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REVIEW

Teff (*Eragrostis tef*) as a raw material for malting, brewing and manufacturing of gluten-free foods and beverages: a review

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Abstract The demand for gluten-free foods is certainly increasing. Interest in teff has increased noticeably due to its very attractive nutritional profile and gluten-free nature of the grain, making it a suitable substitute for wheat and other cereals in their food applications as well as foods for people with celiac disease. The main objective of this article is to review researches on teff, evaluate its suitability for different food applications, and give direction for further research on its applications for health food market. Teff is a tropical low risk cereal that grows in a wider ecology and can tolerate harsh environmental conditions where most other cereals are less viable. It has an excellent balance of amino acid composition (including all 8 essential amino acids for humans) making it an excellent material for malting and brewing. Because of its small size, teff is made into whole-grain flour (bran and germ included), resulting in a very high fiber content and high nutrient content in general. Teff is useful to improve the haemoglobin level in human body and helps to prevent malaria, incidence of anaemia and diabetes. The nutrient composition of teff grain indicates that it has a good potential to be used in foods and beverages worldwide. The high levels of simple sugars and α-amino acids as a result of breakdown of starch and protein, respectively, are essential for fermentation and beer making.

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Introduction

Africa is rich in a wide range of less explored grain species, including teff and other different types of millets. These grains represent an important source of dietary proteins, carbohydrates, fibre, vitamins, and minerals for the people. They are fermented into a large number of foods and beverages with improved texture, taste, aroma, keeping quality, nutritional values, digestibility, and microbial quality and with reduced antinutrient contents (National Research Council 1996; Yetneberk et al. 2004). Teff (*Eragrostis tef* (Zuccagni) Trotter) is a tropical cereal that belongs to the family of Poaceae, subfamily Eragrostoidae, tribe Eragrosteae, and genus Eragrostis. About 350 species are known in the genus Eragrostis (Demissie 2000), of which teff is the only cultivated species. Chloridoideae is used synonymously for Eragrostoidae of teff (Costanza et al. 1980). Teff cultivars have been recognized and described based on the colour of the grains and inflorescences, ramification of the inflorescences and the size of plants. For marketing purposes, teff is classified on the basis of seed colour: *netch* (white), *qey* (red/brown) and *sergegna* (mixed) (Tefera et al. 1995). Teff grain is hull-less (naked) and comes in a range of colors from milky-white to almost dark brown. The most common colors are white, creamy-white, light brown, and dark brown. The word teff is thought to have been derived from the Amharic word *teffa* which means "lost" due to small size of the grain and how easily it is lost if dropped. The grain is oval-shaped with size 0.9–1.7 mm (length) and 0.7–1.0 mm (diameter). The individual grain mass is generally in the range of 0.2–0.4 mg, perhaps the smallest among carbohydrate-rich kernels (Belay et al.

2009; Bultosa 2007). Teff can adapt to a wide range of environment (National Research Council 1996) and it is considered to be very resistant to insect pests. Teff seeds remain viable for several years provided that direct contact with moisture and sunshine is avoided (Gamboa and Ekris 2008). In comparison with other common cereals, teff grain is less prone to attacks by weevils and other storage pests (Tadesse 1969). Thus, it can be safely stored under traditional storage conditions with no chemical protection. This paper reviews the nutritional value and other aspects of teff and its potential for different applications including brewing and other gluten-free foods and beverages for the health food market.

Chemical composition of teff

The chemical composition of cereals varies widely and depends on the environmental conditions, soil, variety and fertilizer. The importance of teff is mainly due to the fact it has attractive nutritional profile and has no gluten found in other common cereals such as wheat, barley and rye. The demand for gluten-free foods is growing as more people are diagnosed with celiac disease and other types of gluten sensitivity (Bultosa and Taylor 2004; Dekking et al. 2005; Hopman et al. 2008).

Carbohydrates

According a research report by Bultosa (2007) for 13 teff grain varieties, the proximate compositions and flour-starch amylose contents were in some ranges: moisture 9.30–11.22 % (mean 10.53 %), grain protein 8.7–11.1 % (mean 10.4 %), ash 1.99–3.16 % (mean 2.45 %), crude fat 2.0–3.0 % (mean 2.3 %), crude fiber 2.6–3.8 % (mean 3.3 %), and amylose from flour 20–26 % (mean 23.0 %). These values are similar to previous findings by other researchers (Bultosa and Taylor 2004; National Research Council 1996). Studies showed that like other cereals teff is predominantly starchy (73 %) (Bultosa and Taylor 2004; National Research Council 1996) and the starch content of teff is higher than that of most other cereals (Table 1). This makes it to be a potential gluten free cereal that replaces wheat and other cereals in their applications as sources of food energy. Teff starch granules are conglomerates of many polygonal simple granules (Bultosa et al. 2002; Helbing 2009) (Figs. 1 and 2).

The individual starch granules are very small (2–6 μm in diameter) and similar in size to rice starch granules (2–10 μm) but larger than amaranthus (1–2 μm) and quinoa (0.5–3 μm) starch granules (Bultosa et al. 2002; Jane et al. 1992; Lindeboom et al. 2004). The shape is polygonal, smooth with no surface pores. A few granules are essentially

Table 1 The proximate (db[1]) and microelement compositions of teff grain compared with some gluten containing and gluten free cereals

Component	Gluten rich cereals			Gluten-free cereals				
	Barley	Wheat	Rye	Teff	Maize	Brown rice	Sorghum	Pearl millet
Starch (%)	60.6[¤]	71.0[§]	69[α]	73.0[†]	72[β]	64.3[β]	62.9[β]	67.0[σ]
Crude protein (%)	11.1[¤]	11.7*	7.98[α]	11.0[†]	8–11[β]	7.3[γ]	8.3[γ]	11.5[Ω]
Crude fat (%)	3.2[¤]	2.0*	1.98[α]	2.5[†]	4.9[γ]	2.2[γ]	3.9[γ]	4.8[σ]
Moisture (%)	10.6[φ]	12.6 [¥]	–	10.5[Φ]	14.0[γ]	14.0[γ]	14.0[γ]	9.5[Ω]
Ash (%)	2.4 [¤]	1.6[§]	1.72[α]	2.8[†]	1.4[γ]	1.4[γ]	1.6[Ω]	1.7[Ω]
Crude fiber (g/100 g)	3.7[¤]	2.0[§]	1.56[α]	3.0[§]	–	0.6–1.0[γ]	0.6[Ω]	0.5[Ω]
Food energy (kJ/100 g)	–	1105[§]		1406[†]				
Calcium (mg/100 g)	34[‡]	39.45[¥]	31.5[α]	165.2[†]	48.3[β]	6.85[λ]	50[θ]	46[σ]
Copper (mg/100 g)	0.52 [‡]	0.23[a ¥]		2.6[†]	1.3[β]	0.16[λ]	0.41[μ]	1.06[σ]
Iron (mg/100 g)	2.43 [‡]	3.5 [δ]	2.7[α]	15.7 [†]	4.8[β]	0.57[λ]	6[θ]	
Magnesium (mg/100 g)	94.3[‡]	103.5[a ¥]	92[α]	181.0[θ]	107.9[β]	16.88[λ]	180.0[θ]	137[σ]
Manganese (mg/100 g)	8.97[‡]	0.95 [¥]		3.8[†]	1.0[β]	0.36[λ]		
Phosphorus (mg/100 g)	563[φ]	–	359[α]	425.4[†]	299.6[β]	61.7[λ]	263.3[μ]	379[σ]
Potassium (mg/100 g)	507[φ]	–	412[α]	380.0[†]	324.8[β]	181.71[λ]	225.23[μ]	
Sodium (mg/100 g)	25.4[φ]	–		15.9[†]	59.2[β]	0.54[λ]	6.18[μ]	
Zinc (mg/100 g)	2.2[c ‡]	1.94 [¥]	3.0[γ]	4.8[†]	4.6[β]	2.0[γ]	2.0[γ]	3.1[σ]

[Ω] Ahmed et al. 1996; [¤] Aman et al. 1985; [μ] Awadalkareem et al. 2008; [Φ] Bultosa 2007; [†] Bultosa and Taylor 2004; [β] FAO 1992; [γ] FAO 1993; [σ] FAO 1995; [λ] Heinemann et al. 2005; [¥] Kashlan et al. 1991; [‡] Köksel et al. 1999; [δ] Leder 2004; [α] McCance et al. 1945; [θ] Mengesha 1966; [§] Obilana 2003; [φ] Riahi and Ramaswamy 2003; *Saturni et al. 2010

[1] Dry basis

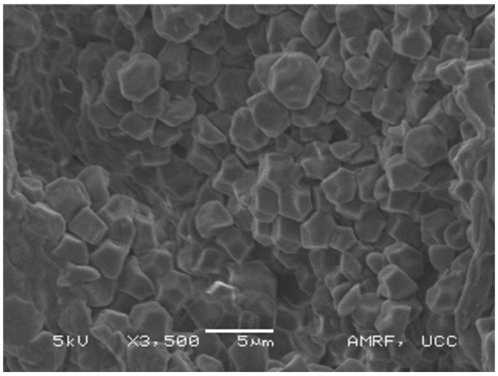

Fig. 1 Teff grain: Starch granules of the endosperm (Source: Helbing 2009)

cubic and at high magnification, and some appear as tortoise-shell shaped (Bultosa and Taylor 2004). According to Helbing (2009), Scanning Electron Microscopy (SEM) was better to identify these small structures accurately than Confocal Laser Scanning Microscopy (CLSM). The information contained in the endosperm starch granules look round from the CLSM images which contradicts the SEM images, there the starch granules were observed as rectangular or square. The reason for the difference in appearance is probably the treatment of CLSM teff grain with the fluorescent dyes that are dissolved in water. Through contact with water the grains are probably swollen and changed in structure.

The composition of teff starch granules is similar to other normal native cereal starches with 25–32 % amylose (Bultosa et al. 2002). However, Bultosa (2007) reported somehow smaller amylose contents for 13 teff varieties. According to Bultosa (2007), among teff flours the highest amylose contents were observed for DZ-01-354 (25.8 %), DZ-Cr-44 (25.6 %), DZ-01-1285 (24.2 %) and DZ-01-787 (23.8 %), and the lowest were for DZ-Cr-255 (20 %) and DZ-01-1681 (21.2 %). Bultosa et al. (2002) reported that the gelatinization temperature of raw teff is in the range of 68–80 °C, which is similar to that of other tropical cereal starches like sorghum (67–81 °C) (Dufour and Melotte 1992; Okolo et al. 1997), but narrower than that of maize (60–79 °C) (Narziss and Back 2009). Starch degradability is improved through the malting process due possibly to differences in the degree of modification of starch structure and composition (Glennie et al. 1983; MacGregor and Matsuo 1982; Okolo et al. 1997). The extent of gelatinization and the gelatinization temperature can also be affected by many other factors, including fat content, amylose content and granule size. As the gelatinization temperature of teff is too high for the amylolytic enzymes, an adjunct mashing regimen may be considered for wort production. The higher gelatinization temperature of raw teff may indicate that teff starches have high crystallinity and high perfect crystallites than barley and wheat starches which have lower gelatinization temperatures of 60–62 °C and 52–64 °C, respectively. This may be due to structural differences in their amylose and amylopectins (Briggs 1998; Sablani 2009; Tester

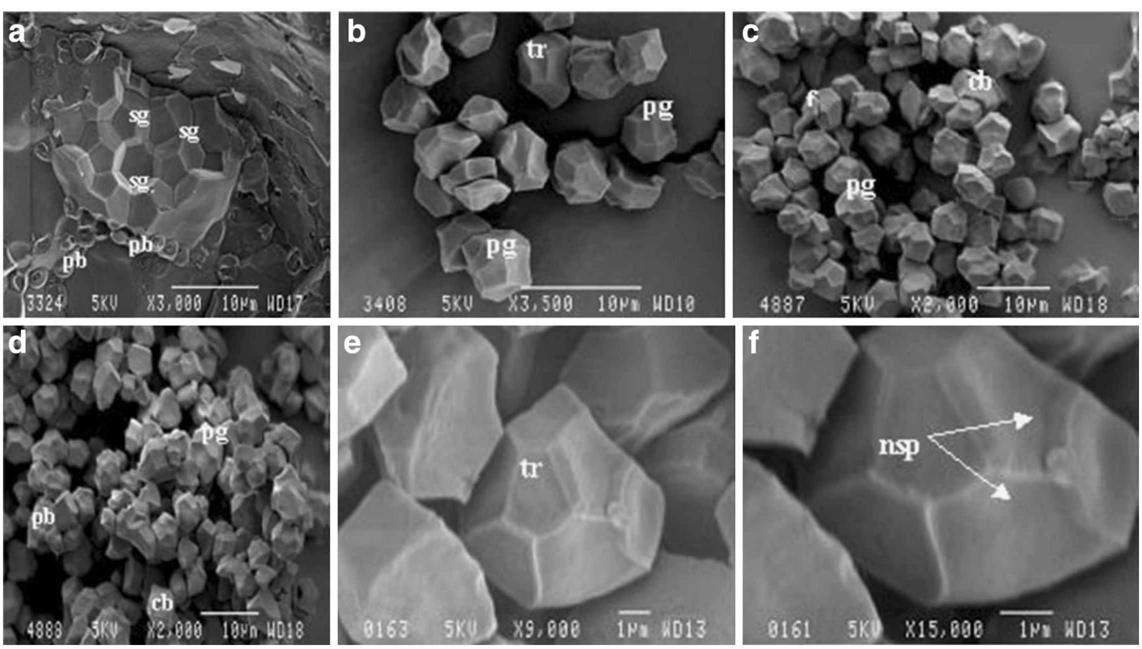

Fig. 2 Compound (**a**) and individual (**b**–**f**) starch granules from different teff varieties: (**a**, **b**) South African brown teff (**c**) DZ-01-1681, and (**d**–**f**) DZ-01-196; (sg = starch granules, pg = polygonal, cb = cubic, tr = tortoise-shell, pb = protein, f = fiber, and nsp = no surface pores). (*Source*: Bultosa and Taylor 2004)

and Morrison 1990). Gelatinization of starch is important in the processes such as baking of bread, gelling of pie fillings, formulation of pasta products, and thickening of sauces to produce a desirable texture or consistency. The proportion of raw and gelatinized starch in ready-to-serve starchy products may be critical in determining the acceptability. Texture of many foods such as breakfast cereals, beverages, rice, noodles, pasta, and dried soups depends on the fraction of gelatinized starch in the product (Sablani 2009). However, in most food systems the actual temperature at which starch gelatinizes is less important than those properties that depend on swelling, such as pasting behavior and rheological properties of the partially or fully swollen starch granules. The pasting temperatures for 13 teff varieties ranged from 67.7–75.9 °C with mean 72.7 °C (Bultosa 2007). The highest pasting temperatures were reported for teff varieties DZ-Cr-82 (75.7 °C) and DZ-01-1681 (75.9 °C) and the lowest was for DZ-Cr-44 (67.7 °C). The pasting temperatures reported by Bultosa (2007) were somehow similar to the reported Rapid Visco Analyzer (RVA) pasting temperatures (72.1–74.8 °C mean 74 °C) for five teff starches by Bultosa et al. (2002). According to Bultosa et al. (2002), the pasting temperature of teff (74 °C) is similar to that of maize starch (74.1 °C), but cooking time (4.19 min) to peak viscosity is longer than that of maize (2.90 min). The pasting character predicts the processing qualities of starch based raw material food ingredients. The pasting character is fundamentally determined by the starch granule composition and its nature (ultra-structures) and is also influenced by the non-starch flour components. Most of the gelling properties are due to amylose, which precipitates in aqueous solution to initiate gelatinization when heated. The paste clarity of teff starch is opaque, and the gel texture is short and smooth (Bultosa 2007). The branched molecules within the swollen granules undergo a slow association to rigidify the swollen granules. It is possible that the intra-granular amylose fraction enhances the rigidity of starch granules on bread staling. Specialty starches can provide a number of functional benefits in making snack products, including different expansion, crispness, oil pickup, and overall eating quality. The crisp texture of bakery products is due to recrystallization of sugar on removal of water during baking. Sugars also act to tenderize bakery products by slowing the rate at which starch molecules become interlinked and proteins break down (Hug-Iten et al. 1999).

The viscosity of teff starch is considerably lower than that of maize-starch. Peak, breakdown, and setback viscosities of teff starch 269 RVU, 79 RVU, and 101 RVU, respectively, are lower than those of maize starch 313 RVU, 129 RVU, and 161 RVU, respectively (Bultosa et al. 2002). Shimelis et al. (2006) reported that final viscosity is used to indicate the ability of starch to form various paste or gel after cooling and that less stability of starch paste is commonly accompanied with high value of breakdown. This implies that teff starch paste will have high stability after cooling when compared to that of maize starch paste. Sanni et al. (2001) reported that lower set back viscosity during cooling indicates higher resistance to retrogradation. This means that teff starch will exhibit higher resistance to retrogradation; thus, its products have high resistance to staling. Similar to other small-granule starches teff-starch granules offer good functionality as a fat substitute, flavor and aroma carrier since they are very small, smooth, and of uniform size. Teff starch has good resistance to shear breakdown, and thus it may find good application in high-shear processed foods. Its water absorption index is higher (108 %, db) than that of maize (86 %, db) whereas its water solubility index is lower (0.34 %, db) than that of maize (0.98 %, db) (Bultosa et al. 2002). Many carbohydrates are excellent scavengers of metal ions. Glucose, fructose and sugar alcohols have the ability to block the reactive sites of ions, such as copper, iron and to a lesser extent, cobalt. This is characteristic of monosaccharides and aids in food preservation by retarding catalytic oxidation reactions (Ferrier 1992).

Proteins

The average protein level of teff is comparable to that of barley, wheat, maize and pearl millet, and higher than that of rye, brown rice and sorghum (Table 1). The fractional composition of the protein in teff indicate that glutelins and albumins are the major protein storage components; and their order of fractional importance was: glutelins (44.55 %) > albumins (36.6 %) > prolamin (11.8 %) > globulins (6.7 %) (Seyfu 1997; Tatham et al. 1996). The distribution of these protein fractions varies among different cereals and there is considerable variation in the solubility classes among the cereals. Albumins range from 4 % in maize to 44 % in rye, globulins from 3 % in maize to 55 % in oats, prolamins from 2 % in rice to 55 % in maize, and glutelins from 23 % in oats to 78 % in rice. Among these fractions in cereals, the prolamin fraction has been the most studied (Haard et al. 1999). Prolamins are characterized by a particular amino acid composition with domains with a high content of proline and glutamine. It has been demonstrated that these protein domains are resistant to degradation by gastric, pancreatic and proteases in the human intestinal brush border membrane (Saturni et al. 2010). The prolamin fractions in teff were extracted from ball-milled teff samples from which Albumins and globulins were extracted by stirring with 1 M NaCl for 1 h and centrifuged (10000 g for 15 min). The prolamins were extracted with 70 % (v/v) aqueous ethanol for 1 h followed by 50 % (v/v) aqueous propan-1-ol, 2 % (v/v) acetic acid and 2 % (v/v) 2-mercaptoethanol for 1 h (Tatham et al. 1996). The amino acid composition of teff flour is favourable and its protein is easily digestible in comparison to cereals such as maize and sorghum because the main protein fractions such as albumin, glutelin, and globulin are the most digestible types.

Bultosa (2007) reported that the grain protein contents of 13 teff varieties are ranged from 8.7–11.1 % with mean 10.4 %. The grain protein in DZ-01-354 (10.6 %), DZ-01-99 (10.8 %), DZ-Cr-44 (10.7 %), DZ-Cr-82 (10.6 %), DZ-Cr-37 (11 %), DZ-Cr-255 (11.1) and DZ-01-1281 (11.1 %) varieties were the highest; and in DZ-01-1285 (8.7 %) was the lowest. Belay et al. (2005) also reported the grain protein contents of these 13 released teff varieties in the range of 12.4–8.7 % with mean 11.0 % and the highest was for DZ-01-99 and the least was for DZ-01-1285 like Bultosa's (2007) findings.

Protein level is very important in malting and brewing processes. Grain protein content is a key "gateway" characteristic for malting quality. Excessively high protein level is commonly associated with lower soluble substance content and malt extract quality, resulting in unacceptable malt quality. However, if the protein content of malt is too low, brewing performance may be impaired through poor yeast amino acid nutrition. Protein levels in general must not be too low as proteins serve four basic functions in brewing. They are the origin of enzymes that catalyze the complex biochemical reactions involved in turning the cereal into malt, and malt into wort. They are required for yeast nutrition; they contribute to foam and are involved in the flavor development that malt contributes to beer and whiskey. The protein content of teff (11 %) is in the range (9.5 to 11.5 %) that a good quality malting material should possess to yield the above-mentioned quality-attributes (Asano and Hashimoto 1980; Bamforth 1985; Bishop 1930; Chen et al. 2006; Kunze 2004; Steiner et al. 2011). Thus, its protein content is an indicator for production of good quality gluten-free malt from teff grains. The proteins also play an important role in determining the texture of a food, and may be used as thickening, binding, or gelling agents and as emulsifiers or foaming agents (Vaclavik and Christian 2008).

Amino acid composition

Teff seeds appear to be similar to wheat in food value; however, the National Research Council of USA suggested that teff seeds are actually more nutritious (National Research Council 1996) and contain generally higher amounts of the essential amino acids (Table 2). Research findings (Jansen et al. 1962) indicated that teff has an excellent balance among the essential amino acids that makes it comparable to that of egg, except for its somewhat relatively low lysine and isoleucine contents. The other amino acids compositions of teff are also excellent and its lysine content (3.68 g/100 g) is also higher when compared to other cereals (Table 2). Isoleucine, leucine, valine, tyrosine, threonine, methionine, phenylalanine, arginine, alanine and histidine contents of teff are higher than in barley, wheat and most other cereals. Isoleucine, valine, tyrosine, serine, and glycine contents of teff are slightly lower than those of brown rice. The overall amino acid profile of teff can be regarded as well-balanced (Table 2).

Yigzaw et al. (2004) reported that spontaneous fermentation of teff caused decreases in threonine, valine, isoleucine, and lysine contents by 30, 8, 20 and 17 %, respectively. According to this research finding, amino acids such as leucine, phenylalanine, and histidine showed no significant change, whereas methionine was increased by 90 %. Fermentation with *Lactobacillus plantarum* (lactic acid bacteria) caused decreases in threonine, isoleucine, lysine, and valine by 28, 14, 17, and 6 %, respectively (Yigzaw et al. 2004). They found that fermentation with lactic acid bacteria increased the amounts of leucine (12 %) and methionine (110 %), whereas phenylalanine and histidine remained practically the same. In general, the bacterial fermentations did not improve the essential amino acid profile of the fermented food product. The fungal fermentation, on the other hand, improved essential amino acid profiles of teff. Almost all amino acids increased during fungal fermentation (or fermentation with *Aspergillus oryzae* and *Rhizopus oligosporus*) by 10 to 36 %. The effect was even higher for methionine, which was increased by 180 %.

The well balanced amino acid composition of teff makes it an excellent material for malting and brewing. Nutritional value and stability are the most important qualities of alcoholic beverages. In addition to some other food components, proteins and some amino acids are also responsible for nutritional value and stability of beer. Proline and lysine are the most important amino acids in beer. It is known that proline residues are responsible for the affinity towards proanthocyanidins and take part in the production of aromatic compounds and, in this way, influence beer quality. The difference in amino acid contents will affect beer flavors (Gorinstein et al. 1999; Jones and Pierce 1964; Outtrup 1989; Perpète et al. 2005). Amino acid contents also play a crucial role in yeast nutrition. As a result their concentration affects fermentability and flavour profile of the finished product (Clapperton 1971; Gibson et al. 2009; Procopio et al. 2011).

Fat

Bultosa (2007) found that the crude fat content of teff is in the range of 3.0–2.0 % with mean of 2.3 % which is similar to the review report (3.09–2.00 %) of previous findings (Bultosa and Taylor 2004). According to Bultosa (2007), the highest crude fat was for DZ-Cr-82 (3 %) and the lowest values were among DZ- 01-354 (2.1 %), DZ-01-99 (2.1 %),

Table 2 Amino acid content of teff (g/16 gN) compared with some gluten containing and gluten free cereals, and whole egg

Amino acid	Gluten rich cereals		Gluten free-cereals				
	Barley	Wheat	Teff	Pearl millet*	Rice[φ]	Sorghum[μ]	Whole egg[*]
Lysine	3.46†	2.08†	3.68†	2.89	3.7	0.34	6.6
Isoleucine	3.58†	3.68†	4.07*	3.09	4.5	0.65	7.5
Leucine	6.67†	7.04†	8.53†	7.29	8.2	2.13	9.4
Valine	5.04†	4.13†	5.46†	4.49	6.0	0.79	7.2
Phenylalanine	5.14†	4.86†	5.69†	3.46	5.5	0.87	5.8
Tyrosine	3.10†	2.32†	3.84†	1.41	5.2	0.70	4.4
Tryptophan	1.54†	1.07†	1.30*	1.62	1.2	0.22	1.4
Threonine	3.31†	2.69†	4.32†	2.50	3.7	0.53	4.2
Histidine	2.11†	2.08†	3.21†	2.08	2.3	0.36	2.1
Arginine	4.72†	3.54†	5.15†	3.48	8.5	0.62	6.9
Methionine	1.66†	1.46†	4.06†	1.35	2.7	0.28	3.8
Cystine	2.21[c §]	2.42[d ¥]	2.50*	3.19	1.8	0.33	2.4
Asparagine + Aspartic Acid	4.62[a c §]	5.12[d ¥]	6.4[¤]		9.0		–
Serine	3.51[c §]	4.98[d ¥]	4.1[¤]		5.0	0.76	–
Glutamine + Glutamic Acid	18.86[b c §]	29.53[d ¥]	21.8[¤]		17		–
Proline	9.58[c §]	10.18[d ¥]	8.2[¤]		5.0	1.34	–
Glycine	3.29[c §]	4.04[d ¥]	3.1[¤]		4.5	0.48	–
Alanine	4.51[c §]	3.56[d ¥]	10.1[¤]		5.5	1.55	–

[a] Aspartic acid only; [b] Glutamic acid only; [c] Mean value of three varieties; [d] Mean value of 12 varieties

[¤] Bultosa and Taylor 2004; [§] Chatterjee et al. 1975; *Jansen et al. 1962; [φ] Khoi et al. 1987; [¥] Mosse et al. 1985; †Seyfu 1997; [μ] Shoup et al. 1969

DZ-01-974 (2.1 %), DZ-Cr-37 (2 %), and DZ-01-1681 (2 %). The crude fat content of teff grain, in general, is higher than that of wheat, rye, and brown rice but lower than that of barley, maize, sorghum and pearl millet (Table 1). The fat contents are mainly of fatty acids. Teff grains are rich in unsaturated fatty acids. The seeds contain 22 % w/w of fixed oil rich in unsaturated fatty acids (72.46 %), among which oleic acid is predominant (32.41 %), followed by linoleic acid (23.83 %) (El-Alfy et al. 2011). The unsaturated fatty acids are not only important for our nutrition, especially as some cannot be synthesized by humans (essential fatty acids), but also play important role in the production of beer. They are useful for the structure of the yeast cell wall. Their derivatives are also responsible for aging processes in beer taste after filling. Long-chain fatty acids (in particular linoleic and palmitic acid) play a key role in the improvement of fermentation performance in hot trub/break. Besides the contribution of long chain fatty acids for fermentation performance, their fast release from hot trub into wort improve yeast nutrition and therefore, favor its metabolism (Kunze 2004; Kühbeck et al. 2006).

Crude fiber

The crude fiber content in teff (3.0 g/100 g) is by far higher than in most other gluten containing and gluten-free cereals (Table 1). Inadequate fiber intake is likely to be related to the composition of many gluten-free foods made with starches and/or refined flours with low content in fiber (Thompson 2000). In fact during refining, the outer layer of grain containing most of the fibre is removed, leaving only the starchy inner layer. Exceptionally in the case of teff, due to the small size of its grains, it is almost always made into a whole-grain flour (bran and germ included), resulting in a very high fibre content compared with the other grains, and high nutrient content (Vinning and McMahon 2006). Teff has as much, or even more, food value (Tables 1 and 2) than the major grains: wheat, barley, and maize, for instance. This is probably because it is always eaten in the whole-grain form: the germ and bran are consumed along with the endosperm. Although germ in teff is known to occupy large proportion as in other small grains, its crude fat is known to be not as such high. The crude fiber ranged from 3.8–2.6 % with mean 3.3 % (Bultosa 2007) and apparently the crude fiber contents observed in these 13 varieties are almost similar with the earlier report of 3.5–2.0 % with typical value 3.0 % (Bultosa and Taylor 2004). According to Bultosa (2007), the crude fiber contents were high among teff varieties DZ-01-787 (3.5 %), DZ-Cr-82 (3.5 %), DZ-01-974 (3.5 %), DZ-Cr-358 (3.5 %) and DZ-01-1281 (3.4 %) and highest in brown teff varieties DZ-01-99 (3.8 %) and DZ-01-1681 (3.7 %). The crude fiber for DZ-Cr-44 (2.7 %) and DZ-Cr-255 (2.6 %) were the lowest. Consumption of dietary fiber provides many health benefits. The dietary fiber content of teff (8.0 g/100 g) is high when compared to some fruits, nuts, pulses and cereals such as corn and rice (Saturni et al. 2010). Studies revealed that high fiber diets prevent many human diseases, colon cancer, coronary heart disease and diabetes (Anderson et al. 2009)

Minerals

Research data (Table 1) show that the proximate and mineral contents of whole teff grain are comparable with, in some cases higher than, wheat, barley and most other cereals. Bultosa (2007) reported that the ash content of 13 teff varieties ranged 3.16–1.99 % with mean of 2.45 %. The ash contents in the brown teff varieties DZ-01-99 (3.16 %) and DZ-01-1681 (2.99 %) and in DZ-Cr-255 (3.10 %) were comparatively high, and in teff varieties DZ-01-787 (2.06 %), DZ-Cr-358 (1.99 %) and DZ-01-1285 (2.02 %) appeared low. In general, compared to the other cereals, teff is rich in minerals such as calcium, zinc, magnesium, iron, phosphorous and copper (Abraham et al. 1980; Bultosa and Taylor 2004; Kashlan et al. 1991; Mengesha 1966; Seyfu 1997).

Calcium is the most common mineral in our body and is indispensable for the strength of the skeleton and hardness of teeth. It also plays numerous functions in the body. High calcium diets prevent gaining of weight and fat accumulation (Teegarden 2003; Zemel 2003). Epidemiologic evidence (Norat and Riboli 2003) and at least one intervention study (Holt et al. 2001) have shown that higher calcium intake lowers the risk of developing colon cancer. A disease caused by failure to build adequate bone mass or by progressive bone loss during aging called osteoporosis can be prevented by generous intake of calcium. Thus, a high consumption of calcium rich foods will help build optimum bone mass during childhood and adolescence and will also slow the rate of bone loss that naturally occurs with aging (Dickinson 2002). Teff contains an excellent concentration (0.165 %) of calcium and the level of this mineral in teff is by far higher than other cereals (Table 1). This leads us to conclude that teff is an excellent cereal to prevent the aforementioned health problems associated with less consumption of calcium. An invention by Roosjen (2007) revealed that flour should preferably contain at least 0.15 % calcium. None of the major cereals such as barley (0.034 %), wheat (0.039 %), rye (0.032 %), maize (0.048 %), sorghum (0.05 %), brown rice (0.0069 %), and pearl millet (0.046 %) fulfill this requirement. However, teff and some other cereals such as finger millet (0.182 %) contain naturally higher than 0.15 % calcium (Shukla and Srivastava 2011)

As magnesium deficiency alters calcium metabolism and the hormones that regulate calcium (Elisaf et al. 1997; Rude et al. 1999), magnesium deficiency could be a risk factor for osteoporosis. The concentration of magnesium in teff is much higher than in other cereals except sorghum which has magnesium concentration comparable to that of teff (Table 1). Malabsorption of iron, folate, and calcium is common, as these nutrients are absorbed in the proximal small bowel. In particular, it has been reported that the frequency of iron-deficiency in celiac disease varies from 12 to 69 % (Tikkakoski et al. 2007). Studies showed that teff consumers have higher level of haemoglobin in their blood than non-teff consumers, and they do not suffer from hookworm anaemia even when infested; however, hookworm anaemia develops in non-teff eaters if they are infested with hookworm (Molineaux and Biru 1965; Tadesse 1969). In Ethiopia, an absence of anaemia seems to correlate with the levels of teff consumption and is presumed to be due to the grain's high content of iron. In addition, according to the same studies, malaria is frequently found in the groups with lower haemoglobin levels. Teff has been implicated in the low incidence of anaemia in Ethiopia. The severity of these nutritional deficiencies is modulated by different factors: the length of time that people have lived with the active but undiagnosed disease, the extent of damage to the gut intestinal tract and the degree of mal-absorption. Previous studies have demonstrated that most of these nutritional deficiencies disappear after following strictly a gluten free diet (Annibale et al. 2001; Bardella et al. 2000).

Recent studies have examined athletes' endurance higher iron requirements. Runners, for example, might need 30 % to 70 % more iron due to losses from foot strike hemolysis and gastrointestinal blood loss (Food and Nutrition Board, 2002). It is well known in a worldwide level that the resistance and general good fitness of Ethiopian sport people is high. The general high nutritional value of teff and its iron content are believed to be the major contributors for this. The high iron content of teff increases the haemoglobin level of the blood that helps more oxygen to be transmitted (Andrews et al. 1999). Due to the aforementioned health benefits of teff, new scientists are interested to know all about the teff composition, nutritional properties, and the changes that happen at the moment of grain fermentation during the preparation of *injera*, a flat bread that is responsible for about 70 % of the Ethiopian population. More and more interest is being shown in teff research and in the future it might also be used for different food and beverages applications in the different parts of the world because of its high nutritional value and potential for health food market.

Metal cations are also well known to promote beer foam stability (Rudin 1957). More recently, Roza et al. (2006) confirmed that the inclusion of non-toxic metal cations in beer has a significant foam stability benefit, such as the inclusion of Zn^{2+}. Kühbeck et al. (2006) reported that zinc plays a key role in the improvement of fermentation performance. They also reported that similar to the long chain fatty acids, fast release of zinc from hot trub into wort also improved yeast nutrition and favor its metabolism.

Vitamins

Vitamins are useful to prevent and treat various diseases including heart problems, high cholesterol levels, eye disorders, and skin disorders. Most of the vitamins also facilitate the body mechanism and perform functions which are not performed by any other nutrient (WHO 2003). Most of the vitamins in cereals and malt are solubilized into wort during the brewing process. Their importance to the brewing process depends on their content in wort, more than sufficient to ensure a regular yeast performance during fermentation. In particular the B-group vitamins are crucial as growth factor for yeast, especially biotin, inositol and panthotenic acid (Buiatti 2009). Teff contains good levels of certain vitamins such as vitamin C (88 mg), niacin (2.5 mg), vitamin A (8 retinol equivalent (RE)), riboflavin (0.2 mg) and thiamin (0.30 mg), all per 100 grams of grain (National Research Council 1996). Thiamin in teff is typically lower when compared to that of wheat (0.43 mg), and barley (0.37 mg) (Guerrant and Fardig 1947).

Enzymes

Enzymes, particularly amylases, are responsible for the degradation of starch molecules during mashing. Presence of too little enzyme activities in the mash may lead to several undesirable consequences such as low extract, longer time to separate the wort, slow fermentation process, too little alcohol in the final product, microbiological instability, reduced filtration rate of the beer, and inferior flavour and stability of the beer. Zarnkow et al. (2008) reported that teff malt has good level of enzyme activities though the recorded α- and β-amylase activities (75 and 213 U/g, respectively) are lower than those of barley malt 106 and 514 U/g, respectively (Phiaraise et al. 2005). The levels of the enzyme activities of four different teff varieties reported by Zarnkow et al. (2008) were enough to use them as suitable raw materials for malting. However, the gelatinization temperature of teff (68–80 °C) (Bultosa 2007) is too high for the amylolytic enzymes. Thus, it may be useful to consider an adjunct mashing regimen for wort production. Research findings showed that the highest limit dextrinase value of teff malt (894 U/Kg) is twice the average limit dextrinase value of barley malt (400 U/Kg) (Zarnkow et al. 2008).

Phenolic compounds

The other most important health-promoting aspect of teff as food is that like other millets it is generally assumed to contain substantial amounts of phenolics (Dykes and Rooney 2007). Research findings revealed that ferulic acid (285.9 μg/g) is the major phenolic compound in teff. Some other phenolic compounds such as protocatechuic (25.5 μg/g), gentisic (15 μg/g), vanillic (54.8 μg/g), syringic (14.9 μg/g), coumaric (36.9 μg/g), and cinnamic (46 μg/g) acids are also present in teff in considerable amounts (McDonough and Rooney 2000). Phenolics are notable for their antioxidant activity, which appears to be beneficial in terms of prevention of cardiovascular disease and cancer (Awika and Rooney 2004). They also act as natural antioxidants for the food industry. At the same time, they might inhibit digestive enzymes and reduce food digestibility (Maheshu et al. 2011; Qiang et al. 2006). The role of phenolic compounds in relation to the colour, taste, and stability of beer is well known. Beer rich in phenolic antioxidants shows higher quality, more stable sensory properties such as flavor and aroma, foam stability, and longer shelf life (Drost et al. 1990; Guido et al. 2007; McMurrough et al. 1996; Woffenden et al. 2001).

Teff utilization

Teff is a major food grain in Ethiopia but is a minor cereal crop worldwide. In Ethiopia, teff is traditionally grown as a cereal crop. The grain is ground to a flour mainly used for making a popular pancake-like local bread called *injera,* which has a honeycomb-like appearance. *Injera* is made from dough fermented for 2–3 days. Sometimes the flour is also used for making porridge, *kitta* (unleavened bread), and *atmit* or *muk* (gruel) (Selinus 1971). Various studies (Yetneberk et al. 2004; Zegeye 1997) showed that in its *injera* making and keeping quality features, teff grain appeared superior among other cereal grains because of its high resistance to staling. During the baking of *injera*, starch is completely gelatinized to form a steam-leavened, spongy matrix, in which fragments of bran, embryo, microorganisms and organelles are embedded (Bultosa et al. 2002; Parker et al. 1989). Yetneberk et al. (2004) studied the staling properties of *injera* prepared from teff (DZ-01-196) and 12 varieties of sorghum. They reported that *injera* prepared from teff grain is resistant to staling and the maximum force required for bending fresh teff-*injera* and *injera* stored for 24 and 48 h is lower than that of sorghum-*injera*. The maximum forces required for bending fresh teff-*injera* and *injera* stored for 24 and 48 h were 0.13, 0.12 and 0.15 N, respectively. However, the force required for bending fresh sorghum-*injera* and sorghum-*injera* stored for 24 and 48 h were 0.23, 0.3, and 0.37 N, respectively. This indicates that sorghum-*injera* easily undergoes staling, and the keeping quality and palatability of teff-*injera* is much better than sorghum-*injera*. Various research findings also showed that teff flour can be mixed with barley or sorghum flour to make *injera*. But pure teff flour produces the best quality *injera*, pliable, soft with glossy appearance, which does not fall apart under handling or stick to the fingers, and has a slightly sour taste (Yetneberk et al. 2004; Zegeye 1997). *Injera* is traditionally consumed with *wot,* a sauce made of meat or ground pulses like lentil (*Lens culinaris*), faba bean (*Vicia faba*), field pea (*Pisum sativum*), and chickpea (*Cicer arietinum*). The traditional way of consuming teff-*injera* with *wot* provides a well balanced diet because of the high nutritional composition of the whole grain teff and the sauce made from nutritious raw materials; *wot* also supplements the lysine deficit in teff (Seyfu 1997). White-grained types of teff are preferred for food, but consumption of *injera* from red- or brown-grained types is also increasing, especially for health-conscious urban people.

An invention on processing of teff flour revealed that teff flour with falling number higher than 250 s is an excellent raw material for baking (Roosjen 2007). However, teff flour which is obtained by grinding the grain directly after harvesting causes instability and unattractive taste and structure to the final product. The main reason for this is that teff grain directly after harvesting has too low falling number. This can be solved by letting the grain to go through an after-ripening process (storing for some time) after harvesting in which the falling number of the grain increases (Hidetoshi 2001; Lukow et al. 1995). According to the invention (Roosjen 2007), a high quality product, which meets the market standard of 7.5 (on a scale of 1–10) by a test panel, can be obtained by using teff flour with falling number of at least 400 s. Teff flour having falling number between 400 and 550 s results in a dough or batter with high baking qualities. According to this invention, dough prepared from teff flour with falling number higher than 250 s can be used for the preparation of a wide range of baked food products such as bread, pastry, cookies, pizza, pasta, noodles, etc.

In wheat-bread-dough the gluten proteins naturally form a visco-elastic network required for the desired functional properties of bread products (Xu et al. 2007). Since these kinds of proteins are lacking in gluten free cereals, other techniques such as enzyme treatment (e.g. glucose oxidase) (Renzetti & Arendt 2009), and high pressure treatment (Vallons et al. 2011) can be used to improve the functional properties of gluten-free flours by promoting a protein network. According to these research findings, protein polymerisation can improve the bread making performance of gluten-free flours by enhancing elastic-like behaviour of batters. The teff grain, owing to its high mineral content, has started to be used in mixtures with soybean, chickpea, and other grains in the baby food industry (Seyfu 1997). The high fiber content of the grain makes it to be useful in preventing diabetes and other health problems as well as assisting with blood sugar control. Anderson et al. (2009) reported that individuals with high intakes of dietary fiber appear to be at significantly lower risk for developing coronary heart disease, stroke, hypertension, diabetes, obesity, and certain gastrointestinal diseases. Increased fiber intake lowers blood pressure and serum cholesterol levels, improves glycemia and insulin sensitivity in non-diabetic and diabetic individuals, and benefits a number of gastrointestinal disorders including the gastroesophageal reflux disease, duodenal ulcer, diverticulitis, constipation, and hemorrhoids. Fiber supplementation in obese individuals significantly enhances weight loss (Anderson et al. 2009). An additional advantage is that teff is almost always grown and stored under organic conditions. Several recipes that fit Western tastes have been developed from teff flour particularly in the United States, where it has found niches in the health food market and as a gourmet food. Teff flour is used as a thickening agent in a range of products, including soups, stews, gravies, and puddings (Seyfu 1997).

In Ethiopia, the grain is also used to make traditional local alcoholic beverages such as opaque beer called *tella,* a sprit called *katikala/arake,* and *shamit* at household level.

Tella has a smoky flavor due to the addition of bread darkened by baking and use of a fermentation vessel which has been smoked by inversion over smoldering *weyra*-wood. In addition to the cereal, the other most important ingredient in making *tella* is the leaves of *Gesho* (*Rhamnus prinoides*). It imparts characteristic bitterness of the beverage. Research findings indicated that *Gesho* regulates the microflora responsible for the fermentation process (Kleyn and Hough 1971). It is also revealed that the bitterness of the brew is directly related to the amount of *Gesho* added. *Tella* is not processed under government regulations and the alcohol content varies between 2 to 4%vol. Filtered *tella* has a higher alcohol content ranging from 5 to 6%vol (Selinus 1971).

Arake is a distilled beverage. Ground *Gesho*-leaves and water are kept for 3–4 days and after that unleavened bread called *kita* made of teff or other cereals, and germinated barley or wheat are added. The mixture is allowed to ferment for 5–6 days and then distilled. In the villages, distillation is carried out with primitive equipments made of gourds and wood. It is usually redistilled and its alcoholic content is in the range of 45–50%vol (Selinus 1971).

Shamit is a local beer made among the Gurage ethnic group. Unleavened teff bread, called *kita,* and germinated barley, called *bekel*, are milled and mixed with water, and the mixture is filtered after 3–4 days of fermentation. Dehusked barley is toasted on metal plate called *mitad*, milled and added to the mixture, and the beverage is ready to serve the next day, when Ethiopian cardamom, *mitmitta*, black cummin and bishop's weed are added (Selinus 1971).

Teff as a potential gluten-free cereal for malting and brewing

The food alternatives for Celiac Disease (CD) patients are mostly based on maize, rice, and soy. Teff appears to be another interesting possibility. Beer is commonly produced from malted barley; therefore beer is excluded from the diet of celiac disease patients. No beers or other beverages of any kind made with any amount of malted barley will meet the standard of gluten-free, because the definition of "gluten-free" typically used by physicians and clinical nutritionists is "made from gluten-free raw materials only." That is the food must contain no particle of any material derived from wheat, barley and/or rye (FAO/WHO 1994). Celiac disease is a lifelong inflammatory condition of the gastrointestinal tract caused by permanent intolerance to gluten proteins present in cereals such as wheat, barley and rye (Green et al. 2005). The only effective treatment for celiac disease is the total lifelong avoidance of gluten ingestion; this is not easy because many staples of the Western diet are based on wheat flour. A cereal like teff lacking T-cell-stimulatory peptides would thus be of great value to patients with celiac disease. The present "raw-materials" definition of gluten-free foods will permanently exclude any malt-based beer, or any other malt-based beverages, regardless of how it might be made. This is not a good outcome for the brewing industry and their consumers, and the brewing industry should take a lively interest in this debate. The most obvious way to make a gluten-free beer is to start with gluten-free raw materials (Zarnkow et al. 2010). Gluten-free cereal products represent a growing market opportunity, within the global health and wellness market, for food manufacturers that develop consumer-led new products with high added-value levels, which ultimately gain consumer acceptance. Beer usually contains appreciable quantities of hordein (barley gluten prolamin) (Ellis et al. 1994); however, some low gluten beers have been presented in the market. Rice, corn and potatoes have been widely used as substitute of gluten containing grains. A number of nutrient dense grains, seeds, pulses offer increased variety, improved palatability and high nutritional quality for the gluten free diet (Gallagher et al. 2004; Lee et al. 2009).

There is a growing interest on teff grain utilizations because of nutritional merits (whole grain), and the protein is essentially free of gluten the type found in wheat (Dekking et al. 2005; Hopman et al. 2008; Taylor et al. 2006) making it a suitable substitute for wheat and other gluten containing cereals in foods for people with celiac disease. Thus, it can be an alternative food for consumers allergic to wheat glutens. However, other cereals have proteins that exert a toxic effect for celiac disease patients. Studies on structural composition of raw and malted grains indicate that like other cereals the main differences between the raw and malted teff grains are mainly in the endosperm (Helbing 2009). Enzymatic breakdown of the endosperm cell walls occur faster in germinated (malting) cereals (Figs. 3 and 4).

The endosperm cells have an angular, polygonal shape with a size of up to 70 microns (Helbing 2009). According to this research finding it was possible to see the endosperm structure somehow better in the SEM image of the whole grain in the top view of the belly. Teff produces nutritionally rich grain, comparable to or better than wheat, barley and maize (National Research Council 1996). Thus, it is a potential cereal for brewing process and can be used as a substitute for wheat flour in almost all its applications. Malting and brewing processes for teff have not been extensively investigated except for the study conducted by Zarnkow et al. (2008) on the optimization of the malting conditions of teff (Fig. 5).

They used four different varieties of teff (Ivory, Dessie, Sirgaynia and Brown) with average moisture of 10.0 %. Based on the result of this study, they concluded that the optimal malt is obtained after 4 days of germination with 48 % degree of steeping, and a set temperature of 24 °C for steeping and germination. Studies showed that like other cereals teff is predominantly starchy; the starch content and its malt quality are indicators of its suitability as raw material for brewing (Bultosa 2007; Zarnkow et al. 2008). Protein content of teff is comparable to those of wheat and barley, and it is nutritionally superior because of its high levels of amino acid profile (FAO 1970; National Research Council 1996), making it an excellent material for malting and brewing. Research findings (Zarnkow et al. 2008) indicate that teff malting causes an increase in the levels of simple sugars and free amino nitrogen (FAN) as a result of breakdown of starch and protein, respectively. These products are essential for beer making. Therefore, malt produced from teff is of high nutritional quality for brewing and food use. However, the extract values determined by using the

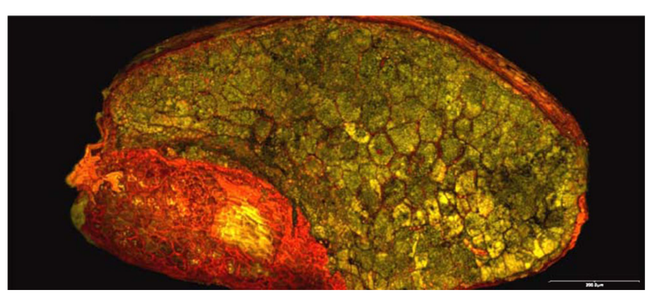

Fig. 3 Teff grain: Longitudinal section with germ and endosperm (SEM image) (*Source*: Helbing 2009)

Fig. 4 Teff malt kernel: Scanning Electron Microscopy (SEM) image (*Source*: Helbing 2009)

congress mashing ranged at low level between 13.6 and 55.7 %, which is lower than that of barley (>80 %) (Briggs 1998). The low extract in teff may indicate that the congress mashing program is not suitable condition for mashing teff malt. The results reported by Zarnkow et al. (2008) could be used as a base for further studies on uses of various teff varieties as malt. Apart from teff's intrinsically good brewing quality, what is driving this brewing revolution is economics. In developing countries the commercial processing of these locally grown grains in to value-added food and beverage products is an important driver for economic development.

Research gaps and opportunities

Research gaps

Teff is used for many applications including products such as *injera* and *tella*. The production of *injera* and *tella* involve fermentation stages, and are dependent on temperature and other environmental factors (Magazoni et al. 2010) but there is no standard for the amounts of the starter culture and other ingredients, and little is known about the identity and relative importance of species of yeasts and bacteria involved in the preparation of *injera*. Standard processing conditions are also required for making these environment dependent products in the different parts of the world. Although *injera* and *tella* are parts of the main staple foods for Ethiopian community, their preparation techniques are still too traditional, labor intensive and time consuming. It is also a burden for women as it is considered as females work. Attention should be given mainly to its processing technology at small and/or large scale production. Teff-*injera* has high keeping quality than *injera* prepared from other cereals (Yetneberk et al. 2004). However, its shelf life is not more than 4 days if it is kept under room temperature with the local preserving techniques. Thus, there is a research need to develop packaging technique for preserving *injera* so as to supply it for local and export markets. The by-product during *tella* preparation is called *atela*. *Atela* (sediment) is a residue that settless at the bottom of a pot at the end of *tella* preparation. It is commonly used in Ethiopia across the country for cattle feeding. However, its nutritional value has not yet been studied.

Many research reports concluded the medicinal value including gluten free nature of teff (Dekking et al. 2005; Hopman et al. 2008). The growing demand of gluten free foods in the western countries needs an urgent research on teff products and application of teff in other food products as a substitute for gluten rich cereals.

Opportunities

– Teff is a highly nutritious (Bultosa and Taylor 2004; Guerrant and Fardig 1947; Jansen et al. 1962; Obilana 2003; Seyfu 1997) and gluten free cereal (Dekking et al. 2005; Hopman et al. 2008). It has an excellent amino acid profile that makes it comparable to egg, and the best cereal with respect to its nutritional value (Jansen et al. 1962; Seyfu 1997). Thus, it is an interesting alternative raw material for manufacturing nutritionally improved gluten free foods.
– Many gluten-free products may not meet the recommended daily intake for fiber, minerals, and vitamins.

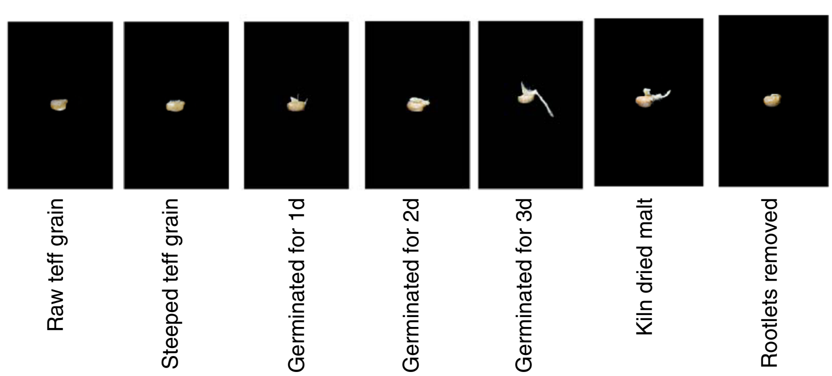

Fig. 5 Structures of teff grain under different stages of malting (*Source*: Zarnkow et al. 2008)

Thus, they need to be fortified to fulfill the requirements of the daily intake (Gallagher et al. 2004; Suliburska and Krejpcio 2011). Teff has naturally higher nutritional value when compared to many other grains, and doesn't need to be fortified.

– One of the major problems associated with gluten-free products is their inferior taste and/or structure (Gallagher et al. 2004). However, use of teff grain with falling number higher than 250 seconds at the moment of grinding solves these problems (Roosjen 2007). According to this report teff flour with the above-mentioned falling number has great advantage that it can be processed in to a stable gluten-free product with an attractive taste and structure.
– Due to its high fiber content (Bultosa 2007) and gluten free property, teff is getting acceptance as medicinal ingredient (Hopman et al. 2008). In connection to its medicinal values interests are growing in many countries to utilize teff for production of gluten free foods.
– Use of teff as food consumption is already well known in some parts of the world like Ethiopia, the Netherlands, North America and so on. It will not be difficult for the processors to introduce this cereal in other parts of the world.
– Teff-*injera* is one of the best staple foods and widely used in Ethiopia. In addition to the high consumption of teff in the country, there is a growing demand for *injera* and other teff products by Ethiopians living abroad and foreigners who are accustomed to Ethiopian dish.
– Production of teff is increasing by using improved varieties (Tefera et al. 1995; Tefera et al. 2001).
– It is a tropical low risk cereal that grows in a wider ecology and can tolerate harsh environmental conditions where most other cereals are less viable. Thus, it has the potential to be grown in every part of the world.

Conclusion

Teff is a reliable and low risk cereal that grows on a wider ecology under moisture stress and waterlogged areas with few plant diseases and grain storage pest problems. Processing of teff for different foods is usually done by traditional ways and is mostly limited to the household level. Processing of the grain for different commercial foods is needed to promote worldwide teff utilization. The nutrient composition of teff grain indicates that it has high potential to be used in foods and beverages worldwide. Teff has its own unique qualities and advantages, and thus its introduction to other parts of the world could benefit many nations. It has the potential to add variety to our diet and may have useful health promoting properties, particularly antioxidant activity. The very high concentration of calcium in teff makes it to be an excellent cereal to prevent health problems associated with less consumption of calcium such as gaining of weight, accumulation of fat, colon cancer, osteoporosis, weakening of skeleton and teeth, and so on. Teff grain nutrients are promising and it is also an excellent gluten free alternative for people with celiac disease and other gluten allergy. The high carbohydrate content, lack of gluten and its high germinative energy and malt quality make it to be a suitable raw material for brewing and producing other gluten free beverages. Though the α- and β-amylase activities of teff malt are lower than that of barley, it has sufficient level of enzyme activities to be used as a raw material for malting. Currently only sorghum, rice, maize, millet, and buckwheat appear to be successful gluten-free beer ingredients, while others have only shown adjunct possibilities. The search for new gluten-free brewing materials is still in its infancy and researchers in this field of study are continuously researching on the malting, mashing, fermentation conditions and other aspects of teff so as to use it as a raw material for gluten-free beer, functional beverages and other gluten-free foods.

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