamura et al. (2022)
Bread	To evaluate the potential use of fermented TF for making teff-enriched gluten-free bread, as well as the kind and degree of starch and protein alterations that occur during teff fermentation.	*Fermented/ unfermented TF *Corn starch *Skimmed milk *Sugar *Guar gum *Psyllium fiber *Corn maltodextrin *Yeast *Salt	Fermented TF can be used as a suitable ingredient for gluten-free bread, taking into account the improved nutritional quality of the dietary fibre component as well as textural features.	Marti et al. (2017)
Bread	To assess SF, teff, and yacon flour (YF)-based gluten-free bread recipes using the Just About Right, Flash Profile, and acceptability test.	***B1:** 100% SF ***B2:** 100% TF ***B3:** 100% YF ***B4:** 33.3% SF, 33.3% TF, and 33.3% YF	B4 received positive evaluations for its pleasant aroma, yeast scent, sweet flavor, crumb texture, and porosity, making it the top-rated option in terms of overall acceptability.	Pelinson Tridapalli et al. (2023)
Bread	To evaluate the recipe, nutritional content, cost, and consumer acceptance of four homemade gluten-free breads made with different flour blends.	**Control:** Gluten free bread mix (100%) **B1:** Gluten free bread mix (75%), TF (25%) **B2:** Gluten free bread mix (87.5%), amaranth (12.5%) **B3:** Gluten free bread mix (87.5%), quinoa (12.5%)	The substitution significantly improved the levels of several nutrients, particularly protein, magnesium, calcium, potassium, zinc, iron, and manganese in teff-based bread, and magnesium, potassium, zinc, and manganese in amaranth-based bread. Despite the nutritional differences, the bread prices remained comparable, with quinoa and teff breads receiving the highest consumer acceptance among people following a gluten-free diet.	Rybicka et al. (2019)
Bread	To assess the sensory characteristics of gluten-free bread enriched with teff and yacon flour using flash profile and common dimension analysis	***B1**: 100% (gluten-free mix (GFM, 52% of RF; 36% of potato starch and 12% cassava starch) ***B2:** 40% GFM, 60% TF ***B3:** 40% GFM, 60% yacon flour ***B4:** 70% GFM, 30% TF ***B5:** 70% GFM, 30% yacon flour ***B6:** 40% GFM, 30% TF, 30% yacon flour ***B7:** 60% GFM, 20% TF, 20% yacon flour	The incorporation of teff and yacon flour (up to 35%) effectively maintained the sensory attributes of gluten-free bread. Yacon flour imparted a white color and a soft texture, whereas the combination of both flours resulted in a product characterized by a brown hue, a rough texture, and a distinct bitter taste.	Viell et al. (2020b)

Bread	To investigate the effects of incorporating different TF varieties into gluten-free bread formulations, examining their impact on the physicochemical, nutritional, and sensory qualities.	**B1:** %50 TF, %50 maize starch **B2:** %75 TF %25 maize starch **B3:** %100 TF, %0 maize starch	Replacing maize starch with TF improved the mineral content and reduced the glycemic response of gluten-free bread. The DZ-Cr-37 variety at 100% substitution produced the highest hedonic scores, while TF-fortified breads contained significantly higher levels of calcium, iron, and magnesium than the control.	Villanueva et al. (2022)
Bread	To measure the bread quality included yield, volume, and total baking loss in addition to organoleptic analysis and staling process investigation.	***Control:** WF ***B1:** 95% WF, 5%TF ***B2:** 90% WF, 10%TF ***B3:** 85% WF, 15%TF ***B4:** 95% WF, 5% Ground chia seed (CS), ***B5:** 90% WF, 5% CS	The crumb's textural characteristics were positively impacted by the addition of 5% TF; in particular, it became less chewy and firm. Additionally, bread made with TF had higher organoleptic ratings. Furthermore, compared to control, TF incorporation made with it have higher levels of protein, fat, ash, and dietary fiber.	Zięć et al. (2020)
Breakfast cereal	To investigate how enriching gluten-free breakfast cereals with teff, along with adjusting feed moisture and temperature, affects their physical, microstructural, and nutritional properties.	***BC1:** 30% TF, 70% RF ***BC2**: 50% TF, 50% RF ***BC3**: 70% TF, 30% RF	By incorporating at least 50% teff, the extrudates could meet EU health claims for dietary fiber, while adjusting extrusion variables like temperature improved the sensory qualities, yielding a highly crispy texture.	Caporizzi et al. (2023)
Cake	To assess the chemical, technical, and sensory attributes	***M1**: 100% TF ***M2**: 75% TF, 12.5% RF, 12.5% cassava starch (CS) ***M3**: 50% TF, 25% RF, 25% CS ***M4**: 25% TF, 37.5% RF, 37.5% CS	M1 scored the lowest overall average for flavor (5.03). Purchase intention for cakes did not significantly differ between M3 and M2 (3.25 and 3.08 respectively). M2, M3, and M4 achieved acceptance indices higher than 70%.	Haas et al. (2007)
Cake	To explore how TF influences the characteristics of pound cakes.	***Control:** 0% TF ***TF 5:** 5% TF ***TF 10:** 10% TF ***TF 15:** 15% TF ***TF 20:** 20% TF	Pound cakes with 20% TF (TF20) exhibited the lowest baking loss and highest batter yield, moisture content, and overall acceptability compared to the control.	Joung et al. (2017a)
Cake	To assess the impact of replacing RF with sorghum and TF on the acceptance, texture, and sensory characteristics of gluten-free chocolate cakes.	***C1:** 100% RF ***C2:** 100% sorghum flour ***C3:** 100% TF ***C4:** 50% RF, 50% sorghum flour ***C5:** 50% RF, 50% TF ***C6:** 50% sorghum flour, 50% TF ***C7: 33**% RF, 33% TF, 33% sorghum flour	While the sensory profile of chocolate cake formulations changed with the substitution of RF for sorghum and TF, overall acceptance remained unaffected. The optimized formulation yielded a softer texture, demonstrating that RF can be successfully replaced without compromising product acceptance.	Nespeca et al. (2021)
Cake	To manufacture cakes with varying teff percentages and assess the potential of TF in cakes by analyzing its chemical, physical, and sensory properties.	***T1:** 100% TF ***T2:** 75% TF, 12,5% RF, 12.5% CS ***T3:** 50% TF, 25% RF, 25% CS ***T4:** 25% TF, 37.5% RF, 37.5% CS.	T1 example received the lowest average according to the hedonic scale, while T2, T3, and T4 examples obtained acceptance rates above 70%.	Oliveira et al. (2020)
Cake	To optimize a gluten-free cake recipe with an orange flavor using RF, TF, and SF.	***F1:** 100% RF, 0% SF, 0% TF ***F2:** 0% RF, 100% SF, 0% TF ***F3:** 0% RF, 0% SF, 100% TF ***F4:** 50% RF, 50% SF, 0% TF ***F5:** 50% RF, 0% SF, 50% TF ***F6:** 0% RF, 50% SF, 50% TF ***F7:** 33% RF, 33% SF, 33% TF ***F8:** 33% RF, 33% SF, 33% TF ***F9:**33% RF, 33% SF, 33% TF	SF and TF in orange-flavored gluten-free cake formulations result in a product with favorable overall acceptance and purchase intent. SF, particularly, received high approval from assessors.	de Souza Nespeca et al. (2023)
Chicken patties	To create a gluten-free chicken patty suitable for individuals with celiac disease by exploring the impact of incorporating TF	***Control:** 100% bread crumb ***CP1**:100% CS flour ***CP2**: 100% TF	TF significantly increased hardness, gumminess, and chewiness in gluten-free chicken patties, while CS flour reduced cohesiveness and resilience. TF also positively affected diameter	Dilek et al. (2024)

	and CS flours on its pH, color, texture, and size reduction during cooking.		reduction during cooking and altered color attributes, indicating good potential for industrial development.	
Complementary food	To assess the effects of fermentation time and malt concentration on the nutrient density and bulkiness of cereal-based complementary foods in Ethiopia.	***Cereal type:** Oats, barley and TF ***Malt concentrations:** 0, 2 and 5% ***Fermentation duration:** 0, 24 and 48 h.	A 24-h fermentation period, regardless of malt concentration, improved the sensory properties of oats, barley, and teff flours. The combination of fermentation and malt addition significantly reduced fiber, fat, carbohydrate, phytate, tannin, bulk density, and viscosity while increasing protein content and caloric value. A 24-h fermentation with 2% malt enhanced energy density and palatability, making the complementary foods more suitable for infants and young children by improving nutrient intake and reducing dietary bulkiness.	Forsido et al. (2020)
Cookie	To manufacture functional nutrient-dense cookies are a good source of macronutrients, micronutrients, and flavonoid polyphenols, which support healthy bones.	*TF, oat flour, whey protein, cacao powder, soy milk powder, chickpea flour (CHF, 2:0.5:0.5:0.5:0.5:0.5)	During the 9-day storage period, no statistical difference was observed in the shelf life and acceptability of the cookies. It was discovered that all eight flavonoid polyphenols were able to bind with the receptor activator of nuclear factor kappa-B ligand (RANKL) at least at one of the critical binding sites, suggesting their potential use in osteoporosis prevention.	Asfha et al. (2022)
Cookie	To identify the sensory attributes that influence consumer acceptance of cookies made with RF, sorghum, and TF.	***C1:** 100% RF, ***C2:** 100% sorghum, ***C3:** 100% TF, ***C4:** 50% RF and 50% sorghum, ***C5:** 50% RF and 50% TF, ***C6:** 50% sorghum and 50% TF, ***C7:** 33.3% RF, 33.3% TF and 33.3% sorghum	The study concludes that the optimized formulation of gluten-free cookies, containing 16.7% RF, 35.8% sorghum flour, and 47.5% TF, improves sensory acceptance and nutritional value, making it ideal for commercial production and fortified diets.	de Castro et al. (2022)
Cookie	To effectively utilize okara flour (OF) utilization opportunities in cookie preparations using D-optimal mixture experiment.	***C1:** 35% Red TF (RTF), 15% WF, 50% OF ***C2:** 40% RTF, 20% WF, 40% OF ***C3:** 30% RTF, 20% WF, 50% OF ***C4:** 30% RTF, 20% WF, 50% OF ***C5:** 37% RTF, 16% WF, 47% OF ***C6:** 40% RTF, 10% WF, 50% OF ***C7:** 34% RTF, 20% WF, 46% OF ***C8:** 35% RTF, 18% WF, 47% OF ***C9:** 40% RTF, 17% WF, 43% OF ***C10:** 38% RTF, 18% WF, 44% OF ***C11:** 40% RTF, 15% WF, 45% OF ***C12:** 40% RTF, 10% WF, 50% OF ***C13:** 34% RTF, 20% WF, 46% OF ***C14:** 35% RTF, 15% WF, 50% OF ***C15:** 40% RTF, 20% WF, 40% OF ***C16:** 33% RTF, 18% WF, 49% OF ***C17:** 0%R TF, 100% WF, 0% OF	The optimum composition ratios for cookies with the highest nutritional quality were determined as 33-38% RTF, 18-20% WF and 45-47% OF.	Hawa et al. (2007)
Cookie	To evaluate the acceptability of teff-oat	***C1:** TF (100%) ***C2:** TF (80%)-Nutrim	The pasting viscosities of teff-OBC and teff-WOF 4:1 blends resembled that of	Inglett et al. (2016)

	cookies to those made with WF in terms of texture, color, and flavor.	composites (20%) ***C3:** TF (80%)-OBC composites (oat bran concentrate, 20%) ***C4:** TF (80%)-WOF composites (whole oat flour, 20%) ***C5:** WF (100%)	TF, yet they exceeded those of WF. Additionally, the elastic characteristics of teff-OBC and teff-WOF doughs slightly surpassed those of pure teff dough.	
Cookie	To look into the TF-based gluten-free cookies' quality attributes and antioxidant activity.	***Control:** 100% WF ***C1:** 25% TF, 75% WF ***C2:** 50% TF, 50% WF ***C3:** 75% TF, 25% WF ***C4:** 100% TF	C1 had the largest baking loss rate, whereas C3 had the lowest. Between the samples, there was no discernible variation in density.	Joeng et al. (2017b)
Cookie	To assess the impact of dephytinisation methods on the nutritional and functional properties of cookies enriched with teff flour.	***Control:** 100% WF ***C1:** 10% TF, 90% WF ***C2:** 20% TF, 80% WF ***C3:** 30% TF, 70% WF ***C4:** 40% TF, 60% WF	Dephytinisation effectively reduced phytic acid content, with fermentation being the most efficient method, while enhancing the cookies' mineral and antioxidant profiles. Cookies with dephytinised TF (up to 20%) displayed improved nutritional value without compromising sensory acceptability.	Karaçoban et al. (2023)
Cookie	To examine the rheological behavior of composite flours in wheat-barley flour premixes that comprise varying proportions of whole meal chia or teff (white/brown) flours.	WF-Barley flour (BF) premixes: *70% WF and 30% BF *50% WF and 50% BF Added ingredients: *White or dark whole meal chia and TF *Replaced 5% or 10% of the base mixes.	When compared to chia cookies, the spread ratio of cookies with teff varieties attained greater levels. Common consumers may find the flavor of barley flour less agreeable, however whole meal chia and TF can both cover up that aftertaste.	Švec et al. (2017)
Crackers	To investigate the effects of incorporating different levels of white and brown TF on the nutritional, bioactive, and sensory properties of gluten-free rice-teff crackers.	TF composed of white and brown TF (1:1, w:w) in equal proportions ***C1:** 100% RF ***C2:** 25% TF, 75% RF ***C3:** 50% TF, 50% RF ***C4:** 100% TF	Crackers made with white TF had significantly higher mineral content, including almost double the iron, compared to those made with brown teff. Additionally, white teff crackers exhibited superior antioxidant activity. The inclusion of TF also lowered the levels of rapidly digestible starch, enhancing the nutritional value of the gluten-free product.	Rico et al. (2019)
Egg-free Fusilli Pasta	To develop gluten-free and lactose-free fusilli pasta using whole grain such as teff, buckwheat, quinoa, and amaranth.	***P1:** 100% TF ***P2:** 100% buckwheat ***P3:** 100% quinoa ***P4:** 100% amaranth	The taste and acceptance of teff and buckwheat pasta were similar and notably higher compared to quinoa pasta. The acceptance level for teff, buckwheat, and quinoa pasta ranged from 61% to 87%, indicating a desirable level of acceptance.	Kahlon & Chiu (2015)
Emulsion-type sausages	To investigate the use of quinoa flour and TF as partial substitutes for beef fat in the formulation of emulsion-type sausages.	***S1**: Beef (70%), beef fat (20%), ice (10%), pre-emulsion agents (4%), quinoa flour (0%), TF (0%), curing agents (3.07%), spice mix (1.2%) ***S2:** Beef (70%), beef fat (10%), ice (20%), pre-emulsion agents (4%), quinoa flour (5%), TF (0%), curing agents (3.07%), spice mix (1.2%) ***S3:** Beef (70%), beef fat (10%), ice (20%), pre-emulsion agents (4%), quinoa flour (0%), TF (5%), curing agents (3.07%), spice mix (1.2%) ***S4:** Beef (70%), beef fat (10%), ice (20%), pre-emulsion agents (4%), quinoa flour (2.5%), TF (2.5%), curing agents (3.07%), spice mix (1.2%)	The findings demonstrated that incorporating these flours can effectively reduce animal fat while enhancing the emulsions' functional properties and technological quality. Additionally, quinoa offered benefits over teff by boosting protein and dietary fiber content with minimal changes to color and texture.	Öztürk-Kerimoğlu et al. (2020)
Fresh egg pasta	To efficiently apply Response Surface Methodology to ascertain the best blends of TF, WF, and oat flours (OAF) for	*Egg white powder (12.5%-17.5% for OAF/TF, 5-10% for WF) *Emulsifier (0-2% for all flours)	Pasta made from OAF and TF had a mechanical texture similar to wheat pasta, but its elasticity was much lower. SEM results show that when wheat pasta cooks, starch gelatinization and	Hager et al. (2012b)

	egg pasta recipes.	*Water (37.5-47.5% for OAF/TF, 32.5-37.5% for WF)	protein denaturation cause a transparent outer layer to form. But teff and oat pasta has less of this characteristic.	
Fresh egg pasta	To design a fresh egg pasta including WF, OAF and TF and determine their *in vitro* digestibility and sensory attributes	***P1**: 69.6% WF, 22.8% water, 7.0% egg white powder, 0.6% emulsifier ***P2**: 62.8% TF, 25.1% water, 11.0% egg white powder, 1.1% emulsifier ***P3**: 64.7% OAF 24.3% water, 9.7% egg white powder, 1.3% emulsifier	While P2's sensory qualities were found to be lower, P3's were found to be fairly similar to P1's, with the exception of the need for improvement in smoothness and scent. P1 had the highest anticipated glycemic index, followed by P2 and P3.	Hager et al. (2013)
Gruel	To formulate a nutrient-dense gruel for children under five by incorporating fish powder into red teff and oat-based composite flour.	***G1:** 100% TF ***G2:** 50% TF, 34.20% oat, 15.80% fish powder ***G3:** 80% TF, 20% fish powder ***G4:** 50% TF, 50% oat ***G5:** 90% TF, 10% fish powder ***G6:** 75% TF, 25% oat ***G7:** 64.50% TF, 16.80% oat, 18.60% fish powder ***G8:** 61.80% TF, 36.80% oat, 1.40% fish powder ***G9:** 86.70% TF, 13.30% oat ***G10**: 76.90% TF, 11.90% oat, 11.30% fish powder ***G11:** 60.90% TF, 27.80% oat, 11.30% fish powder ***G12:** 50% TF, 50% oat ***G13:** 100% TF ***G14:** 80% TF, 20% fish powder ***G15:** 50% TF, 34.20% oat, 15.80% fish powder ***G16:** 90% TF, 10% fish powder	The inclusion of dried fish powder significantly increased the protein, ash, iron, and calcium content of the composite flours. Among the formulations, the blend containing 64.5% TF, 16.8% oat, and 18.6% dried fish powder was found to provide the most balanced nutrient composition and was recommended for use.	Berhe & Kifle (2022)
Injera	To assess the potential usage of taro flour (TAF) in place of traditional Ethiopian "injera," a flat, sour pan cake using D-optimal mixture design.	***I1:** 75% TF, 25% TAF ***I2:** 85% TF, 15% TAF ***I3:** 75% TF, 25% TAF ***I4:** 80% TF, 20% TAF ***I5:** 80% TF, 20% TAF ***I6:** 85% TF, 15% TAF ***I7:** 70% TF, 30% TAF ***I8:** 90% TF, 10% TAF ***I9:** 70% TF, 30% TAF ***I10:** 90% TF, 10% TAF	With an increase in the amount of TAF, the sensory quality of Injera decreased. There were no statistically significant differences in the nutritional values of composite flour among different mixing ratios. The optimum ratio for the preparation of the injera was determined in I6 samples.	Abera et al. (2016)
Injera	To evaluate the effects of blending ratios and fermentation time on the quality of injera made from quality protein maize and TF.	***I1:** 100% Quality protein maize (QPM) ***I2:** 80% QPM, 20% TF ***I3:** 70% QPM, 30% TF ***I4:** 60% QPM, 40% TF	The blending ratio and fermentation time influenced the nutritional composition of injera, affecting moisture, protein, fat, fiber, and mineral content. Higher teff proportions and 60-h fermentation improved the sensory acceptability of the maize-teff composite injera.	Asrat et al. (2022)
Injera	To examine how different blending ratios of teff, sorghum, and fenugreek flours affect the quality attributes of injera using a D-optimal mixture design.	***I1:** 95% TF, 0% sorghum, 5% fenugreek ***I2:** 100% TF, 0% sorghum, 0% fenugreek ***I3:** 75% TF, 25% sorghum, 0% fenugreek ***I4:** 87% TF, 12% sorghum, 1% fenugreek ***I5:** 84% TF, 12% sorghum, 4% fenugreek ***I6:** 62% TF, 37% sorghum, 1% fenugreek ***I7:** 73% TF, 24% sorghum, 3% fenugreek ***I8:** 62% TF, 34% sorghum, 4% fenugreek ***I9:** 50% TF, 45% sorghum, 5% fenugreek ***I10:** 50% TF, 50% sorghum, 0% fenugreek	The addition of sorghum and fenugreek flours to TF enhanced the fiber, fat, protein, and total energy content of the injera, while reducing the average mineral content compared to injera made solely from TF. Additionally, the composite flour injera exhibited higher alkaline retention capacity, a lower staling rate, and better sensory acceptability.	Awulachew et al. (2023)

Injera	To optimize the blending ratios of teff, sorghum, and fenugreek flours to enhance the quality of injera, utilizing a D-optimal design to evaluate fourteen formulations.	***I1:** 95% TF, 0% sorghum, 5% fenugreek ***I2:** 100% TF, 0% sorghum, 0% fenugreek ***I3:** 75% TF, 25% sorghum, 0% fenugreek ***I4:** 87% TF, 12% sorghum, 1% fenugreek ***I5:** 75% TF, 25% sorghum, 0% fenugreek ***I6:** 84% TF, 12% sorghum, 4% fenugreek ***I7:** 62% TF, 37% sorghum, 1% fenugreek ***I8:** 73% TF, 24% sorghum, 3% fenugreek ***I9:** 62% TF, 34% sorghum, 4% fenugreek ***I10:** 95% TF, 0% sorghum, 5% fenugreek ***I11:** 50% TF, 45% sorghum, 5% fenugreek ***I12:** 100% TF, 0% sorghum, 0% fenugreek ***I13:** 50% TF, 50% sorghum, 0% fenugreek ***I14:** 50% TF, 50% sorghum, 0% fenugreek	The optimal blend of 64.1% TF, 32% sorghum, and 3.80% fenugreek improved the nutritional value, sensory appeal, and textural characteristics while reducing the staling rate.	Awulachew & Kuffi (2023)
Injera	To examine how varying the blending ratios of TF, BWF, and pearl millet flour (PMF), as well as fermentation duration, impacts the overall quality of injera.	***Control:** 100% TF ***I1:** 40% PMF, 55% TF, 5% BWF ***I2:** 30% PMF, 60% TF, 10% BWF ***I3:** 20% PMF, 65% TF, 15% BWF ***I4:** PMF 10%, 70% TF, 20% BWF	All blends of injera were well-received in terms of sensory evaluation. Yet, the blend consisting of 20% PMF, 65% TF, and 15% BWF, fermented for 72 h, stood out as the most favored option.	Anberbir et al. (2023)
Injera	To create and assess the quality of teff-based injera enhanced with underutilized indigenous tuber Oromo dinich (*Plectranthus edulis*) and maize flours, utilizing a D-optimal constrained mixture design to generate fourteen formulations.	***I1:** 5% maize, 15% *P. edulis*, 80% teff ***I2:** 5% maize, 5% *P. edulis*, 90% teff ***I3:** 15% maize, 5% *P. edulis*, 80% teff ***I4:** 15% maize, 5% *P. edulis*, 80% teff ***I5:** 15% maize, 15% *P. edulis*, 70% teff ***I6:** 5% maize, 10% *P. edulis*, 85% teff ***I7:** 10% maize, 5% *P. edulis*, 85% teff ***I8:** 5% maize, 5% *P. edulis*, 90% teff ***I9:** 5% maize, 15% *P. edulis*, 80% teff ***I10:** 10% maize, 15% *P. edulis*, 75% teff ***I11:** 10% maize, 8% *P. edulis*, 82% teff ***I12:** 15% maize, 15% *P. edulis*, 70% teff ***I13:** 10% maize, 10% *P. edulis*, 80% teff ***I14:** 15% maize, 10% *P. edulis*, 75% teff	The results indicated that increasing the amount of *Plectranthus edulis* flour in the formulations improved protein, fat, gross energy, total phenolic content, and antioxidant capacity. The optimum blending ratio was found to be 77.6% teff, 13.1% maize, and 9.3% *Plectranthus edulis*, yielding favorable nutritional values and sensory acceptance. Overall, supplementing up to 10% *Plectranthus edulis* flour in the teff-maize composite was deemed acceptable for both nutritional and sensory quality.	Fekadu et al. (2022)
Injera	To conduct a sensory analysis of injera and analyze the proximate composition, nutrients, energy content, and total phenolics of cereals and injera when whole and ground flaxseed (FF) is	*Control injera *Whole flaxseed and FF into TF	Injera prepared with 9% FF, both whole and ground, as substitutes for a portion of TF exhibited enhanced nutritional composition and functional qualities. These enhancements potentially include higher levels of dietary fiber, ALA (18:3n-3), proteins, lignans, and total phenolics with antioxidant properties.	Girma et al. (2012)

	substituted for cereal flour at 3%, 6%, and 9%.		However, the appearance of the injera, particularly the characteristic eyes and color, appeared more favorable in the control version made entirely with 100% TF.	
Injera	To evaluate the nutritional value and sensory quality of injera made from different ratios of teff and barley flour blends.	**I1**: 100% TF **I2:** 90% TF, 10% barley flour **I3: 8**0% TF, 20% barley flour **I4:** 70% TF, 30% barley flour **I5: 6**0% TF, 40% barley flour **I6: 5**0% TF, 50% barley flour **I7: 10**0% TF	Micronutrient content, particularly iron and calcium, improved in the blended injeras. Sensory evaluations for taste, color, and texture were favorable, with I1 formulation ranked highest. These findings suggest that teff-barley blends could serve as a nutritionally beneficial and cost-effective alternative for injera production.	Kefale (2020)
Injera	To evaluate the effects of different blending ratios of teff, sorghum, and faba bean flours, as well as fermentation time (24, 48, and 72 h), on the mineral content and sensory properties of injera.	***I1:** 55% TF, 30% sorghum, 15% faba bean ***I2:** 65% TF, 20% sorghum, 15% faba bean ***I3:** 65% TF, 30% sorghum, 5% faba bean ***I4:** 70% TF, 20% sorghum, 10% faba bean ***I5:** 100% TF	Combining faba bean and sorghum with teff significantly enhanced the iron, zinc, and calcium content of the injera, with the highest values observed after 72 h of fermentation. All blended injera received positive sensory ratings, with the most preferred formulation being 70% teff, 20% sorghum, and 10% faba bean fermented for 72 h.	Mihrete (2019)
Injera	To optimize the blending ratios of amaranth, teff, and barley flours to enhance the nutritional and sensory qualities of injera.	***I1:** 60% amaranth, 40% TF ***I2:** 20% barley, 80% TF ***I3:** 12.5% amaranth, 10% barley, 77.5% TF ***I4:** 30% amaranth, 70% TF ***I5:** 32.5% amaranth, 15% barley 52.5% TF ***I6:** 42.5% amaranth, 5% barley 52.5% TF ***I7:** 100% TF ***I8:** 10% barley, 90% TF ***I9:** 40% amaranth, 20% barley 40% TF ***I10:** 20% amaranth, 20% barley 60% TF	Increasing amaranth improved protein and energy content, while adding barley raised carbohydrate levels. Minerals like calcium, iron, and zinc were boosted with higher TF and amaranth proportions. The optimal blend was found to be 40–77.5% TF, 12.5–60% amaranth, and 0–10% barley, balancing improved nutrition with sensory acceptability.	Woldemariam et al. (2019)
Injera	To explore the feasibility of blending lupine flour with TF to produce injera and to evaluate the effects of different lupine varieties and blending ratios on the nutritional and sensory properties of the resulting product.	***I1:** 100% TF, 0% local white lupine (DLSF) ***I2:** 97.5% TF, 2.5% DLSF ***I3**: 95% TF, 5% DLSF ***I4:** 92.5% TF, 7.5 DLSF ***I5**: 90% TF, 10% DLSF ***I6:** 85% TF, 15% DLSF ***I7**: 82.5% TF, 17.5% DLSF ***I8**: 80% TF, 20% DLSF ***II2:** 97.5% TF, 2.5% Australian sweet lupine (ASLF) ***II3**: 95% TF, 5% ASLF ***II4:** 92.5% TF, 7.5 ASLF ***II5**: 90% TF, 10% ASLF ***II6:** 85% TF, 15% ASLF ***II7**: 82.5% TF, 17.5% ASLF ***II8**: 80% TF, 20% ASLF	Blending lupine flour with TF enhances injera's protein content and reduces anti-nutritional factors. Consumer acceptance was high with up to 15% lupine, but declined beyond that level.	Yegrem et al. (2022)
Macaroni	To enhance the nutritional quality of macaroni while preserving its cooking quality by blending durum wheat semolina with teff and chickpea flours.	Blends of and chickpea (0-15%), teff (0-40%), and durum wheat semolina (60-100%)	Incorporating teff and chickpea flours into semolina improved water absorption and cooking weight but reduced wet gluten content. The optimal macaroni formulation for sensory and cooking quality was determined to be a blend of semolina (73.46%), TF (11.55%), and chickpea flour (14.25%), resulting in better firmness and reduced stickiness.	Kore et al. (2022)
Muffins	To manufacture a teff type-I sourdough that is propagated by back-slopping and utilize it to make gluten-free muffins	-	With their high total free amino acids content (up to about 1000 mg/kg), proteins (>6%), and the *in vitro* protein digestibility value (70%), along with low the starch hydrolysis index (52%)	Dingeo et al. (2020)

	that have a notable sensory character, high nutritional content, and a long shelf life.		and high fiber content (>3%), the suggested muffins are highly intriguing for those following a balanced and healthful gluten-free diet.	
Muffins	To investigate how the physical, textural, and sensory qualities of gluten-free muffins are affected when different ratio of RF is replaced with TF.	***Control:** 100% RF ***C1:** 25% TF, 75% RF ***C2:** 50% TF, 50% RF ***C3:** 75% TF, 25% RF ***C4:** 100% TF	Because of its increased protein, iron, calcium, and fiber levels, the C2 formulation not only yields acceptable gluten-free muffins but also more healthy ones.	Tess et al. (2015)
Muffins	To ascertain how rice muffins' TF addition ratios affect their sensory and antioxidative activities as well as organoleptic features.	***C1:** 25% TF ***C2**: 50% TF ***C3**: 75% TF	The high antioxidant potential of teff increased the antioxidant activity of baked products. Rice muffins enriched with TF acquired a sweet and nutty taste.	Minarovičová et al. (2019)
Noodles	To evaluate the quality features of gluten-free noodles by the use of multiple properties, including physicochemical, morphological and textural attributes	***Control:** 100 g WF ***N1:** 75 g WF, 25 g TF ***N2:** 50 g WF, 50 g TF ***N3:** 25 g WF, 75 g TF ***N4:** 0 g WF, 100 g TF ***N5:** 0 g WF, 100 g TF, 2 g guar gum ***N6:** 0 g WF, 100 g TF, 2 g xanthan gum	In sample N4, the lowest value was found for pH, and the highest value was found for hardness. In sample N6, the highest value was found for water absorption, and the lowest value was found for hardness.	Joung et al. (2017d)
Cakes, cookies, biscuits and bread	To assess the baking properties of teff and ascertain its ability to yield satisfactory baked goods.	***F1:** 0% WF: 100% TF ***F2:** 10% WF: 90% TF ***F3:** 20% WF: 80% TF ***F4:** 30% WF: 70% TF ***F5:** 40% WF: 60% TF ***F6:** 100% WF: 0% TF	Although the fracture strength of cookies remained consistent, those made with 40% and 100% TF exhibited significantly greater spread.	Coleman et al (2013)
Pasta	To formulate and produce gluten-free pasta using RF and various wheat alternative flours (AF, chia, teff, quinoa, amaranth, and buckwheat) while evaluating their qualitative properties, including color, texture, cooking characteristics, and sensory attributes.	***P1:** 95% RF, 5% AF ***P2:** 75% RF, 25% AF ***P3:** 50% RF, 50% AF ***P4:** 5% RF, 95% AF ***P5:** 25% RF, 75% AF ***Control:** Commercial pasta	P5 formulation yielded the best overall sensory evaluation, highlighting the potential of AF to enhance the quality of gluten-free pasta.	Ghasemi et al. (2024)
Pasta	To make tagliatelle without gluten using TF and various amounts of a recently developed white-seeded common bean flour that is low in phytic acid and lectin.	***P1:**100% (w:w) TF ***P2:** TF and white-seeded low phytic acid and lectin free bean flour (WPLF, 80:20, w:w) ***P3:** TF: WPLF, 60:40, w:w)	Dry matter and total starch were lower in P2 and P3, but the dietary fibre and protein content of these samples were higher than in control samples. The addition of WPLF decreased the *in vitro* glycemic index but increased the resistant starch content.	Giuberti et al. (2015)
Pasta	To manufacture a gluten-free pasta formulation by adding two distinct gluten-free flours (TF and CHF) to buckwheat along with XG, a natural thickening.	*TF: 5-10% *CHF: 5-10% *XG: 0-1%	By combining CHF, TF, and XG in addition to buckwheat with the developed formulation, dough matrix was improved, and protein content was fortified significantly. The ideal formulation consists of buckwheat supplemented with 10% CHF, 5% TF, and 1% XG.	Güngörmüşler et al. (2020)
Pasta	To optimize the formulation of macaroni using durum wheat semolina (SEF), TF, and CHF while assessing the factors related to cooking, sensory, and textural quality using response surface methods.	***P1:** SEF:TF.CHF:80:20:0% ***P2:** SEF:TF.CHF:100:0:0% ***P3:** SEF:TF.CHF:72.76:12.76:14.48 % ***P4:** SEF:TF.CHF:60:32.58:7.42% ***P5:** SEF:TF.CHF: 60:40:0% ***P6:** SEF:TF.CHF: 60:25.11:14.89% ***P7:** SEF:TF.CHF: 92.50:0:7.50% ***P8:** SEF:TF.CHF: 85:0:15% ***P9:**	Greater cooking weight, water absorption capacity, and shorter cooking times were among the better cooking characteristics of the macaroni made from the composite containing higher levels of TF and CHF. A blending ratio of 67%, 17%, and 15% for SEF, TF, and CHF, respectively, can yield macaroni with a satisfactory level of cooking and texture.	Kore et al. (2022)

		SEF:TF.CHF:68.44:28.08:3.48 % ***P10:** SEF:TF.CHF:82.15:9.11:8.74% ***P11:** SEF:TF.CHF:89.61:10.39:0%		
Pasta	To manufacture nutritionally optimized pasta formulations using cowpea (CW), TF, and amaranth leaves (AL) to fulfill women's protein and nutrient needs while reducing antinutritional factors, and to assess the processability and consumer acceptance of these formulations.	***P1:** 100% CW ***P2:** 90% CW, 10% AL ***P3:** 60% CW, 40% TF ***P4:** 55% CW, 35% TF, 10 %AL	The CW and AL formulation had the best nutritional profile and minimal phytate levels. Additionally, the combination of cowpea, teff, and AL showed superior processability, attributed to its lower lipoxygenase activity and higher antioxidant capacity, while the cowpea-only formulation closely matched the color of durum wheat semolina.	Pinel et al. (2024)
Probiotic functional beverage	To assess if *Lactobacillus rhamnosus* GG and *Lactobacillus plantarum* A6, two promising probiotics, may be delivered via a teff-based substrate in order to create probiotic-functional beverages.	***Substrate:** 4-7 (% w/v) ***Inoculum ratio**: 5-7 (log cfu/mL)	In mixed-strain fermentation, it was observed that microbial growth rates, pH decrease, and increase in total acidity were more pronounced. This likely enhances both the safety and sensory attributes of the food. The fermentation results were superior when teff substrate was inoculated with a combination of strains compared to using a single strain.	Alemneh et al. (2021)
Probiotic beverage	To develop a fermented teff-based probiotic beverage and evaluated its cell viability, sugar and acid content, TA, pH, sensory properties, and microbial safety over 25 days of refrigerated storage.	*7 g of whole grain TF *100 ml of distilled water, *Inoculated with co-culture strains of *Lactiplantibacillus plantarum* and *Lacticaseibacillus rhamnosus* (at 6 log cfu/mL) and fermented for 15 h at 37°C.	Throughout refrigerated storage, the cell counts of *Lactiplantibacillus plantarum* and *Lacticaseibacillus rhamnosus* declined, while glucose, lactic acid, maltose, and acetic acid contents significantly increased. The beverage showed a reduction in pH, a rise in titratable acidity, and was free from pathogens, with sensory acceptance confirmed after 10 days of storage.	Alemneh et al. (2022b)
Ready to eat supplementary food	To develop a nutrient-dense, ready-to-eat supplementary food for mothers using barley, teff, beans, sesame seeds, pumpkin seeds, and groundnuts.	***SF1:** 40% barley, 15% TF, 20% bean, 5% sesame, 15% pumpkin seed, 5% groundnut ***SF2:** 40% barley, 15% TF, 20% bean, 15% sesame, 5% pumpkin seed, 5% groundnut ***SF3:** 40% barley, 15% TF, 20% bean, 15% sesame, 0% pumpkin seed, 10% groundnut ***SF4:** 40% barley, 15% TF, 20% bean, 0% sesame, 15% pumpkin seed, 10% groundnut ***SF5:** 40% barley, 15% TF, 20% bean, 10% sesame, 10% pumpkin seed, 5% groundnut	The formulation SFF1, containing 40% barley, 15% teff, 20% beans, 5% sesame, 15% pumpkin seeds, and 5% groundnuts, provided the best nutritional value and is recommended to be consumed with milk to enhance calcium content and meet the dietary needs of pregnant and lactating mothers.	Bekele (2021)
Tarhana	The study aimed to develop gluten-free tarhana using varying ratios of TF, corn flour, and potato starch, and to assess the effects of TF on its physical, chemical, nutritional, and sensory properties.	***T1:** 20% TF, 40% Corn Flour, 40% Potato Starch ***T2:** 40% TF, 30% Corn Flour, 30% Potato Starch ***T3:** 60% TF, 20% Corn Flour, 20% Potato Starch ***T4:** 80% TF, 10% Corn Flour, 10% Potato Starch ***T5:** 100% TF, 0% Corn Flour, 0% Potato Starch	Incorporating TF into tarhana formulations enhanced the ash, protein, and fat content while significantly influencing total phenolic content, antioxidant activity, and phytic acid levels. Additionally, higher levels of TF improved oil absorption, foaming capacity, and stability, although it had only a minor effect on the sensory qualities of the tarhana.	Köten (2021)
Teff-based puffed/extruded food blended with CHF	To manufacture a teff-based puffed product combined with CHF and to evaluate how various extrusion process parameters-such as moisture content, barrel temperature, screw speed,	***S1:** 90% TF, 10% CHF ***S2:** 85% TF, 15% CHF ***S3:** 80% TF, 20% CHF	The study identified optimal processing conditions, including a barrel temperature of 130°C, screw speed of 170 rpm, moisture content of 15%, and a teff-to-chickpea flour ratio of 15:85. Under these conditions, the extrudates demonstrated enhanced quality,	Kebede Ali et al. (2023)

	and blending ratio-affect the quality of the resulting extruded food.		particularly in expansion, water absorption, and density, as well as improved sensory characteristics.	
Traditional foods, including injera, porridge, and malt-based porridge, made from blends of teff, sorghum, and soybean grains or flours.	To optimize the incorporation levels of sorghum, teff, and soybean grains and flours in the development of value-added traditional foods like injera, porridge, and malt-based porridge, by assessing their sensory acceptability.	**Injera and porridge:** ***Control:** 100% TF ***I1:** 30% TF, 50% sorghum flour, 20% soybean flour ***I2:** 50% TF, 30% sorghum flour, 20% soybean flour ***I3:** 70% TF, 20% sorghum flour, 10% soybean flour **Malt porridge:** ***Control:** 100% TF ***I1:** 30% malted TF, 50% malted sorghum flour, 20% malted soybean flour ***I2:** 50% malted TF, 30% malted sorghum flour, 20% malted soybean flour ***I3:** 70% malted TF, 20% malted sorghum flour, 10% malted soybean flour	Blending teff, sorghum, and soybean in a 50:30:20 ratio significantly improved the sensory quality of traditional foods like injera and porridge. Processing methods such as soaking, fermentation, and malting enhanced the flavor and texture, making these foods highly acceptable to all age groups.	Lavanya et al. (2022)

4. Conclusion

In an age where health-conscious eating habits continue to shape consumer demand, the search for nutritious and functional alternatives has accelerated. Teff stands out as a promising ingredient, particularly for gluten-free formulations, thanks to its rich nutritional profile, technological advantages, and favorable sensory properties. With its high fiber content, essential minerals, and mild flavor, teff has emerged as an ideal substitute for wheat flour, offering a gluten-free solution for individuals with celiac disease or gluten sensitivity. This review highlights the versatility of teff in enhancing both the nutritional and sensory attributes of gluten-free products, from bread and cakes to cookies and breakfast cereals. However, the success of teff-based products largely depends on carefully selecting complementary ingredients and processing techniques to achieve a balanced and appealing final product. Future studies should delve deeper into understanding consumer preferences, particularly regarding teff-based gluten-free products, to bridge existing knowledge gaps and further optimize product formulations. By doing so, teff can continue to play a vital role in developing high-quality, nutritious, and sensory-pleasing gluten-free alternatives that cater to the growing demand for health-focused diets.

Author Contributions

Gozde Kutlu: Supervision, writing original draft, review&editing, visualization, investigation; Egemen Ozsuer: Investigation, writing-original draft; Merve Madenlioğlu: Investigation, writing-original draft; Güneş Eroglu: Investigation, visualization, writing-original draft; Ilayda Akbas: Investigation, visualization, writing-original draft.

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Conflicts of Interest

The authors state that they have no conflicts of interest.

Supplemental Material

No additional materials available.

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