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REVIEW ARTICLE

ORIGIN, DOMESTICATION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETIC DIVERSITY AND BREEDING OF TEFF OR ETHIOPIAN MILLET [*Eragrostis teff* (Zucc.) Trotter]

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ABSTRACT

Teff belongs to the Grass or Poaceae Family (formerly Gramineae), sub-family Chloridoideae, tribe Eragrostideae and genus *Eragrostis* and species *Eragrostis tef* (Zucc.) Trotter. The genus contains about 300 species. The word 'teff' originates from the Amharic word 'teffa' which means 'lost' due to the small size of the grain or from the Arabic word 'tahf' used by the Semites in South Arabia. The word 'teff' comes from the Ethiopian word 'teffa', which means 'lost' because of its minute grain size. Teff grains are manually harvested by sickles and threshed with ox tramping on them. It was estimated that 25-30% of teff would be lost before and after harvest, and lodging may contribute to the yield loss up to 30%. The high losses along the production processes can reduce the available quantity of teff by up to 50%. Common names of Eragrostis tef (Zucc.) Trotter in English are Tef, Teff, Teff grass, Williams lovegrass, Abyssinian lovegrass, Lovegrass, Annual Bunch Grass, Warm Season Annual Bunch Grass. Also written as: Ttheff, Tteff, Thaff, Tcheff, Thaft, Tcheff. It is also known by the vernacular names tafi in Oromigna and taf in Tigrigna. The species in the genus *Eragrostis* generally range from diploid ($2x = 2n = 20$) to hexaploid ($2x = 6x = 60$). Tef is an allotetraploid species ($2n = 4x = 40$) originating from the hybridisation of two distinct species followed by diploidisation. Tef (*Eragrostis tef* (Zucc.) Trotter) is a crop for which Ethiopia is the center of origin and diversity. Tef is endemic to Ethiopia and its major diversity is found only in this country. Tef is a fine grain that comes in a variety of colors, from white and red to dark brown. The exact date and location for the domestication of tef is unknown, it is native and an important cereal crop to Ethiopia which is believed to be originated between 4000 and 1000 BC. However, there is no doubt that it is a very ancient crop in Ethiopia, where domestication took place before the birth of Christ. Teff grain is the smallest of all whole flour grains in the world with a length of about 1.0 mm and a width of about 0.60 mm. The average thousand grain weight of teff kernels is only 0.26 g. The grain color ranges from a light ivory to very dark reddish brown depending on the variety. However, when the whole grain is finely ground, the difference in flour color becomes less noticeable. This may indicate that the pigmenting compounds of the brown teff grains are mainly accumulated on the grain pericarp. Ethiopians primarily use teff to make their national dish known as ''injera''. Injera is a type of sourdough-risen flatbread which looks like a flat pancake with a unique sponge-like texture. Traditionally it is eaten with a range of different toppings such as stews, salads or sauces. However, like a pancake, there are a great number of ways and possible toppings to eat injera with. Teff is a labour-intensive crop and requires significant soil preparation to ensure even sowing and proper seed depth. Additionally, harvesting, threshing, and winnowing are often done by hand, and the tiny seeds are tedious to handle and transport without loss. Regarding cultivation "Teff" need special attention in contrast to other crops. Indigenous knowledge practiced by farmers were shown the preparation of farmland, weeding time and style, harvesting time and style, why pilled after harvest, preparation of "Awudima" for threshing and the purpose of grain stored. Ethiopian farmers were inherited this indigenous knowledge from their families (father and grandfather) and local communities. In Ethiopia, farmers' indigenous knowledge on "Teff" production and management system were immemorially practiced. Ethiopian mothers and consumers obviously prefer and accordingly pay higher price for "Teff" grain stored for long period. They were mentioned that the qualities of such grain for making "Injera". In conclusion, "Teff" grain most commonly is consumed after being stored for several months and only a rare case or in critical food problem that it would be used immediately after harvest. This indigenous knowledge has already been inherited from their families for several generations. Respondents and many generations of farmers before them, have always harvested, put sheaves of "Teff" on the farmland "Dekel", pilled "Zememen" and finally pilled "Teff" at threshing site. In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Teff or Ethiopian Millet are discussed.

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INTRODUCTION

Tef belongs to the Grass or Poaceae Family (formerly Gramineae), sub-family Chloridoideae, tribe Eragrostideae and genus *Eragrostis* and species *Eragrostis tef* (Zucc.) Trotter (Assefa *et al*., 2011; Kebebew *et al.,* 2017; Kebebew and Solomon, 2018; MNHN, 2023). The genus contains about 300 species (Ketema, 1997). It was recently classified into 35 cultivars which are united into 6 complexes based on inflorescence morphology, grain color, time to maturity and uses. These complexes do not show ecogeographic unity, and they cross ethnological boundaries. Thirty-nine collections of tef were studied in biosystematic detail, and compared with *E. aethiopica* Chiov. and *E. pilosa* (L.) Beauv., two putative ancestors of the cereal. The latter species is morphologically variable but closely allied to *E. tef.* Three morphologically distinct complexes are recognized within the cereal. The ethnological significance of these complexes of tef is not clear (Costanza *et al.,* 1979). The word 'teff' originates from the Amharic word 'teffa' which means 'lost' due to the small size of the grain or from the Arabic word 'tahf' used by the Semites in South Arabia (Sridhara *et al.,* 2021; Academickids, 2023; History, 2023; Petruzzello, 2023; Cumo, 2023). The word 'teff' comes from the Ethiopian word 'teffa', which means 'lost' because of its minute grain size. Teff grains are manually harvested by sickles and threshed with ox tramping on them. It was estimated that 25-30% of teff would be lost before and after harvest, and lodging may contribute to the yield loss up to 30%. The high losses along the production processes can reduce the available quantity of teff by up to 50% (Lee, 2018). Common names of *Eragrostis tef* (Zucc.) Trotter in English are Tef, Teff, Teff grass, Williams lovegrass, Abyssinian lovegrass, Lovegrass, Annual Bunch Grass, Warm Season Annual Bunch Grass, Ethiopian millet and Dwarf millet. Also written as: Ttheff, Tteff, Thaff, Tcheff, Thaft, Tcheff (Wilhelm, 2020; Miller, 2021; Academickids, 2023; Cumo, 2023; Wikipedia, 2023). It is also known by the vernacular names tafi in Oromigna and taf in Tigrigna (Ketema, 1997). The species in the genus *Eragrostis* generally range from diploid ($2x = 2n = 20$) to hexaploid ($2x = 6x = 60$). Tef is an allotetraploid species ($2n = 4x = 40$) originating from the hybridisation of two distinct species followed by diploidisation. This has been hypothesised based on the following two evidences. Cytological examinations depicted the formation of 20 bivalents in the meiotic Metaphase I in both the inter- and intraspecific hybrids. In support of this, genetic studies further showed disomic inheritance patterns for some qualitative characters including panicle form and branching pattern, and glume/lemma and caryopsis colour (Kebebew *et al.,* 2017).

Tef is a crop for which Ethiopia is the center of origin and diversity. Tef is endemic to Ethiopia and its major diversity is found only in this country. Tef is a fine grain that comes in a variety of colors, from white and red to dark brown. The exact date and location for the domestication of tef is unknown, it is native and an important cereal crop to Ethiopia which is believed to be originated between 4000 and 1000 BC. However, there is no doubt that it is a very ancient crop in Ethiopia, where domestication took place before the birth of Christ (Teshome and Tesfu, 2022). For sustainable and stable food production, maintaining genetic diversity within and between crop types is increasingly being realized as the most appropriate and indispensable action. This is further emphasized by unpredictable human food needs, changes in taste, technological demand, and the biotic and abiotic production constraints that change with the Environments (Teshome and Tesfu, 2022).

Teff grain is the smallest of all whole flour grains in the world with a length of about 1.0 mm and a width of about 0.60 mm. The average thousand grain weight of teff kernels is only 0.26 g. The grain color ranges from a light ivory to very dark reddish brown depending on the variety. However, when the whole grain is finely ground, the difference in flour color becomes less noticeable. This may indicate that the pigmenting compounds of the brown teff grains are mainly accumulated on the grain pericarp (Gebru *et al*., 2020). Ethiopians primarily use teff to make their national dish known as ''injera''. Injera is a type of sourdough-risen flatbread which looks like a flat pancake with a unique sponge-like texture. Traditionally it is eaten with a range of different toppings such as stews, salads or sauces. However, like a pancake, there are a great number of ways and possible toppings to eat injera with. Now that cultures all over the world are coming into contact with this traditional Ethiopian and Eritrean meal, the possibilities are practically endless. Some of the derivated food our customers have created so far include bread, cookies, pancakes, breakfast products (such as cereal), snack crackers, ready-made baking mixes, porridge and much more (Milletsplace, 2023).

A legal tussle over who owns teff, Ethiopia's staple grain, has been settled. A three-judge court in the Netherlands ruled a European patent for the products made of teff lacked "inventiveness," ending a years-long controversy over who owned the ancient grain. The controversial patent, which was initially filed in 2003, listed Dutchman Jans Roosjen as the inventor of the teff flour that's used to make injera flatbread and other traditional Ethiopian food. The Ethiopian embassy in the Netherlands confirmed the ruling, which was first filed in June 2014 and whose verdict was delivered in November last year. While Ethiopia can once again market its teff in the Netherlands, Roosjen's patents remain in force in Belgium, Germany, Britain, Austria and Italy. The Ethiopian attorney general's office has since issued a statement that the ruling was critical to its own efforts to one day restore its "full ownership of teff " (EEB, 2019).

Ethiopia is the only country that produces teff as a cereal crop. Teff occupies the largest area of cultivated land under cereal production in Ethiopia, and as such it is the most important crop. Teff is mainly cultivated as a single crop. However, in a few areas it is cultivated under a multiple cropping system. In such cases it is usually grown as an intercrop with *Brassica carinata*, *Carthamus tinctorius* or *Helianthus annuus*. It is also relay cropped with *Zea mays* and *Sorghum bicolour* (Ketema, 1991). The preferred staple in the Ethiopian and Eritrean diet is engera/injera (pronounced *en-jer-a*, and sometimes spelled *injera*), a flat sour-like fermented pancake that is used with "wot", a stew made with spices, meats and pulses, such as lentils, beans and split peas. In Ethiopia and Eritrea, *teff* is the most common cereal crop used to make engera. Teff is a tiny, round, khaki-colored grain closely resembling millet. "Teffa", the Amharic word for "lost", is so named because of teff's small size. It is the smallest grain in the world and often is lost in the harvesting and threshing process because of its size (Piccinin, 2010).

Tef is an important food staple cereal crop in Ethiopia. Despite its importance in the Ethiopian agriculture, there are constraints that need to be addressed through scientific research. The major constraints are low yield of landrace cultivars under widespread cultivation, susceptibility to lodging and a lack of knowledge concerning the genetic control of agronomic traits. Conventional tef breeding efforts started in the late 1950s, and since then a total of 24 varieties have been developed and released (Assefa *et al.,* 2011). Under a searing midday sun, a herd of cattle circles atop a pile of golden teff, thrashing the wheat-like grain, a method that has been practised by Ethiopian farmers for centuries. The crop, mostly grown in the Horn of Africa, is a key part of the country's heritage and a crucial food staple, but is also gaining increased interest abroad among health afficionados seeking a nutritious, gluten-free alternative to wheat. "Teff is not only gluten-free, which is an increasingly important aspect of foods that is being sought out, but it's also incredibly nutritious. Many people consider teff to be a super-food. In Ethiopia, teff is used to make injera, a spongy fermented pancake topped with meat or vegetable stew and consumed with an almost religious devotion, often three times a day. In the West however, where it is touted by celebrity chefs and health-conscious Hollywood stars, the grain is most commonly ground into flour and used to make biscuits, breads, pastas and even teff juice. It is also a resilient crop; it can grow between sea level and 3,000 metres and is both drought- and flood-resistant, ideal for Ethiopia's dry highlands. But despite its versatility, Ethiopia's 6.5 million teff farmers struggle to meet local demand -- l*et al*one growing demand from abroad -- with limited access to seed varieties, fertilisers and modern machinery that would

allow for higher yields. Teff also suffers from a lack of research since it is considered an "orphan crop. In the last four years, yields have increased from 1.2 to 1.5 million tonnes per hectare (Vaughan, 2014). If you hail from Ethiopia, then teff is no stranger to you. In fact, it is the stuff that the local staple bread – *injera* – is made from. An age-old grain may be ideal for the modern age. The 4,000-year-old teff, or by its botanical name *Eragrostis tef* (literally meaning "the grass of love"), is an annual grass indigenous to the highlands of the Horn of Africa, namely Ethiopia and Eritrea. The seeds look very much like bird seed. Some 3,000 seeds weigh a measly one g. In fact, the word "teff" comes from the Amharic word teffa, which means "lost." That is, the seeds are so small that they can easily get lost (Amare, 2014).

Tef is the major food crop in Ethiopia where it is annually cultivatedon more than three million hectares of land. Compared to other cereals, tef is more tolerant to extreme environmental conditions especially to water-logging. It is unique in its abilityto grow and yield on poorly drained Vertisols which most cereals cannot tolerate. Unlike other cereals, the seeds of tef can be easily stored under local storage conditions without losing viabilitysince the grains are resistant to attack by storage pests (Assefa *et al*., 2015). Tef grain is also a rich source of protein and nutrients and has additional health benefits including that the seeds are free from gluten. According to a recent study,the bio-available iron content was significantly higher in tef breadthan in wheat bread. In general, tef provides quality food and grows under marginal conditions, many ofwhich are poorly suited to other cereals. However, tef is considered to be an orphan crop since it is only of regional importance and has until recently not been the focus of crop improvement (Assefa *et al.,* 2015). Despite its versatility in adapting to extreme environmental conditions, the productivity of tef is very low with the national average standing at 1.5 t/ha. Tef's major yield limiting factors are lack of cultivars tolerant to lodging, drought, and pests. Lodging is the permanent displacement of the stem from the upright position. Tef possesses tall, weak stems that easily succumb to lodging caused by wind or rain. In addition, lodging hinders the use of high input husbandry since the application of increased amounts of nitrogen fertilizer to boost the yield results in severe lodg- ing. When this occurs, both the yield and the quality of the grain and the straw are severely reduced and both manual and mechanical harvesting are impeded. Various attempts have been made by the research community to develop lodging-resistant tef cultivars but presently no cultivar with reasonable lodging resistance has been obtained (Assefa *et al*., 2015).

The analysis of genetic relationships amongst tef varieties is an important component of improvement programs because it provides information about the genetic diversity of the crop and sets a platform for stratified sampling of breeding populations. Tef represents a unique biodiversity component in the agriculture and food security of millions of farmers in Ethiopia. The conservation, characterization, and utilization of the existing tef genetic diversity are becoming increasingly important in view ofthe evolving needs and manifold challenges of small-scale farmersin Ethiopia. This is primarily because tef has remarkable genetictraits useful for most Ethiopian farmers to utilize for coping witherratic climatic conditions, generation of household income, and fulfilling concerns of nutritional needs. Moreover, the conservation and utilization of the tef genetic resources offer a reliable basis for enhancing food security and developing crop diversification in the moisture stress and challenging agro-ecological areas of the country (Assefa *et al*., 2015). Tef is a cereal crop resilient to adverse climatic and soil conditions, and possessing desirable storage properties. Although tef provides high quality food and grows under marginal conditions unsuitable for other cereals,it is considered to be an orphan crop because it has benefited little from genetic improvement. Hence, unlike other cereals such as maize and wheat, the productivityof tef is extremely low. In spite of the low productivity, tef is widely cultivated by oversix million small-scale farmers in Ethiopia where it is annually grown on more than three million hectares of land, accounting for over 30% of the total cereal acreage (Assefa *et al*., 2015). It originated and domesticated in Ethiopia. There are about 350 *Eragrostis* species of which *E. tef* is the only species cultivated for human consumption. At the present time, the gene bank in Ethiopia holds over five thousand tef accessions collected from geographical regions diverse in terms of climate and elevation. These germplasm accessions appear to have huge variability with regard to key agronomic and nutritional traits. In order to properly utilize the variability in developing new tef cultivars, varioustechniques have been implemented to catalog the extent and unravel the patterns ofgenetic diversity (Assefa *et al.,* 2015).

Tef is the major Ethiopian cereal grown on 3.02 million hectares annually and serving as staple food grain for over 70 million people. The crop constitutes 30% of the total area allocated to cereals and contributes more than 20% of the total cereals production. The major constraints in Ethiopia's tef husbandry are low productivity (national average 1.6 t ha-1) and susceptibility to lodging. The straw *(chid)* is an important source of feed for animals. Tef is also a resilient crop adapted to diverse agro-ecologies with reasonable tolerance to both low (especially terminal drought) and high (water logging) moisture stresses. Tef, therefore, is useful as a low-risk crop to farmers due to its high potential of adaption to climate change and fluctuating environmental conditions (Chanyalew *et al.,* 2017). Tef is a basic food crop in Ethiopia due to its specific agronomic capabilities. It is possible to harvest tef after a first cereal harvest in the same year. Tef may be used as an emergency crop for famine relief in difficult seasons. Farmers can still sow tef when their other crops are failing, and harvest grain two months later, thus providing food during a famine (Heuzé *et al*., 2017). Scientific research on tef was started in the late 1950s. Since then tremendous commendable achievements have been made through both basic and applied research endeavors. Of these, the major ones include: the release of more than 36 improved varieties; development of the artificial cross- breeding technique; generation of basic knowledge on inheritance of agronomic traits, yield components and yield-related traits, selection methods, and molecular genetics; characterization and development of a working "core-collection" of germplasm; development of appropriate cultural practices (seed rate, planting time, harvesting stage, fertilizer rate) for major tef growing areas; and identification and cataloguing of major diseases, pests and weeds, and control measures. However, tef hybridization began following the discovery of tef flower opening time and consequent to that the artificial surgical binocular-aided hand emasculation and pollination technique. Nevertheless, the national yield per unit area (1.6 t ha-1) still remains low, quite large proportions of tef producing farmers still use unimproved local cultivars, bottleneck problems like lodging have not been alleviated, and the demand for high-quality tef planting seed has become increasingly high. Over the years of tef breeding, the average annual genetic gain in grain yield was estimated as 0.8% under lodging controlled conditions from 1970 until 1995 and 0.58% under lodging uncontrolled condition from 1970 until 2012. The former workers also reported that from 1970 until 1995, grain yield increased from 3.4-4.6 t ha-1(*i.e.,* 27 kg/ha/year), and varieties developed through hybridization showed a yield advantage of 9.5% over those developed through direct selection from farmers' varieties (Chanyalew *et al*., 2017). Tef is a C4 annual cereal, common in Ethiopia, where it was presumably domesticated. Worldwide interest in tef cultivation and consumption has considerably increased in the last few decades because it is a gluten-free grain with high nutritional value (Ben-Zeev *et al*., 2018).

Teff is an annual crop with a very tiny grain. The crop is mainly cultivated in Ethiopia and Eritrea where it is used in preparing a pancake-like staple food called *injera*. Teff grain is the smallest of all whole flour grains in the world with a length of about 1.0 mm and a width of about 0.60 mm. The popularity of the crop is rapidly increasing throughout the world because of its attractive nutritional and functional properties. Thus, the crop is being successfully introduced and cultivated in many parts of the world including the USA, Canada, Australia, Switzerland, and the Netherlands. The growing global demand for the grain is due to its gluten-free nature, high level of essential amino acids (EAA), high mineral content, low glycemic index (GI), high crude fiber content, longer shelf life, and slow staling of its bread products. The grain is linked to

several health benefits including prevention and treatment of diseases such as celiac disease, diabetes, and anemia (**Gebru *et al.,*** 2020). Teff is an indigenous Ethiopian annual crop cultivated mainly for its small grain used in the preparation of a pancake-like staple food called *injera* . Teff is more preferred by farmers and consumers over many other common Eritrean and Ethiopian grain crops such as wheat due to its agronomic traits and uses. But less is known about the crop by the academic and scientific communities outside Eritrea and Ethiopia. It is an unexplored and underexploited grain crop that needs increased attention by researchers for many purposes. Giving increased focus to such underutilized and understudied food crops like teff contributes to food and nutrition security, healthy food availability, income generation for livelihoods of small-scale farmers, and environmental services in the current depleting plant resources and increasing world population (**Gebru *et al.,*** 2020). Recently, there is a growing interest on the crop since its grain is gaining global popularity for its outstanding nutritional properties. It is successfully introduced and cultivated in many parts of the world including the USA, Canada, Australia, Switzerland, and the Netherlands. The total population consuming teff products on daily basis in Ethiopia alone has currently reached more than 30 million. The most attractive property is its gluten-free nature that gives it a big potential to be utilized in a wide range of food products to help people with celiac disease (**Gebru *et al*.,** 2020).

Teff is a C_4 plant that has high chlorophyll a/b ratios and utilizes CO_2 very efficiently during photosynthesis. In recent years, teff is becoming popular in the health-food markets of developed countries due to its attractive nutritional properties and gluten-free nature. The inability to separate the bran from the seed makes teff flour rich in fiber and thus has health benefits as an anti-oxidative and improves the hemoglobin level in the human body (Merchuk-Ovnat *et al.,* 2020). Despite teff's versatility in adapting to extreme environmental conditions, teff is susceptible to lodging, which can drastically reduce yield and grain quality, and complicates harvesting. Lodging can limit productivity directly by reducing the photosynthetic capacity due to changes in sun/shade architecture. Lodging also limits the use of high input Nitrogen fertilizer to boost yield. Lodging is a process through which the shoot cereals are displaced from vertical orientation (upright position) and settle in a permanent horizontal position. It is a complex phenomenon that is influenced by many factors, including wind, rain, geography, landscaping, soil type, crop history, agricultural system, and disease. Stem lodging results from bending or breaking of the lower culm internodes, and root lodging results from a failure in root soil integrity. Lodging is worsened by the use of fertilizers, reducing the yield potential of teff. The problems of lodging can be reduced by decreasing plant height, however, yield might be reduced when plants are shortened too much with dwarfing genes or plant growth regulators. Hence, it was suggested to target traits other than height for further improvement in lodging resistance in teff (Merchuk-Ovnat *et al.,* 2020).

Teff is one of the superfood grains that is gaining huge popularity across the globe for its stupendous nutritional profile. It is an annual cereal grass cultivated for its edible seeds that survive in hot and drought climatic condition. It is one of the tiniest grains known to man, measuring less than 1 mm in diameter and an average thousand kernel weight of about 0.26 grams. Teff is available in brown and white colours that delivers a nutty and mild flavour. This tiny poppy seed-sized grain is called small millet in India, which is quite similar to ragi, both belong to the same biological subfamily (Binu, 2021). Teff is a self-pollinated, warm season annual grass which can be harvested multiple times during the growing season as dry hay, silage or pasture. As a fast-growing crop, Teff combines excellent forage quality with high yield during a relatively short growing season (Miller, 2021). Tef is one of the most important and widely produced cereal crops in Ethiopia where it is cultivated on more than three million hectares of land per year. It is one of the Ethiopian indigenous food crops which have been grown for thousands of years in Ethiopian tropical land areas (Asefa *et al*., 2022). Teff is a C_4 cereal crop that has been cultivated in the Horn of Africa since millennia. In Ethiopia, teff is a staple crop for about 70 million people as well as a source of feed and a cash crop. Teff flour is rich in proteins and minerals, making it prized as a gluten-free superfood in western countries. As a consequence, teff is increasingly under the lens of local and international research to support its cultivation and commercialization (Woldeyohannes *et al*., 2022).

Teff grains are the smallest in the world. A single grain of wheat weighs the same as 150 teff grains! These fine and tiny grains grow on long, delicate stems of an annual grass in the lovegrass group, the genus *Eragrostis.* The grains are so small that enough seeds to sow an entire field can easily be held in the hand or in a small bag, making it an extremely portable crop. The grain comes in three different colours: white, brown or red. The most sought after is the white variety, although the highest iron concentration is in the red grain. Because they are so small, it is not possible to remove parts of the grain and therefore it loses none of its fibre when processed. The grain has a very mild, nutty flavor, and it packs a serious nutritional punch. It contains calcium, phosphorus, iron, copper, aluminum, barium and thiamin in high levels. And for lysine levels (an important amino acid) it can beat wheat or barley hands down! It's low in calories too. Teff does not also contain gluten or sugar. There are a number of ways to use Teff. In Ethiopia, it is primarily used to bake fermented bread called Injera. Served with most meals, much like naan in India, Enjara is a staple food in Ethiopia. It can also be ground into flour to make an excellent gluten-free flour alternative, and can be used to make pie crusts, cookies, breads, and an assortment of other baked goods (History, 2023).

Elagrostif, also known as teff, Williams lovegrass, or annual bushkweed, is an annual herb and species of lovegrass that is native to both the Horn of Africa, especially Eritrea and Ethiopia. Also known as teff, it is grown for its edible seeds. Teff is one of the earliest domesticated plants. It is one of the most important staple crops in Ethiopia and Eritrea (Academic, 2023). *Eragrostis tef* (commonly known as ''teff'') is an ancient grain from Ethiopia and Eritrea. Its earliest use was by Ethiopians between 1000 BC and 4000 BC, also making it one of the earliest grains to be cultivated by humans. While most of the crops being cultivated today have been genetically engineered, teff is an ancient grain, practically unchanged since it was first used by humans. Its region of origin makes it well-adapted to extreme conditions such as drought and high temperatures. However, cold weather is detrimental to the grain: Freezing temperatures will destroy the plant in the early stages. The seed itself is extremely small (less than 1 mm in diameter), making it very efficient when sowing the seeds; a small portion of seeds will cover a large area of farmland. However, the small size also makes it difficult to hull and clean the grain. Only thanks to recent advances in machinery, the process could be automated instead of doing all this by hand. Teff is recognized as a grain with a high yield and quality. It is planted in late spring, which is later than most crops, when the weather is warmer (which is good for the grain) (Milletsplace, 2023). Because teff yields even in poor years, it is a famine food. Teff is also valuable because few pests and diseases attack it. Yet it is a labor-intensive crop, a fact that dissuades some farmers from growing it. Ethiopians plant teff where corn, sorghum or wheat has failed. Able to grow in acidic soil, teff tolerates a soil pH below 5(Cumo, 2023).

Regarding cultivation, "Teff" need special attention in contrast to other crops. Indigenous knowledge practiced by farmers were shown the preparation of farmland, weeding time and style, harvesting time and style, why pilled after harvest, preparation of "Awudima" for threshing and the purpose of grain stored. Ethiopian farmers were inherited this indigenous knowledge from their families (father and grandfather) and local communities. In Ethiopia, farmers' indigenous knowledge on "Teff" production and management system were immemorial practiced. Ethiopian mothers and consumers obviously prefer and accordingly pay higher price for "Teff" grain stored for long period. They were mentioned that the qualities of such grain for making "*Injera*". In conclusion, "Teff" grain most commonly is consumed after being stored for several months and

only a rare case or in critical food problem that it would be used immediately after harvest. This indigenous knowledge has already been inherited from their families for several generations. Respondents and many generations of farmers before them, have always harvested, put sheaves of "Teff" on the farmland "*Dekel*", pilled "*Zememen*" and finally pilled "Teff" at threshing site (Bekele *et al.,* 2022). The Ethiopian farmers have tried to pass their indigenous knowledge and practices through family line without any charge of money. The communities subjected to indigenous knowledge for the production and management system of "Teff" cultivation. The local people are highly dependent on traditional farming system. However, the community has kept their knowledge and passed it to generation and scientific community. Therefore, the respected government bodies (institutions) at different level and scientific institutions have to be aware of in keeping and giving accreditation to farmers' knowledge. Besides, they have to be done for the effective implementation of fair and equitable sharing of benefits arising from the utilization of genetic resources and associated community knowledge (Bekele *et al*., 2022). Teff is a labour-intensive crop and requires significant soil preparation to ensure even sowing and proper seed depth. Additionally, harvesting, threshing, and winnowing are often done by hand, and the tiny seeds are tedious to handle and transport without loss (Petruzzello, 2023).

The major relative merits of teff over the other crops in terms of husbandry include its (Kebebew and Solomon, 2018):

- broad adaptation to a range of altitudes from below sea level up to 3,000 meters above sea level and to varied agroecological and edaphic conditions;
- reasonable tolerance to both low (drought) and high (water logging) moisture stresses;
- importance as a reliable and low-risk catch crop at times when other crops (such as maize and sorghum) fail due to natural calamities such as drought, pests, and diseases;
- adaptability to various cropping systems and crop rotation schemes;
- relative resilience from serious epidemics of pests and diseases in at least the country's major teff production regions; and
- minimal postharvest losses since the grains suffer less from damage by storage pests (such as weevils) and diseases.

In the tropics, tef is particularly suited for altitudes ranging from 1300-2800 m, but can grow from sea level up to an altitude of 3400 m. Only brown/red tef is grown above 2500 m. Tef is particularly valued for areas too cold for sorghum or maize, and it can be found where temperatures as low as -15°C occur, provided the frost does not last too long. In Ethiopia, tef grows where annual rainfall ranges between 950-1500 mm, with about 450-550 mm during the growing season. Tef cannot withstand more than 2500 mm rainfall. However, tef can adapt to growing conditions ranging from drought to water logging. It is able to withstand wet conditions perhaps better than any cereal other than rice. Tef is mainly grown on sandy loams, but it can grow on black, heavy clay soils (black cotton soils), provided they are well drained and have sufficient N. Neutral or slightly acidic soils are preferred. Tef can withstand as much or more salinity than alfalfa. A C4 plant, tef makes efficient use of water and heat. It can grow in places prone to drought after short rains (Heuzé *et al.,* 2017). To date, a total of 35 varieties have been released in Ethiopia through the National Agricultural Research System. Of these, 21varieties have been Released by Debre Zeit Agricultural Research Center, while14 were released by other six centres. Of the total number of varieties released to date, only 12 varieties were developed through hybridisation, while the remaining 23 were developed using pure line selection technique from the land races (Kebebew *et al.,* 2017).

Teff is grown directly from seed in a prepared seed bed. The field is prepared for planting by plowing several times and, in areas where drainage is poor, furrows or raised beds are created to aid drainage. In moisture-stressed fields, the seedbeds are tightly packed prior to sowing seed to help prevent the soil surface drying too quickly and minimize the effect of low moisture on germination Teff seeds are usually sown on the soil surface and left uncovered or are covered lightly with tree branches. Seeding rates vary by region but generally, 15–55 kg of seeds are sown per hectare of land. If seeds are sown mechanically with a broadcaster or seed drill, lower seeding rates can be used. Higher seeding rates are required when hand sowing teff seed due to the small size of the seeds making it difficult to broadcast evenly (Plantvillage, 2023). Tef is propagated through seeds and should be used in sole cropping systems as it does not withstand intercropping. Tef is commonly grown in rotation with cereals, pulses and niger. It requires a weeded, well-prepared, firm seed-bed. It can be planted, broadcast or sown at 15-20 kg/ha in rows, no deeper than 1 cm, and subsequently rolled. It must be regularly weeded. N fertilizer should be provided in small amounts, or tef should be sown after an N-legume, in order to reduce the risk of lodging. Tef requires little care after establishment. Its rapid growth outcompetes weeds. It suffers few diseases and pest attacks. In Yemen, it is considered a "lazy man's crop" as it does not require any care between sowing, after flash floods, and harvesting (Heuzé *et al*., 2017). Tef is one of the fastest maturing cereal crops. Grain maturity occurs 2 months after sowing for very early-maturing types, 3-9 months after for early-maturing types and 6 months after for late-maturing types. Tef maturity is indicated by the yellowing of the stalks bearing the spikelets. Harvesting after physiological maturity may result in seed shattering, especially in windy and wet conditions. In Ethiopia, harvesting is done between November and early January. Tef is hand-harvested. The plants are cut at ground level with sickles and then transported to the threshing ground. Threshing is done by animal trampling or by using threshers. All grain cannot be completely removed from the straw. Tef straw is soft and fast drying (Heuzé *et al.,* 2017). Teff is ready for harvest between 60 and 120 days after planting when the leaves of the plants turn from green to yellow in color. Prompt harvest before the plants dry out completely helps to prevent the seedheads from shattering, reducing losses. At harvest, care must be taken to ensure that the grain does not get mixed with soil as the small grain size makes it impossible to separate back out. The seed is separated from the chaff by trampling or threshing (Plantvillage, 2023). Planting season is from October to December and harvesting takes place from January to March every year. With teff being such a quick and easy crop to produce, it serves as an ideal crop diversification. Once harvesting is complete, the teff is processed using cleaning methods to produce a clean, edible grain. The grain is consumed by humans, while the grass is processed into hay bales and used as fodder for animal feed. A portion of the cleaned grain is milled using stone mills and modern machinery to make teff flour, which is a suitable alternative to wheat flour for gluten-free diets (Agriorbit, 2022).

Harvesting of teff is accomplished by farmers mowing with sickles when the crops are mature and dry. The harvested crops are first piled up in the field and later transported by humans and/or using donkeys to the threshing ground areas where they are again piled into bigger piles. After preparing the threshing ground, often by coating with a thin layer of cattle dung, the crops are threshed by trampling with oxen. Winnowing to separate the seeds with the help of wind and subsequent cleaning are done manually with the use of various traditional tools. Nevertheless, farmers in some areas have recently started using multicrop threshers and seed cleaners for threshing and seed cleaning of teff. In addition, others (like the Ethiopian Seed Enterprise) have been using combiners for harvesting and threshing of teff grains by adjusting and modifying of the drums and the seed cleaning sieves to fit to the small-seeded teff crop. Considering the difficulties entailed in teff harvesting and threshing by the smallholder farmers, the operation cannot continue to be done traditionally. It seems timely for the willing smallholder farmer to develop harvesting and threshing practices with implements for teff husbandry in Ethiopia (Ebba, 1969). Very early types are ready to harvest in 45–60 days, average types in 60–120 days, and late types in 120-60 days. With good soil, moisture and warmth, yields of 2,000 – 2,200 kg per hectare are attainable. The grain is easy to store and will survive for many years in traditional storehouses making it a valuable safeguard against famine.

Sowing methods may require special attention because the seeds are so small. In Ethiopia, fields are plowed three to five times. Sometimes herds of animals are repeatedly driven back and forth across the field to crush any big clumps of soil. Planting is at the very end of the dry season but not before the rains end (Echocommunity, 2023). Lodging is arguably the most important bottleneck for teff improvement. This issue becomes more prominent with increased yield, panicle size, and biomass and is exacerbated by fertilization in high input areas. Lodging in teff is mainly due to stem failure, as shown by the fact that root lodging is seldom present and that varieties with compact panicles and reduced height have increased lodging resistance. Reduced plant stature is therefore a main breeding target in teff (Woldeyohannes *et al*., 2022).

One advantage of tef grain is that it can be stored for an extended period of time, at least five years, under traditional storage conditions. The seed remains viable under such conditions for up to three years. It is not attacked by weevils or fungi, which reduces postharvest costs, as no protective chemicals are required for storage (Heuzé *et al*., 2017). Teff seeds are usually stored under ambient environmental conditions in traditional storage structures known as *gotera* or *gota.* They are also stored in farmers' houses after being packed in sacks often made of synthetic polymers. Normally teff grains can be stored for three to five years without considerable loss of viability even under traditional storage conditions, since storage pests, such as weevils, and diseases do not attack them. The only problem with the minute-size teff seeds is mechanical mixing and contamination of the pure grain at all stages of operations, starting from sowing up to the final harvesting and threshing as well as storage. The seeds can easily get dropped and missed because of their physical size (Kebebew and Solomon, 2018).

Teff, a hardy crop, can be grown in both kharif and rabi seasons. It is suitable for districts with dry zones in Karnataka. Teff, a drought-resistant rice, is a staple food crop of Ethiopia, and the grain dates back to the Abyssinian civilisation (Amare, 2014). It is grown on 3.01 million hectares in Ethiopia, with a yield of 5.01 million tonnes and productivity of 1.664 tonnes per hectare (Sridhara *et al.,* 2021). In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Teff or Ethiopian Millet are discussed.

ORIGIN AND DOMESTICATION

Tef is an endemic tropical cereal crop of Ethiopia and it has been cultivated for thousands of years in high lands of Ethiopia and Ethiopia is recognized as the center of origin and diversity of tef (**Fig. 1)** .(Vavilov, 1951). Tef is endemic to Ethiopia and its major diversity is found only in that country As with several other crops, the exact date and location for the domestication of tef is unknown. However, there is no doubt that it is a very ancient crop in Ethiopia, where domestication took place before the birth of Christ. It was probably cultivated in Ethiopia even before the ancient introduction of emmer and barley. Tef seeds found in the Pyramid of Dashur (3359 BC) and from the ancient Jewish town of Ramses in Egypt (ca. 1300 BC) were probably *E. aegyptiaca* or *E. pilosa* and thus are not good evidence for the cultivation of tef in ancient Egypt. A bread made of Dourra flour." On the basis of linguistic, historic, geographic and botanical notes, tef is assumed to have originated in northeastern Africa. The current area of cultivation is probably not the initial one of domestication; domestication probably occurred in the western area of Ethiopia, where agriculture is precarious and semi-nomadal (Ketema, 1997).

Fig. 1. Ethiopia- Center of origin and diversity of tef

Genetic diversity for tef exists nowhere in the world except in Ethiopia, indicates that tef originated and was domesticated in Ethiopia. In a study to trace the origin and domestication of tef and identify the species related to it, itn was reported that a noticeable difference between tef and related species is the complete absence of glands in the cultivated species. Progenitors of tef, she states, are therefore likely to have been eglandular plants and the present-day distribution of eglandular representatives of closely related species may provide evidence for the original area of tef domestication. With this hypothesis, a survey was made of the collections of *E. pilosa, E. aethiopica, E. cilianensis, E. minor* a n d *E. barrelieri* at the herbarium of the Royal Botanic Gardens, Kew, to ascertain the distributions of eglandular plants of these taxa in Africa, Asia and Europe and prepared maps to show the geographical distribution of glands in these species **(Fig. 2**). She concluded that "combining the geographical data obtained for all the species examined, there may be a concentration, of eglandular forms in Africa, notably in the North-east (Sudan, Egypt, Ethiopia, Uganda and Kenya). Except in *E. pilosa*, where eglandular forms are widespread, eglandular representatives of otherwise glandular species are rare outside Africa. It seems probable, therefore, that tef was domesticated in Northeast Africa from such plants" (Ketema, 1997).

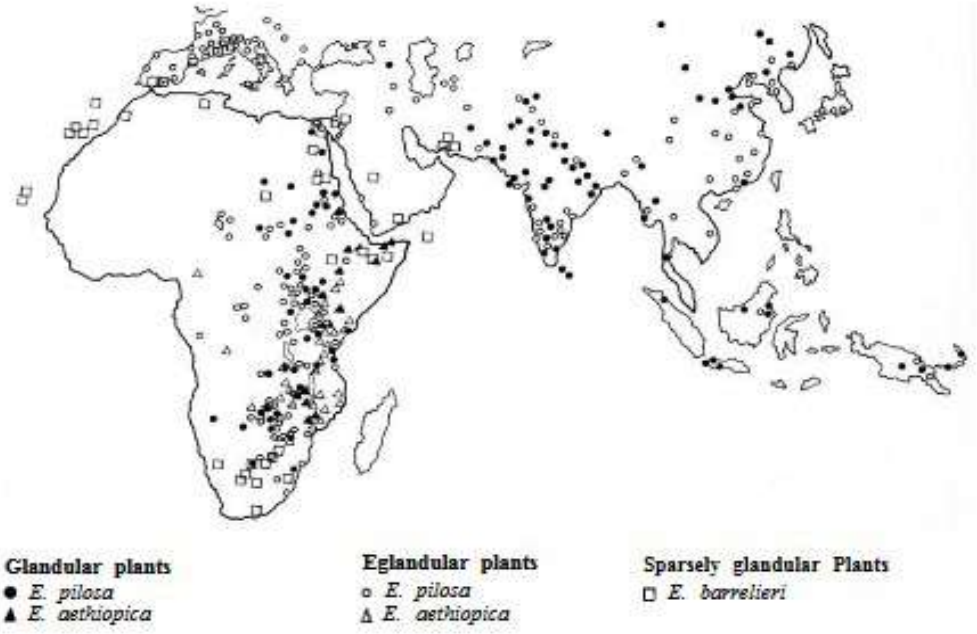

Fig. 2. Geographical distribution of *Eragrostis pilosa, E. aethiopica* and *E. barrelieri* determined from exsiccate in the herbarium of the Royal Botanic Gardens, Kew, UK

Ethiopia is the centre of both the origin and diversity of tef and over the years the crop species has co-evolved with Ethiopians. This is because Ethiopia harbours not only a wealth of diversity in the crop species but also it is believed to be the centre of origin for its domestication, including the existence of the possible wild progenitors. As one of the biggest genus in the grass family, the genus *Eragrostis* contains over 350 species. Of these species, about 43% are considered to have originated in Africa, 18% in South America, 12% in Asia, 10% in Australia, 9% in Central America, 6% in North America and 2% in Europe. Among the 54 species found in Ethiopia, 14 are endemic to the country. Globally, the fact that tef originated in Ethiopia is not debatable; however, the exact location where it was first domesticated in Ethiopia yet remains unknown. Many maintain that tef originated in the northern highlands of Ethiopia, particularly in Tigray, where it is still an important crop. Based on the archaeological remains from northern Ethiopia, it was suggested that the earliest-known cultivation of tef was during the pre-Axumite period from 800 to 400 BC in the northern part of the country (Kebebew *et al*., 2017). Tef is thought to have originated in Ethiopia, where it has been used as a food grain since sometime between 4000 and 1000 BCE. It is mainly cultivated in its native range (Ethiopia and the highlands of Eritrea) and in neighbouring Northern Kenya. It has been introduced into South Africa, the USA, Canada, Australia, the Netherlands and Yemen for small-scale production of gluten-free grain (Heuzé *et al.,* 2017).

Teff is a warm-season annual cereal and the only cultivated species in the genus *Eragrostis*. Ethiopia, located in eastern Africa, is considered the center of origin of teff (Lee, 2018). Concurrently, interests in teff cultivation are spreading to other parts of the world. Those countries include Australia, Cameroon, Canada, China, India, Netherlands, South Africa, the UK, Uganda and the USA. However, comprehensive statistics on the teff production, utilization and trade are little available in those countries (Lee, 2018). Ethiopia is teff's origin and the center of its biodiversity, harboring landraces with a wide array of phenotypic diversity, wild progenitors, and related wild species. The genetic diversity of teff is represented in a very large collection of accessions from across its cultivation range at the Ethiopian Institute of Biodiversity (Merchuk-Ovnat *et al*., 2020). *Eragrostis tef* also called teff, Williams lovegrass or annual bunch grass is a species of lovegrass, an indigenous crop to Africa, mostly harvested in Ethiopia. It is now widely cultivated in many parts of the world, including the USA, Canada, Australia, Switzerland and the Netherlands (Binu, 2021). Teff's origin is thought to be Ethiopia, where it emerged as a grain crop for human consumption sometime between 4000 B.C. and 1000 B.C. Distribution of the crop around the world was initially based on its use as a food grain. Following its North American introduction, Teff production centered around its use by ethnic groups familiar with the grain and the niche market for gluten free fl our. Teff grain is gluten free, and is a good flour source for segments of the population suffering from gluten intolerance or Celiac's Disease. Following its initial introduction in the U.S., researchers began evaluating the world collection of Teff lines for their forage potential. As a result of the initial work in South Dakota and later at Oregon State, Teff's potential as forage was identified. Over the last 10 years Teff has gained momentum as a forage crop and several new, improved types have been developed and commercialized (Miller, 2021). It is said to have originated in Ethiopia between 4000 and 1000 BC (Melak-Hail, 1966; Tadesse, 1969; Costanza, *et al.* 1979; Seyfu, 1997). Teff signifies the modern re-discovery of an ancient civilization's crop (Sridhara *et al*., 2021).

Tef is a crop for which Ethiopia is the center of origin and diversity. Tef is endemic to Ethiopia and its major diversity is found only in this country. Tef is a fine grain that comes in a variety of colors, from white and red to dark brown. The exact date and location for the domestication

of tef is unknown, it is native and an important cereal crop to Ethiopia which is believed to be originated between 4000 and 1000 BC. However, there is no doubt that it is a very ancient crop in Ethiopia, where domestication took place before the birth of Christ (Teshome and Tesfu, 2022). Teff originated and diversified in Ethiopia. It is one of the most important cereal crops in this country: it occupies about 29% of the land devoted to cereals. Many farmers grow teff as cash crop because of its higher and more stable market price. Outside Ethiopia, it was introduced into other tropical countries and traditionally it is grown in Eritrea, and to a lesser extent, in India. In Ethiopia, teff performs well with annual rainfall of 750-850 mm and 450-550 mm during its growing season, but reasonable yield can be obtained with 300 mm during the plant cycle. It grown at altitude of 1000 to 2500 m and a mean temperature range of 10 °C to 27 °C (Dipartimenti, 2023). The native range of this species is NE. and E. Tropical Africa, Arabian Peninsula. It is native to Djibouti, Eritrea, Ethiopia, Kenya, Saudi Arabia, Somalia, Tanzania, Uganda, Yemen. It is introduced into Angola, Argentina Northwest, Belgium, Botswana, Brazil North, Cape Provinces, Czechoslovakia, Denmark, Egypt, France, Free State, Germany, Great Britain, Guinea, India, Italy, Jawa, Kazakhstan, Krym, KwaZulu-Natal, Lesotho, Libya, Madagascar, Malawi, Mauritania, Mexico Central, Mozambique, Myanmar, Namibia, Nansei-shoto, Netherlands, New Caledonia, New South Wales, Northern Provinces, Palestine, Réunion, Senegal, South Australia, South Carolina, South European Russi, Sudan, Switzerland, Tasmania, Ukraine, Victoria, West Himalaya, Zambia, Zaïre, Zimbabwe (Kew, 2023).

Teff originated in the Horn of Africa, corresponding to what is today modern day Ethiopia and Eritrea, where it is one of the most important cereals. Teff is mainly cultivated in Ethiopia and Eritrea, where it originates. In 2016, Ethiopia grew more than 90 percent of the world's teff. It is now also marginally cultivated in India, Australia, Germany, the Netherlands, Spain, and the US, particularly in Idaho, California, Texas, and Nevada. Because of its very small seeds, a handful is enough to sow a large area. This property makes teff particularly suited to a seminomadic lifestyle (Wikipedia, 2023). Teff originated in Ethiopia, where it was domesticated between 4000 and 1000 BCE. Given the long tenure of humans in Africa, it seems surprising that teff was not domesticated earlier. By one account, teff migrated to classical Egypt, where it was found in a pyramid 5,300 years old. Recent scholarship doubts the Egyptian thesis. The seeds found in the pyramid may be only *Eragrostis aegyptiaca,* a wild grass widespread in Egypt and related to teff. It seems probable therefore that teff did not wander from Ethiopia in its early history. In addition to Ethiopia and South Africa, teff spread to Eritrea, Malawi, Kenya, Yemen, Pakistan, Nepal, and, during the Columbian Exchange, the United States, Mexico, Bolivia, Peru, and Ecuador. Teff's tolerance of cold weather may make it attractive to Canada, Alaska, Russia, and northern China. U.S. farmers have made small plantings in Montana, Idaho, Kansas, Oklahoma, Minnesota, and South Dakota to serve a niche market (Cumo, 2023). Originated in Ethiopia between 4000 BCE and 1000 BCE, teff is described as Ethiopia's 'second gift to the world' after coffee (History, 2023). Teff is an ancient crop and was likely domesticated more than 6,000 years ago in Ethiopia, which is the major centre of the plant's diversity (Petruzzello, 2023). Teff was domesticated in the relatively dry environment of Ethiopia between 4000-1000 B.C. as an annual grass that could be harvested for grain at maturity (Echocommunity, 2023). Teff is believed to have originated in Ethiopia between 4000 and 1000 BC. Teff seeds were discovered in a pyramid thought to date back to 3359 BC. The grain has been widely cultivated and used in the countries of Ethiopia, India and its colonies, and Australia **(**Academickids, 2023**).** Teff is mainly grown in its native Ethiopia and Eritrea. He is one of the most important staple crops in these two countries and is used in the production of injera and taita. In 2016, Ethiopia grew over 90 percent of the world's teff. It is now grown in small amounts in India, Australia, Germany, Holland, Spain and the United States, especially in Idaho, California, Texas and Nevada. The seeds are so small that a handful is enough for sowing a large area. This trait makes teff particularly well suited for a semi-nomadic lifestyle (Academic, 2023).

History: Teff is one of the earliest domesticated plants. Teff is believed to have originated in Ethiopia between 4000 BC and 1000 BC. Genetic evidence points to *E. pilosa* as the most likely wild ancestor. The identification of teff seeds from ancient Egyptian sites in the 19th century is now considered questionable. The seeds in question (no longer available for research) are more likely to be from *E. aegyptiaca*, a wild grass common in Egypt. Teff is the most important commodity produced and consumed in Eritrea and Ethiopia. Like flat pancakes, injera supports the livelihoods of some 6.5 million smallholder farmers in the country. In 2006, the Ethiopian government banned the export of raw teff, fearing domestic shortages of exports, such as those suffered by South American countries after the explosion of quinoa consumption in Europe and the United States. Processed teff, or injera, was still available for export, primarily purchased by Ethiopian and Eritrean diaspora living in northern Europe, the Middle East, and North America. Years later, fears of domestic teff shortages in a scenario of international market opening have diminished. While prices have remained stable in Ethiopia, teff yields have increased by 40-50% over the past five years. As a result, the government partially lifted the export ban in 2015. To avoid minimizing domestic production, only 48 commercial farmers who have never grown the plant before have been granted export licenses. Lack of mechanization is a barrier to potential growth in teff exports. However, with demand growing by 7-10% per year and the accompanying increase in exports, the country is accelerating its agricultural modernization and spurring research. Due to its potential economic success, several other countries, including the United States and some European countries, already grow teff and sell it in their domestic markets (Academic, 2023).

Teff is the only fully-domesticated member of the genus Eragrostis (lovegrass). Its name is often assumed to be related to the word "lost" in Amharic – because of the tiny size (less than 1mm diameter – similar to a poppy seed) of its seeds. This tiny size, in fact, makes teff ideally suited to semi-nomadic life in areas of Ethiopia and Eritrea where it has long thrived. A handful of teff is enough to sow a typical field, and it cooks quickly, using less fuel than other foods. Teff also thrives in both waterlogged soils and during droughts, making it a dependable staple wherever it's grown. No matter what the weather, teff crops will likely survive, as they are also relatively free of plant diseases compared to other cereal crops. Teff can grow where many other crops won't thrive, and in fact can be produced from sea level to as high as 3000 meters of altitude, with maximum yield at about 1800-2100 m high. This versatility could explain why teff is now being cultivated in areas as diverse as dry and mountainous Idaho and the low and wet Netherlands. Teff is also being grown in India and Australia. Growing in the fields, teff appears purple, gray, red, or yellowish brown. Seeds range from dark reddish brown to yellowish brown to ivory (WGC, 2023).

Teff is thought to have originated circa 4000 BC. Its seeds were found in an Egyptian pyramid that dates to approximately 3300 BC. In fact, teff was so revered 55 centuries ago, they placed with pharaoh's in pyramids as their "last food." Supposedly, the name Teff is derived from the Amhraic word "Teffa", which means "lost", to show that it is something difficult to trace. Again, Teff is the tiniest known grain in the world. Teff remained an East African secret for centuries, and became a staple in the Ethiopian diet. Teff is very picky about its growing habitat. In fact, Teff only grows well in the highlands of East Africa. Most attempts to grow Teff elsewhere have failed miserably, and as such, it has not been widely available to the International marketplace. Only recently has agricultural science progressed enough that we can grow Teff in selected other climates. In fact, is has only been a few years since an appropriate European cultivation climate was first discovered, and Teff is being produced successfully in Spain for the first time. According to Perdue University: "Teff is an annual grass crop and harvested for grain in Ethiopia. Teff flour is preferred in the production of enjera, a major food staple in Ethiopia. Teff is also grown on a limited basis for livestock forage in other parts of Africa, India, Australia and South America. In the U.S. small acreages of teff are grown for grain production and sold to Ethiopian restaurants (Carlson, Idaho) or utilized as a late planted livestock forage." Teff continues to form the base of the East African diet to

this day. It is revered for its taste, its shelf life, and its nutritional value. It contains 11% protein, 80% complex carbohydrates, and 3% fat. It's also an excellent source of essential amino acids, including lysine, an amino acid often missing in whole grains. Teff is a fantastic source of fiber iron, calcium, potassium, and other essential minerals. Through a new partnership, Teff is finally becoming available in other parts of the world. Thanks to European cultivation, we can now introduce Teff to the Western world. We have managed to source a consistent supply so that Westerners can start taking advantage of all this superfood has to offer. Finally, the rest of the world can begin discovering the best of the ancient grains (Vilenia, 2023).

Teff was one of the earliest plants domesticated. Teff is believed to have originated in Ethiopia between 4000 BC and 1000 BC. Genetic evidence points to *E. pilosa* as the most likely wild ancestor. A 19th-century identification of teff seeds from an ancient Egyptian site is now considered doubtful; the seeds in question (no longer available for study) are more likely of *E. aegyptiaca*, a common wild grass in Egypt. Teff is the most important commodity produced and consumed in Ethiopia where the flat pancake-like injera provides a livelihood for around 6.5 million small farmers in the country. Processed teff, namely injera, could still be exported and was mainly bought by the Ethiopian and Eritrean diaspora living in northern Europe, the Middle East and North America. After a few years, fears of a domestic shortage of teff in the scenario of an international market opening decreased. Teff yields had been increasing by 40 to 50% over the five previous years while prices had remained stable in Ethiopia. This led the government to partially lift the export ban in 2015. To ensure that the domestic production would not be minimized, the export licenses have only been granted to 48 commercial farmers which had not cultivated the plant before. Lack of mechanization is a barrier to potential increases in teff exports. Yet the increasing demand, rising by 7–10% per year, and the subsequent increase in exports is encouraging the country to speed up the modernization of agriculture and is also boosting research. Because of its potential as an economic success, a few other countries, including the US and some European countries, are already cultivating teff and selling it on domestic markets (Wikipedia, 2023).

Introduced to Karnataka in 2016: Dr Sudhakar came across teff, now considered a superfood, while teaching in Eritrea. The grain is cultivated mainly in Ethiopia and Eritrea, where it originated. It is a key crop. Flat pancakes called *injera* are made from teff, providing a livelihood to around 6.5 million farmers in Ethiopia. Two-thirds of the daily protein intake of Ethiopians comes from teff. *Injera* resembles the south Indian *dosa,* except that it is bigger and thicker. "If we ate that half a piece of *injera* at 2 pm with some stir-fried vegetables we wouldn't feel hungry till 8 pm,". "I turned into an *injera* lover very quickly." His love for *injera* motivated him to study it more closely and he vowed to take this superfood to India. At first, he says, he didn't really like the taste of teff. It was a bit sour. But when Dr Sudhakar, a fish processing expert, started comparing the nutritive value of foods in Eritrea, *injera* was right on top. Each half-cup of injera has 127 calories, 5 gm of protein, 1 gm of fat, 25 gm of carbs, and nearly 4 gm of fibre. Teff flour is high in resistant starch, a type of fibre that may help support insulin sensitivity and increase satiety. Teff has caught global attention for being both gluten-free and a complex carbohydrate. No wonder it is now called a superfood "(Padre, 2020). R.S. Patil, an organic farmer in Gadag, procured a 50 g teff seed packet from the Central Food Technological Research Institute (CFTRI) in 2016 and finally managed to grow teff on three acres. Patil is probably the first farmer to grow teff in south India or perhaps in the whole of India on such a scale. For farmers, teff has an added attraction. The grain is also fodder for livestock and parts of it can be used as thatch material for huts. "The teff crop has many farmer-friendly qualities. It grows without fuss and is very drought-resistant," says Patil. Patil says the seeds he got from CFTRI were too few so he opted for transplanting and raised saplings, a method that ensures high survival and a good crop. Direct sowing is actually easier for farmers because it requires less labour and expense. Teff requires around three months to harvest. The plants are then tied into small bundles and placed on a tarpaulin sheet. A tractor is made to run over the plants. That's how Patil separated the grain from the hay. The biggest drawback of teff is that its grains are smaller than *ragi* or sand particles. "So cleaning teff is very labour-intensive and cumbersome. If there is rainfall during the harvest, the grains might fall on the ground and disappear. Even without rain, lodging is common," explains Patil, who has hired a team of women to clean the crop "(Padre, 2020). Teff is similar to millets which undergo a complex process of milling by machines. The problem with millets is that there aren't any small milling machines which farmers themselves could use for processing. Here, teff has an advantage. It doesn't require milling. The downside is that teff grains have to be cleaned by hand and that means employing an army of labourers. Cleaned teff can be boiled and eaten like rice. "We soak it in the morning, grind it in the evening and make *idli* or *dosa* the next morning." All bakery products made with wheat can be made with teff. The seeds sprout in three days and can be harvested in about three months. We can start growing it from late monsoon to the late *kharif* season. In other words, it can be cultivated almost round the year." Hay, a byproduct of teff, makes good fodder, which Patil has already started usingm "(Padre, 2020). He says teff has a good rooting system and can be used to prevent soil erosion. It gives two to three ratoons too. Hay can be used for thatching earthen houses. "There is no awareness about teff in India," "If awareness is built, more farmers would be keen to grow it." "Teff can be used in the same way we use *ragi.* We can make *idli, upma, dosa* and so on. The resistant starch in teff gets converted into glucose very slowly, making it better than wheat for diabetics. Of course, cleaning the grains after harvesting is a major problem. We, too, had to do it manually. The productivity of this crop is low." Patil's advice to farmers is to grow teff for their own consumption. There are two kinds of teff in Eritrea and Ethiopia, brown and white. While the brown variety costs Rs 150 per kg, the white is priced at Rs 200. It is a staple which people eat every day. "Lifestyle diseases like diabetes, high blood pressure and heart disease are much less there. People who are over 70 look much younger. Teff has 10 percent of dietary fibre. Those who eat teff don't get heart disease or diseases of the digestive tract." "It is gluten-free, has important nutrients and minerals that are only available in meat. Fermenting makes it an important **cereal"** (Fig.3) **(Padre, 2020).**

Teff being harvested

A team of women cleaning teff

Grains of Teff

Cooking injera

Fig.3 : Harvesting, Seeds, Cleaning, and Cooking injera

TAXONOMY

Tef belongs to the Grass or Poaceae Family (formerly Gramineae), sub-family Chloridoideae, tribe Eragrostideae and genus *Eragrostis* and species *Eragrostis tef* (Zucc.) Trotter (Assefa *et al.,* 2011; Kebebew *et al.*, 2017; Kebebew and Solomon, 2018; MNHN, 2023; Wikipedia, 2023). The genus contains about 300 species (Ketema, 1997). Teff is a member of the Poaceae family, subfamily Eragrostidae and the genus Eragrostis, with a diploid chromosome number of 2n=40. There are 350 species in this genus and it is the only domesticated cereal species (Sridhara *et al*., 2021). Tef belongs to the Poaceae or Grass family as do all economically important cereals. It is closely related to finger millet (*Eleusine coracana* Gaerth.) as both are in the subfamily Chloridoideae. The genus *Eragrostis* comprises about 350 species from which only tef is cultivated for human consumption. Unlike wheat, barley and rice, which are all C_3 plants, tef (along with maize and sorghum) is a C_4 plant which efficiently utilizes carbon dioxide during photosynthesis.

This can be seen by tef 's Kranz-type leaf anatomy with vascular centers surrounded by bundle sheath cells containing a high number of chloroplasts and by the low CO_2 compensation point of the leaves, also typical of C_4 as opposed to C_3 species (Kebede *et al*.,1989). × Tef is an allotetraploid (2n = 4x = 40). Over the past few decades the ancestry of tef has been investigated usingmorphological and cytogenetic methods,biochemical methods and phylogenetic analysis using ribosomal DNA and transcription factor genes or nuclear and plastid genes.It has been suggested that *Eragrostis pilosa* is closely related to tef while *E. heteromera* and *E. cilianensis* are more distantly related. Similar conclusions were reached using biochemical methods. The close relationship between tef and *E. pilosa* is also evidenced by the successful hybridization of these two species. This hybridization generated viable offspring and ultimately resulted in the release in 2009 of a variety called *Simada* (DZ- Cr-285 RIL295) from the inter-specific hybrid of tef [DZ-01- 2785 *E. pilosa* (line 30-5); MoA, 2013]. However, since *E. pilosa*, like tef, is a tetraploid, the diploid ancestors of tef remainun known (Assefa *et al.,* 2015).

The genus *Eragrostis* comprises about 350 species.. Although the crop species have had several synonyms previously used by several authors, its presently most accepted binomial nomenclature is *E. tef* (Zucc.) Trotter. In cultivation as a cereal, tef is the only species in the genus *Eragrostis* and together with finger millet (*Eleusine crocana* L.) they constitute the sole two species in the sub-family *Chloridoideae* cultivated for human consumption of the grains (Assefa *et al.,* 2011). It is a C4, self-pollinated, chasmogamous annual cereal. It has a fibrous root system with mostly erect stems, although, some cultivars are bending or elbowing types. The genus contains about 350 species of which tef is the only cultivated species. Fifty four *Eragrostis* species are found in Ethiopia, out of which fourteen are known to be endemic (Chanyalew *et al*., 2017). The genus Eragrostis constitutes about 350 species of which only tef is cultivated for human consumption. It is a C4, self-pollinated, and allotetraploid plant species and closely related to finger millet (Eleusine coracana Gaerth) as both are in the sub family Chloridoideae (Teshome and Tesfu, 2022).

Tef is an allotetraploid 2n = 4x = 40) cereal crop whose origin within the large genus *Eragrostis* is unknown. Previous studies have suggested a total of 14 wild *Eragrostis* species as potential progenitors. Phylogenetic analysis of sequence data from the nuclear gene waxy and the plastid locus rps16 strongly supports the widely held hypothesis of a close relationship between tef and *E. pilosa*, a wild allotetraploid. *Eragrostis heteromera*, another previously proposed progenitor, is shown by the waxy data to be a close relative of one of the tef genomes. Other putative progenitors included in the taxon sample are not supported as closely related to tef. Plastid sequences from five varieties of tef and four *E. pilosa* accessions are identical and therefore are uninformative with respect to the question of multiple origins of these polyploids. The waxy phylogeny also resolves the relationships among other allopolyploids, supporting a close relationship between the morphologically similar allotetraploids *E. macilenta, E. minor*, and *E. mexicana*. *Eragrostis cilianensis*, another morphologically similar allopolyploid, appears to have shared one diploid progenitor with these species but derived its other genome from an unrelated diploid (Ingram and Doyle, 2003).

As one of the biggest genus in the grass family, the genus *Eragrostis* contains over 350 species. Of these species, about 43 percent are considered to have originated in Africa, 18 percent in South America, 12 percent in Asia, 10 percent in Australia, 9 percent in Central America, 6 percent in North America, and 2 percent in Europe. Among the 54 species found in Ethiopia, 14 are endemic to the country. Teff and finger millet (*Eleusine coracana* (L.) Gaertn.) constitute the sole species in the subfamily Chloridoidae cultivated as a cereal crop for human consumption. Various nomenclatures have been given to teff by several authorities at different times. However, the most accepted binomial nomenclature for teff is *Eragrostis tef* (Zucc.) Trotter. In this nomenclature "Zucc." stands for Zuccagni, the taxonomist who gave the species epithet "tef"; "Trotter" stands for the name of the taxonomist who proposed the binomial name *Eragrostis tef* in 1918 based on the species epithet first given by Zuccagni (Kebebew and Solomon, 2018). Various nomenclatures names given to tef by various authorities at different times are summarised in Table 1 (Kebebew *et al*., 2017).

Table 1. Various binomial nomenclatures given to teff by authorities in different years

Suggested name	Year
Poa tef Zuccagni	1775
Poa abyssinica Jacquin	1781
Poa cerealis Salisb	1796
Cynodon abyssinicus (Jacq.) Rasp.	1825
Eragrostis abyssinica (Jacq.) Link	1827
Eragrostis pilosa (L.) P. Beauv. subsp. *abyssinica* (Jacq.) Aschers and Graben	1900
Eragrostis tef (Zucc.) Trotter	1918
Eragrostis pilosa (L.) P. Beauv. var tef (Zucc.)	1923

However, presently the most accepted binomial nomenclature is *Eragrostis tef* (Zucc.) Trotter. This name which is based on the specific epithet 'tef' previously used by Zuccagni was proposed by Trotter in 1918.

The word 'teff' originates from the Amharic word 'teffa' which means 'lost' due to the small size of the grain or from the Arabic word 'tahf' used by the Semites in South Arabia (Sridhara *et al*., 2021; Academickids, 2023; History, 2023; Petruzzello, 2023; Cumo, 2023). The word 'teff' comes from the Ethiopian word 'teffa', which means 'lost' because of its minute grain size. Teff grains are manually harvested by sickles and threshed with ox tramping on them. It was estimated that 25-30% of teff would be lost before and after harvest, and lodging may contribute to the yield loss up to 30%. The high losses along the production processes can reduce the available quantity of teff by up to 50% (**Lee, 2018).**

It was recently classified into 35 cultivars which are united into 6 complexes based on inflorescence morphology, grain color, time to maturity and uses. These complexes do not show ecogeographic unity, and they cross ethnological boundaries. Thirty-nine collections of tef were studied in biosystematic detail, and compared with *E. aethiopica* Chiov. and *E. pilosa* (L.) Beauv., two putative ancestors of the cereal. The latter species is morphologically variable but closely allied to *E. tef.* Three morphologically distinct complexes are recognized within the cereal. The ethnological significance of these complexes of tef is not clear (Costanza *et al.,* 1979).

In general, there are three main types of teff: white, mixed (red, brown, white) and red/brown. *White teff* is the preferred type but only grows in certain regions of Ethiopia. White teff grows only in the Highlands of Ethiopia, requires the most rigorous growing conditions, and is the most expensive form of teff. *Red/brown teff,* the least expensive form and the least preferred type, has the highest iron content. The third main type of teff is *mixed* (red/brown and white) and has moderate iron content (Piccinin, 2010).

Synonyms of *Eragrostis tef* (Zucc.) Trotter (Ketema, 1997).

- E. pilosa (L.) P. Beauv. var. tef (Zucc.) Fiori, Nuov. Fl. Anal. Ital. 1: 123.1923;
- E. pilosa (L.) P. Beauv. subsp. abyssinica (Jacq.) Aschers et Graebn., Syn. Mitteleur. Fl. 2(1): 374.1900;
- E. abyssinica (Jacq.) Link, Hort. Berol. 1:192.1827;
- Cynodon abyssinicus (Jacq.) Rasp., Ann. Sci. Nat. 5:302.1825;
- Poa cerealis Salisb., Prodr. Stirp. 20.1796;
- P. abyssinica Jacquin, Misc. Austr. 2:364.1781;
- P. tef Zuccagni, Diss. Istoria di una piante panizabile. 1775.

Synonyms (Heuzé *et al*., 2017).

- *Eragrostis abyssinica* (Jacq.) Link,
- *Poa abyssinica* Jacq.,
- *Poa tef* Zuccagn

Synonyms (MNHN, 2023)

- *Eragrostis abyssinica* (Jacq.) Link, 1827 (Espèce CD_NOM = 96574)
- *Eragrostis pilosa* subsp. *abyssinica* (Jacq.) Asch. & Graebn., 1900 (Espèce CD_NOM = 134180)
- *Eragrostis pilosa* var. *tef* (Zuccagni) Fiori, 1923 (Espèce CD_NOM = 160864)
- *Cynodon abyssinicus* (Jacq.) Raspail, 1835 (Espèce CD_NOM = 619394)
- *Eragrostis tef f. spiciformis* Serp., 1934 (Espèce CD_NOM = 160621)
- *Eragrostis tef* subsp. *spiciformis* (Serp.) Portal & H.Scholz, 2002 (Espèce CD_NOM = 160620)
- *Eragrostis tef* (Zuccagni) Trotter, 1918 subsp. *tef* (Espèce CD_NOM = 96636)
- *Poa abyssinica* Jacq., 1781 (Espèce CD_NOM = 114098)
- *Poa cerealis* Salisb., 1796 (Espèce CD_NOM = 114152)
- *Poa radicans* Moench, 1794 (Espèce CD_NOM = 114349)
- *Poa tef* Zuccagni, 1775 (Espèce CD_NOM = 114402)

Synonyms (*Kew, 2023*).

Homotypic Synonyms:

- *Eragrostis pilosa* var. *tef* (Zuccagni) Fiori in Nuov. Fl. Italia 1: 123 (1923)
- *Poa tef* Zuccagni in Diss. Ditef: [s.p.] (1775)

Heterotypic Synonyms

- *Cynodon abyssinicus* (Jacq.) Raspail in Ann. Sci. Nat. (Paris) 5: 302 (1825)
- *Eragrostis abessinica* Link in Hort. Berol. 1: 192 (1827), orth. var.
- *Eragrostis abyssinica* (Jacq.) Link in Hort. Berol. 1: 192 (1827)

- *Eragrostis abyssinica* var. *alba* Hochst. ex Chiov. in Annuario Reale Ist. Bot. Roma 8: 64 (1903 publ. 1902)
- *Eragrostis abyssinica* var. *viriidis* Hochst. ex Chiov. in Annuario Reale Ist. Bot. Roma 8: 64 (1903 publ. 1902)
- *Eragrostis pilosa* subsp. *abyssinica* (Jacq.) Asch. & Graebn. in Syn. Mitteleur. Fl. 2(1): 374 (1900)
- *Eragrostis tef* subsp. *spiciformis* (Serp.) Portal & H.Scholz in Eragrostis France & Europe Occid.: 309 (2002)
- *Eragrostis tef* f. *spiciformis* Serp. in Trudy Prikl. Bot. Selekts. 14: 141 (1924)
- *Poa abyssinica* Jacq. in Misc. Austriac. 2: 364 (1781)
- *Poa cerealis* Salisb. in Prodr. Stirp. Chap. Allerton: 20 (1796), nom. superfl.
- *Poa flaccida* Moench ex Steud. in Nomencl. Bot., ed. 2, 1: 561 (1840), pro syn.
- *Poa radicans* Moench in Methodus: 186 (1794)

Wild relatives of tef

Tef is considered an allotetraploid crop. However, there is no definite information to date regarding the diploid putative parents that contributed to the origin of tef. Nevertheless, based on morphological data the following species have been identified, by different researchers.
Ancestors to the origin of tef or as species closely related to teff : *Eragrostis pilosa, E. macilenta, E. aethiopica, E. pseudo tef, E. longifolia and E. atrovirens*.

Species suggested as contributors to the origin of teff: *E. pilosa, E. curvula, E. aethiopica, E. cilianensis, E. mexicana and E. bicolor.*
Species suggested as very closely related to teff: *E. pilosa* and *E. aethiopica.*
Species sufficiently related to teff: *E. mexicana, E. cilianensis, E. minor and E. barrelieri*.
Species suspected to be close enough but need further investigation: *E. macilenta and E. aegyptica* .
Species more closely related to teff than others: *E. papposa, E. heteromera and E. bicolour.*
Species suggested as closely related to tef based on cytological evidence: *E. aethiopica* 2x, *E. pilosa* 2x, *E. mexicana* 6x, *E. barrelieri* 6x, *E. minor* 2x, 4x and *E. cilianensis* 2x, 4x, 6x (Ketema, 1997). .

BOTANICAL DESCRIPTION

Teff plants rarely root from nodes above the base, with the roots growing 4–8 centimeters deep in a very thin, fibrous (threadlike) root system under field conditions. Generally, teff plants grow to 20–156 centimeters high, of which the culm or stem (11–82 centimeters) and the panicle (10–65 centimeters) comprise 47–65 percent and 35–53 percent, respectively. The stems are mostly erect, rarely creeping or bending or elbowing (geniculate) in few cultivars. They are jointed with hollow internodes separated by nodes. The culm internodes normally increase in length and decrease in thickness toward the tip (acropetal), often being short and thick at the basal part and long and thin at the uppermost internodes. The teff leaves consist of a basal light green to dark purple sheath distinctly shorter than the corresponding culm internode, a very short and ciliated ligule and a blade or lamina. The latter are slender, narrow, flat, and nearly linear or linear-lanceolate with elongated acute tips. The blades vary in color and in size, generally measuring 2–55 centimeters long and 2–10 millimeters wide at the broadest part. The inflorescence of teff is paniculate, which varies in form from very compact with the panicle branches appearing fused to the rachis forming a whiplike structure to very loose types of open and laterally spread branches. The color of the lemmas, which is important in the classification of teff cultivars, can be grayish olive, yellow green, green, dark purple, dark red, grayish yellow green, or variegated with red or purple tips and margins of yellow green, greenish yellow, grayish olive, or green basal color backgrounds. In these variegated cultivars, the mix of colors is not all over the lemmas but rather across the tips and the margins. The seeds are very small, generally ovoid or oblong to ellipsoidal, and opaque or lustrous, and their embryo marks facing the lemmas are about five-sevenths the size of the grain. The grains range in color from dark brown to orange white. Teff generally takes 25–81 days to emerge the panicle tips, 60–140 days to mature, and 29–76 days for the grain filling period. It is a C4 plant having Kranz-type leaf anatomy with the vascular bundles surrounded in a circular manner bundle, with sheath cells consisting of high concentrations of chloroplasts, and depicting low CO2 compensation of leaves, which is typical of C4 as opposed to C3 species (Fig. 4) (Ebba 1975).

<table>
<tr><td>  </td><td>  </td><td>  </td></tr>
<tr><td>Seed (magnified)</td><td>Field</td><td>Young plants</td></tr>
<tr><td>  </td><td>  </td><td>  </td></tr>
<tr><td>Teff Fields</td><td>Teff Fields</td><td>Plants in Flowering</td></tr>
</table>

		
Field	**Field**	**Field**
		
Inflorescences	**Inflorescences**	**Inflorescences**
		
Matured Field of teff	**Traditional teff harvesting**	**Carrying to threshing yard**
		
Teff threshed by using animals walking on the harvest	**Seeds**	**Seeds**

Fig. 4. Botanical Description

Tef is a C4, self-pollinated, chasmogamous annual cereal. It has a fibrous root system with mostly erect stems, although some cultivars are bending or elbowing types. The sheaths of tef are smooth, glabrous, open and distinctly shorter than the internodes. Its ligule is very short and ciliated while its lamina is slender, narrow and nearly linear with elongated acute tips. It has a panicle type of inflorescence showing different forms – from loose to compact, the latter appearing like a spike. Its spikelets have 2-12 florets. Each floret has a lemma, palea, three stamens, an ovary and mostly two, in exceptional cases three, feathery stigmas. The caryopsis is 0.9-1.7 mm in length, and 0.7-1.0 mm in diameter, which is very small, and its colour varies from white to dark brown. The development of the embryo sac and embryo of tef was studied. The development of the female gametophyte was normal and of the monosporic type common to most angiosperms. The three antipodals divide several times as is common in grasses. Study of many ovules before and after fertilization showed absence of any apomictic type of embryo formation. Fertilization was found to occur in the basal floret of a spikelet when that floret was at the base of the flag leaf blade. The maturation of flowers is basipetal on the panicle and on each branch, while acropetal on the spikelet basis. The flowers of tef are hermaphroditic with both the stamens and pistils being found in the same floret. Florets in each spikelet consist of three anthers, two stigmas and two lodicules that assist in flower opening. Tef is a self pollinated chasmogamous plant. The degree of outcrossing in tef is very low, 0.2-l.0% (Ketema, 1997).

Physiologically, tef is an herbaceous annual plant requiring 60–140 days to attain physiological maturity. Morphologically, the tef plant root system is thin and fibrous (thread-like) rarely emerging from nodes above the base, and cm deep under field conditions. The stems are mostly erect (ascending), but creeping or bending or elbowing (geniculate) in some cultivars, and jointed with hollow internodes separated by nodes. Each culm internode, except the most basal one, bears one leaf consisting of a sheath and a blade. The paniculate tef inflorescence ranges in form from very compact (whip-like) to very loose and open. The panicles ramify into primary, secondary and tertiary branches bearing spikelets. Each spikelet bears a pair of unequal sized glumes at the base and a number of florets (3–17) above. Each floret in turn comprises a tri-nerved lemma, a two-nerved bow- or boat-shaped palea, three stamens (arising from the ovary base and having very fine and slender filaments bearing length-wise opening anthers at the apex), and an ovary or a pistil. The ovary consists of two or, in a few exceptional cases; three styles each ending in a plumose (feathery) yellowish white stigma. Tef is a highly self-fertilized species with natural out-crossing of about 0.2–1% . Flowering, anthesis and maturity of florets and grains are basipetal (top–down) on a panicle basis and acropetal (bottom–up) on individual spikelet basis (Assefa *et al*., 2011).

Tef is an annual, leafy, tufted grass that reaches a height of 150-200 cm at maturity. The culms are fine, erect, simple or sparsely branched, prone to lodging. The root system is shallow and fibrous. Tef is a leafy species. Its leaves are glabrous, linear, 25-45 cm long x 0.1-0.5 cm wide. The seed head is a long panicle of 10-65 cm bearing 10-40 slender racemes, which may be either very loose or very compact. Panicles bear 30-1100 spikelets. Fruits are ellipsoid, minute (1-1.5 mm x 0.5-1 mm), yellowish-white to deep brown caryopsis (grain). Tef is possibly the smallest cereal grain, with an average length of about 1 mm. The average thousand kernel weight of 12 tef varieties is 0.264 g. The word "tef" is connected by folk etymology to the Ethiopian Semitic root "ṭff", which means "lost", because of the small size of the grain (Heuzé *et al*., 2017).

Teff is a self-pollinated warm season annual grass with the advantage of a C4 photosynthetic pathway. . Plant height at maturity ranges from 75-100 cm. It is fine stemmed and similar in appearance to bunch grasses. It has a massive, fibrous, shallow diverse root system with small-stemmed tillers originating from one crown. Stems are mostly erect with some cultivars having bending or elbowing plant types. The sheaths of Teff are smooth, glabrous, open and distinctly shorter than the internodes. Its ligule is very short and ciliated while its lamina is slender, narrow and nearly linear with elongated acute tips. It has a panicle type of inflorescence (seed head) showing different forms – from loose to compact; its spikelets have 2 to 12 florets. Each floret has a lemma, palea, three stamens, an ovary and mostly two, in exceptional cases three, feathery stigmas. Floret colors vary from white to dark brown, to red. Grain maturity varies from 90 to 130 days. The seed is very small, and its color varies from white to dark brown. Number of seeds per pound is approximately 1.3 million (Miller, 2021).

Tef is an herbaceous annual plant requiring 60–140 days to attain physiological maturity. Tef is possibly the smallest cereal grain with an average length of ~ 1 mm. The name tef is said to have probably originated from the Amharic word “tefa”, which means lost because of small seed size that is difficult to find once it is dropped. However, other more credible sources state that it was derived from the Arabic word “tahf” a name given to a similar wild plant used by Semites of south Arabia during the time of food insecurity. The seed sizes are quite small, ranging from 1–1.7 mm long and 0.6–1 mm diameter with l000 seed weight averaging 0.3–0.4 g and 150 grains of tef has equivalent weight with almost one seed of wheat. The minuteness of tef grains has nutritional and technological implications. For instance, as tef grains are difficult to decorticate, the cereal is consumed as a wholegrain, improving nutrient intake for consumers. Morphologically, tef is a fine stemmed, tufted annual grass characterized by a large crown, many shoots and a shallow, diverse root system. Its inflorescence is a loose or compact panicle and is a fine grain that comes in a variety of colors from white and red to dark brown. The tef plant root system is thin and fibrous (thread-like) rarely emerging from nodes above the base, and growing 4–8 cm deep under field conditions. The stems are mostly erect (ascending), but creeping or bending or elbowing (geniculate) in some cultivars, and jointed with hollow internodes separated by nodes. Each culm internode, except the most basal one, bears one leaf consisting of a sheath and a blade. The Paniculate tef inflorescence ranges in form from very compact (whip-like) to very loose and open. The panicles ramify into primary, secondary and tertiary branches bearing spikelet’s. Each spikelet bears a pair of unequal sized glumes at the base and a number of florets (3–17) above. Each floret in turn comprises a tri-nerved lemma, a two-nerved bow- or boat-shaped palea, three stamens (arising from the ovary base and having very fine and slender filaments bearing length-wise opening anthers at the apex), and an ovary or a pistil. The ovary consists of two or, in a few exceptional cases; three styles each ending in a plumose (feathery) yellowish white stigma. Tef is a highly self-fertilized species with natural out-crossing of about 0.2–1% . Flowering, anthesis and maturity of florets and grains are basipetal (top–down) on a panicle basis and acropetal (bottom–up) on individual spikelet basis. The color of tef can vary from white (ivory) to dark brown (black) depending on the variety. In Ethiopia, three major categories can be identified: white (nech), red (quey) and mixed (sergegna). It is also common for wholesalers to further subdivide white tef into very white (magna) and white (nech). White tef generally grows only in the Ethiopian highlands and require relatively good growing conditions. This, along with its higher consumer preference, may justify why white tef is the most expensive type of tef. However, in recent years, red tef, which is believed to be more nutritious, is also gaining popularity among health conscious consumers in Ethiopia. Due to lack of knowledge on the floral biology of tef, crossing techniques were unavailable in these years (Teshome and Tesfu, 2022).

Eragrostis tef is a self pollinated tetraploid annual cereal grass. Teff is a C_4 plant, which allows it to more efficiently fix carbon in drought and high temperatures, and is an intermediate between a tropical and temperate grass. The name teff is thought to originate from the Amharic word *teffa*, which means "lost". This probably refers to its tiny seeds, which have a diameter smaller than 1 mm (0.039 in). Teff is a fine-stemmed, tufted grass with large crowns and many tillers. Its roots are shallow, but develop a massive fibrous rooting system. The plant height varies depending on the cultivation variety and the environmental conditions. As with many ancient crops, teff is quite adaptive and can grow in various environmental conditions; particularly, teff can be cultivated in dry environments, but also under wet conditions on marginal soils. It is grown for its edible seeds and also for its straw to feed the cattle. The seeds are very small, about a millimeter in length, and a thousand grains weigh approximately 0.3 g (0.011 oz). They can have a color from a white to a deep reddish brown. Teff is similar to millet and quinoa in cooking, but the seed is much smaller and cooks faster, thus using less fuel (Wikipedia, 2023).

Teff is a tufted or bunching grass with thin narrow stems and a broad crown. The shallow fibrous roots form a massive root system, and the plant is resistant to both drought and waterlogging. The self-pollinating flowers are borne in open panicles and produce seeds that range in colour from white to deep red-brown. Teff seeds are among the smallest of all cereal grains, usually measuring less than 1 mm (0.04 inch) in diameter. Teff utilizes a photosynthetic pathway known as C_4 carbon fixation, which largely prevents photorespiration and thus contributes to the plant’s drought tolerance (Petruzzello, 2023). Teff is an annual grass also known as bunch grass. Culms up to 120 cm high in selected varieties, but often rise 60-100 cm (figure 1). Rooting depth differs with genotype and ranges and an average of 60-80 cm at the heading stage. Spikelets are grey or golden, 8 mm long with up to ten florets. Panicle is 18-20 cm long and can range from loose to compact. The caryopsis is 0.9-1.7 mm in length, and 0.7-1.0 mm in diameter, which is very small and its color varies from white to dark brown. Seeds are extremely small, weighing 250 to 350

mg per 1000 seeds. In Ethiopia two types are grown, one with white seeds (preferred) and one with brown seeds (Dipartimenti, 2023). A teff grain is about the size of a poppy seed and grows from a bunched grass. Because of its small size, the grain germinates fast, within 3 to 12 days after sowing. The grain is harvested two to six months after sowing, a short growing season that maximizes minimal land resources. Teff is harvested once a year, in rotation with other cereals and legumes to regenerate the soil in an agroecological cycle. Teff grain is used for human consumption and animal fodder; teff straw is a strong natural fiber and is used in local construction (Mann, 2023). *Eragrostis tef* is a self-pollinated tetraploid annual cereal grass. Teff is his C4 plant, able to fix carbon more efficiently under drought and high temperatures, and is intermediate between tropical and temperate grasses. The name teff is believed to be derived from the Amharic word teffa, meaning "lost". This probably refers to small seeds less than 1 mm (0.039 inches) in diameter. Teff is a thin-stemmed, tufted grass with a large crown and many tillers. It has shallow roots but develops a huge fibrous root system. Plant height varies depending on cultivar and environmental conditions. Like many ancient crops, teff is highly adaptable and can grow in a wide variety of environmental conditions. In particular, teff can be grown in dry environments, but also in moist environments in marginal soils. Teff originated in the Horn of Africa, equivalent to today's Ethiopia and Eritrea, where it is one of the most important grains. Cultivated for its edible seeds and straw for cattle. The seeds are very small, about 1 mm long, and 1,000 seeds weigh about 0.3 g. The color ranges from white to deep reddish brown. Teff cooking is similar to millet or quinoa, but it has much smaller seeds and cooks faster, so it uses less fuel (Academic, 2023). Teff, *Eragrostis tef*, is a warm season annual grass in the family Poaceae grown for its grain which can be ground into flour. The teff plant characteristically possesses a large crown and many tillers (lateral offshoots originating from the base of the stem). The plant is fine stemmed and grows in tufts. It produces a panicle (a branched flower cluster) with spikelets that hold the grain. The panicle can possess 190 to 1410 spikelets and can be either compact or loose in form. The teff grain ranges in colour from white to brown or reddish purple and is very small in size (1.0-1.7 mm in length). The plant produces 2-12 white or dark brown flowers on the spikelets. Teff is an annual plant, harvested after one growing season and it can grow 25-135 cm in height depending on the cultivar (Plantvillage, 2023).

Floral biology

The tef inflorescence is paniculate, ranging in form from very compact with the branches appearing fused to the rachis thereby forming a whip-like or rat-tail-like structure to very loose types of open and laterally spread branches **(Fig.5a.)** Broadly, four major panicle forms are distinguished. These are, very compact, semi-compact, fairly loose and very loose. The primary panicle branches (10–40 per panicle) may rarely start to ramify from near the panicle base or first they are bare for some centimeters, and then they are divided above into secondary and tertiary branches. Both the quantity and size of ramification of branches is greatest at the first node and gradually decreases upward becoming single and shortened at the end. In addition, the internodes are longest for the lower panicle branch, but become scabrous or branched at the apical parts. The branching or ramification pattern along the nodes of the central axis (rachis) can be either unilateral (in-equilateral or asymmetrical) or multilateral (equilateral or symmetrical). The panicle branches ultimately bear numerous spikelets varying in number from 30–1070 per panicle (Kebebew *et al.*, 1999). The spikelets are laterally compressed with a flexuous rachilla (with 3–18 nodes and about 1 mm long internodes) borne on a pedicel up to 2 mm long (Tadesse, 1975). The spikelets are generally linear, oblong to lanceolate in shape, and each individual spikelet measures 3–15 mm long and 1–3 mm wide at the broadest part (**Fig. 5b**). Each spikelet has got two unequal-sized glumes at the base and a number of florets above. The color of the young glumes can generally be greyish-olive green, dark red, purple, yellow-green or variegated getting flecked with dark purple or dark red on a greyish yellow-green or greyish olive-green background. There are more florets per spikelet at the top of the tef panicle than at the bottom, fewer pedicels per branch at the top of the panicle than at the bottom, and the numbers of florets are greater at the top than at the bottom. The tef florets (3–17 per spikelet) are characterized by asynchronous development and maturation which is basipetal commencing at the top of the panicle and proceeding downwards. While this is on panicle basis, the flowering on spikelet basis, on the other hand, is acropetal beginning at the bottom of each spikelet and proceeding upwards. Each floret comprises a tri-nerved lemma, a two-nerved, bow-shaped palea, three stamens arising from near the ovary base and having very fine slender filaments apically bearing two-celled, length-wise opening anthers, and a pistil or an ovary (Tadesse, 1975). Tef flowers are hermaphrodites, with three anthers and two stigmas that ripen at the same time. Soon after daybreak, all of the flowers on the panicle begin to open at the same time (**Fig. 5c**) **(**Kebebew *et al*., 2017; Solomon *et al*., 2021).

a b c

Fig. 5. The inflorescence and flower of tef. (a) Panicles of tef differ in form, colour and size (scale bar = 10 cm); (b) spike of tef showing individual spikelet (scale bar = 1 mm); (c) structure of tef flower indicating three stamens and a pair of hairy stigmas (scale bar = 1 mm)

Emasculation and hybridization technique: Until the discovery of tef flowering time or its chasmogamous nature that deciphered the opening of the florets early in the morning at about 06:45–07:45 hours by Tareke (1975), tef was thought to be entirely cleistogamous (closed flowers) with no options for out-crossing. The rate of natural out crossing in tef is 0.2% in the field and 0.05–1.37% in the greenhouse. Hence, due to this very low level of out crossing, tef is considered as a strictly self-pollinated crop.

Based on the breakthrough discovery of the chasmogamous nature of tef florets, Tareke (1975) developed the artificial surgical hybridization method which is still in use in the tef hybridization program. The conventional binocular aided tef crossing involves (Solomon *et al.,* 2021):

- Emasculation of the maternal parent (by removal of the three stamens) at about 1600-1900 hours a day before.
- Storage of the paternal parent under dark and cold conditions in a refrigerator (4 °C) overnight.
- Collection of pollen from the paternal parent and subsequent brushing of the pollens over the stigma of the previously emasculated florets of the maternal parent.

Surgical hand emasculation and pollination procedure: The items required for the surgical tef emasculation and pollination include binocular microscope, refrigerator or dark boxes, very fine blunt needles or a pencil, a pair of forceps, paper clips or a stapler, and a marking pen**(**Solomon *et al*., 2021) .

- Grow parental tef plants in a 12 cmdiameter pot in the glasshouse.
- Sow the seeds of the parents at various time intervals to synchronize panicle emergence.
- Take parental plants to the laboratory when more than half of the panicle has emerged from the flag leaf sheath.
- Emasculate 15-20 basal florets of the seed bearing parent plant using fine tweezers and fine needle under a dissecting microscope (30-50×) the day before pollination.
- Remove all florets above the emasculated basal floret and all spikelets above the emasculated portion of the panicle. Moreover, detach spikelets 5-10 cm below the emasculated florets.
- Whilst keeping the emasculated plants in the laboratory overnight put the pollen donor plants in a refrigerator (3-5 oC) to prolong the time of anther dehiscence in the morning. Putting the pollen donor plants in a dark box can also serve the purpose of delaying anther dehiscence.
- Take the pollen donor plant out first and wait for 3-5 minutes. As soon as it starts to open its flowers, detach and collect in Petri-dish spikelets with open florets from the pollen donor plant in the morningusing forceps.
- Lay down the emasculated panicle on one side of the field of the dissecting microscope, and collect matured anthers from the open florets of the spikelets quickly on the other side and put close to the emasculated florets.
- As soon as the anthers start to dehisce (burst open along the crease), transfer anther to each emasculated floret. Alternatively, pollen grains spilled over the stage of the microscope could be used to pollinate in cases where there are too few anthers.
- Clean the instruments and the stage of the dissecting microscope using alcohol before doing another pollination work with different parental combination.
- Normally, each pollination activity may take half an hour to one hour for experienced person. Hence, the maximum number of crosses per day may not be more than three.
- Cover pollinated panicle with transparent bags attached to a supporting stick.
- Return the plants to the glasshouse to mature. Experiences show that covering with parchment bag is optional in tef, as the risk of stray pollen coming to emasculated and pollinated floret is very low.
- Normally, hybrid seeds of tef mature one month after pollination in the glasshouse. The pedicel dries up when seeds mature and this provides a good indicator.
- Harvest and thresh hybrids carefully in a Petri dish.

GENETICS AND CYTOGENETICS

Genetics: The inheritance of lemma colour, seed colour and panicle form in tef was studied to determine the gene actions and interactions, the number of genes involved, the presence or absence of maternal effects and linkages and the kind of tetraploidy in the crop species. Four tef cultivars (*viz*., Fesho, Bursa, Kaye Murri and Trotteriana) having differing and contrasting phenotypic characteristics for the three traits were used, and six crosses and their reciprocals were made among the four cultivars. Data collected on individually transplanted plants and their progenies in the F1, F2 and F3 as well as in backcross generations were used to determine the inheritance patterns (Kebebew *et al*., 2017).

Lemma Colour: Four genes controlled lemma colour inheritance as demonstrated by F2 segregation ratios of 3:1, 12:13:1, 15:1, 45:3:16 and 180:12:48:16. Dominance, complementary and epistatic gene actions and interactions were found.

Seed Colour: Duplicate pairs of genes were involved in seed colour inheritance, and the gene action between the genes and their alleles was simple dominance with additive effects. The cultivar Fesho (dark brown seed) produced an F2 ratio of 15 brown:1 white when crossed with Kaye Murri (yellowish white seed), and 3 brown:1 white for the cross between Trotteriana (medium brown seed).

Panicle Form: This was controlled by duplicate pairs of genes for the degree of looseness and another pair of genes for branching pattern. Segregation ratios in the F2 of 15 loose:1 compact in the loose × compact crosses showed duplicate dominance gene action. Loose × loose crosses were all loose and compact × compact crosses were all compact in the F2. On the other hand, an F2 segregation ratio of 13 multilateral:3 unilateral for branching pattern suggested a recessive-suppressor type gene action. Generally, the inheritance studies of all the three qualitative traits depicted no maternal effects, and all of them showed disomic inheritance patterns indicating that tef is an allotetraploid. This, in turn, indicates that quantitative genetic theories developed for diploids can be applied for the genetic improvement of the crop through breeding.

Cytogenetics: Tef is an allotetraploid plant with a chromosome number of 2n =40 and the basic chromosome number of the genus Eragrostis is x =10. This is based on a genetic study that resulted in disomic inheritance patterns for different characters of tef and supporting cytological evidence that showed regularity of meiosis in both the pure lines and the intraspecific hybrids which formed 20 bivalents in metaphase I. In a karyotype study made on 15 *Eragrostis* spp. it was shown that the chromosomes of tef are very small even by the standards of the genus. When two accessions of tef were observed, measurements of the largest chromosome were 1.6-2.9 µm and of the smallest were 0.8-1.1 µm. The range within each measurement was attributed to differences in condensation (Ketema, 1997).

The genus *Eragrostis* is generally a complex taxon characterized by the prevalence of polyploidy (about 69%) and common presence of cytological races. The species in the genus range from diploids (2n=2x=20) to hexaploids (2n=6x=Tef is an allotetraploid (2n =4x=40) forming 20 bivalents in the meiotic Metaphase I,, coupled with disomic inheritance patterns. Nevertheless, the putative diploid progenitors have not yet

been identified. Recent DNA-based studies suggested that *Eragrostis pilosa*, also an allotetraploid, is the closest relative and possibly the immediate wild progenitor of tef (Assefa *et al*., 2011).

The species in the genus *Eragrostis* generally range from diploid ($2x = 2n = 20$) to hexaploid ($2x = 6x = 60$). Tef is an allotetraploid species ($2n = 4x = 40$) originating from the hybridisation of two distinct species followed by diploidisation. This has been hypothesised based on the following two evidences. Cytological examinations depicted the formation of 20 bivalents in the meiotic Metaphase I in both the inter- and intraspecific hybrids. In support of this, genetic studies further showed disomic inheritance patterns for some qualitative characters including panicle form and branching pattern, and glume/lemma and caryopsis colour (Kebebew *et al*., 2017).

The species in the genus *Eragrostis* generally range from diploid (2x = 2n = 20) to hexaploid (2x = 6x = 60). Teff is an allo-tetraploid species (2n = 4x = 40) originating from the hybridization of two distinct species followed by diploidization. Through cytological examinations the formation of 20 bivalents in the meiotic Metaphase I in both the interspecific and intraspecific hybrids provides evidence of it being an allotetraploid hybrid. In support of this, other genetic studies further depicted disomic inheritance patterns for some qualitative characters, including panicle form and branching pattern as well as glume/lemma and caryopsis color. Although the putative ancestral diploid progenitor species for teff are not fully known, based on morphological and cytological evidences, suggested that the following species are closely related to teff: *Eragrostis aethopica* (2x), *E. pilosa* (4x), *E. mexicana* (6x), *E. barrelieri* (6x), *E. minor* (2x, 4x), and *E. cilianensis* (2x, 4x, 6x). Recent DNA-based studies confirmed that *E. pilosa* is the closest relative and presumably one of the intermediate wild progenitors of teff. As revealed from the karyotype analyses of 15 *Eragrostis* species, the chromosomes of teff are minute even by the standards of the genus, with the largest and smallest chromosomes of teff measuring from 1.6–2.9 and 0.8–1.1 micrometers (μm) respectively. The range in each of these two size groups is due to differences in condensation. Indeed, flow cytometric analysis revealed that the tetraploid nuclear genome size of teff is about 730 megabase pair (Mbp), and no significant teff genotype differences were noted. This indicates that the genome size of teff is roughly 50 percent larger than the rice genome, and the equivalent diploid teff genome size is about 75 percent the size of the rice genome (Kebebew and Solomon, 2018).

GENETIC DIVERSITY

Due to the enormous diversity in teff genetic resources available to breeders, and due to the relatively early stage of its improvement, several reports have focused on the diversity of teff collections. We have discussed how much of teff cultivation in the Horn of Africa depends on landraces and traditional varieties that farmers select and propagate since centuries. As a result, landraces acquired traits for local adaptation that could be very relevant for breeding. The diversity included in these landraces is very large for agronomic traits, adaptation traits, and farmer preference (Woldeyohannes *et al*., 2022). For sustainable and stable food production, maintaining genetic diversity within and between crop types is increasingly being realized as the most appropriate and indispensable action. This is further emphasized by unpredictable human food needs, changes in taste, technological demand, and the biotic and abiotic production constraints that change with the Environments (Teshome and Tesfu, 2022).

The seeds are very small, generally ovoid or oblong to ellipsoidal, and opaque or lustrous, and their embryo marks facing the lemmas are about five-sevenths the size of the grain. The grains range in color from dark brown to orange white (Ebba 1975). The caryopsis is 0.9-1.7 mm in length, and 0.7-1.0 mm in diameter, which is very small, and its colour varies from white to dark brown (Ketema, 1997). Fruits are ellipsoid, minute (1-1.5 mm x 0.5-1 mm), yellowish-white to deep brown caryopsis (grain). Tef is possibly the smallest cereal grain, with an average length of about 1 mm. The average thousand kernel weight of 12 tef varieties is 0.264 g (Heuzé *et al*., 2017). The s Teff grain is the smallest of all whole flour grains in the world with a length of about 1.0 mm and a width of about 0.60 mm. The average thousand grain weight of teff kernels is only 0.26 g. The grain color ranges from a light ivory to very dark reddish brown depending on the variety. However, when the whole grain is finely ground, the difference in flour color becomes less noticeable. This may indicate that the pigmenting compounds of the brown teff grains are mainly accumulated on the grain pericarp (Gebru *et al.,* 2020). Depending on the varieties, the color of teff grain can be ivory, light tan to deep brown or dark reddish-brown to purple. Based on people's preference for their consumption, white teff is the most expensive, while in terms of benefit, red teff is more nutritious and gains acceptance by the health-oriented consumers in Ethiopia and worldwide (Merchuk-Ovnat *et al*., 2020).

Seed is very small, and its color varies from white to dark brown. Number of seeds per pound is approximately 1.3 million or 1 kg is approximately 2.86 million (Miller, 2021). Depending on the type, teff grains can be white, light tan to deep brown or dark reddish-brown purple. It is the world's tiniest grain, measuring 1-1.7 mm in length and 0.6-1 mm in diameter, with an average seed weight of 0.3-0.4 g for 1000 seeds and 150 grains required to equal one grain of wheat. Teff has a mellow, nutty flavour with a hint of molasses sweetness. The white teff has a chestnut flavour, while the darker types have a more earthy hazelnut flavour. The grain has a mucilaginous texture. It is of tiny size but with a giant nutritional content. Teff's nutritional worth and health advantages and its quality value as a gluten-free grain have piqued attention throughout the world (Sridhara *et al.,* 2021). The seed sizes are quite small, ranging from 1–1.7 mm long and 0.6–1 mm diameter with l000 seed weight averaging 0.3–0.4 g and 150 grains of tef has equivalent weight with almost one seed of wheat. The color of tef can vary from white (ivory) to dark brown (black) depending on the variety. In Ethiopia, three major categories can be identified: white (nech), red (quey) and mixed (sergegna). It is also common for wholesalers to further subdivide white tef into very white (magna) and white (nech). White tef generally grows only in the Ethiopian highlands and require relatively good growing conditions. This, along with its higher consumer preference, may justify why white tef is the most expensive type of tef. However, in recent years, red tef, which is believed to be more nutritious, is also gaining popularity among health conscious consumers in Ethiopia (Teshome and Tesfu, 2022). Tef grain has a variety of colors including milky-white, white, creamy-white, light brown and dar white, creamy-white, light brown and dark brown (Asefa *et al*., 2022).

The seeds are very small, about a millimeter in length, and a thousand grains weigh approximately 0.3 g. They can have a color from a white to a deep reddish brown (Wikipedia, 2023). Teff seeds that range in colour from white to deep red-brown. Teff seeds are among the smallest of all cereal grains, usually measuring less than 1 mm in diameter (Petruzzello, 2023). The caryopsis/seed is 0.9-1.7 mm in length, and 0.7-1.0 mm in diameter, which is very small and its color varies from white to dark brown. Seeds are extremely small, weighing 250 to 350 mg per 1000 seeds. In Ethiopia two types are grown, one with white seeds (preferred) and one with brown seeds (Dipartimenti, 2023). The teff grain ranges in colour from white to brown or reddish purple and is very small in size (1.0-1.7 mm in length) (Plantvillage, 2023).

However, seed colour over seed size has been a target for teff breeding in the past decades, as colour is a primary trait for selection of grains in both formal and informal markets. Teff seed color varies from dark brown to white, but white seeds fetch higher market prices and indeed most of teff varieties developed by breeding are white in colour. Still, brown seeded teff genotypes are reportedly associated with aluminium toxicity tolerance and may have higher nutritional content, supporting the need for their valorisation. Though small overall, seed size is highly varied in

teff collections, *e.g.,* for grain length (0.9 to 1.7 mm) and thousand grain weight (0.19 to 0.42 g), suggesting untapped potential for improvement. (Fig. 6).

Teff (small grains) and sorghum (large grains)

Black grains

Yellow grains

White grains

Cream grains

Brown grains

Black grains

Brown grains

Yellow grains

Fig. 6. Genetic variability for seed shape, size and color in Teff

Phenotypic variability in teff was recorded in—grain yield, grain color and size, days to panicle emergence, days to maturity (21 to 81 and 50 to 140, respectively), number of grains/plant (9000–90,000), plant height (20–156 cm), number of tillers/plant (5–35), and culm diameter (1.2–5 mm) (Merchuk-Ovnat *et al*., 2020). Teff yield is positively associated with panicle size, floret abundance, and shoot biomass. Longer panicles are preferred by farmers in agroecologies that allow longer vegetative growth, as they may result in higher yields. Large variation exist in teff collections for panicle related traits, including spikelet length (3 to 15 mm), spikelet width (1 to 3 mm), lemmas length (2 to 3 mm), lemmas width (1.3 to 2.03 mm) and number of grains per panicle (1520 to 6652). The Ethiopian Institute of Biodiversity (EIB) teff collection features accessions exhibiting very different panicle types, from very compact to extremely loose **(Fig.7).** Compact types have a high spikelet number per panicle and are frequently cultivated under more favourable conditions, however loose types can also be high yielding (Woldeyohannes *et al*., 2022). Teff seed heads also show genetic diversity of the crop worldwide **(Fig. 8).**

Fig. 7. Diversity in the form of teff panicles. A. Very compact, B. Semi.compact, C. Fairly lose, D. Very loose

Fig. 8. Teff seed heads showing the genetic diversity of the crop worldwide

The teff genetic resources harbor a tremendous diversity in phenologic, agronomic, and morphologic traits coupled with unexploited aspects in terms of nutritional as well as biotic and abiotic stress-tolerance traits. The wealth of diversity in the species offers ample opportunities for genetic improvement of the crop and to develop varieties suitable for different agroecologies, cropping systems, and purposes (Kebebew and Solomon, 2018). The tef germplasm has been studied by the national research programme in Ethiopia and to the limited extent outside the country. In terms of phenology, tef generally takes 25–81 days to grow the panicle tips, 60–140 days to mature and 29–75 days for the grain filling period. Tef plants grow to a total height ranging from about 20 to155cm, of which the culm (11–82cm) and the panicle (10–65cm) comprise 47–65% and 35–156%, respectively. The existence of variability in tef germplasm for culm internode diameter (1.2–4.5mm) is one key factor among others to possibly identify tef lines with improved lodging resistance **(Table 2)** (Kebebew *et al.,* 2017).

Table 2. Ranges of important traits of tef

Traits	Minimum	Maximum
Time-related		
Daystoheading	25	81
Daystomaturity	60	140
Grainfillingperiod (days)	29	75
Length-related		
Plantheight(cm)	20	156
Culmlength(cm)	11	82
Paniclelength(cm)	10	65
Pedunclelength(cm)	5.8	42.3
Diameter-related		
Firstculminternodelength(cm)	2.7	8.1
Secondculminternodelength (cm)	4.1	11.5
Firstandsecondculminternodediameter(mm)	1.2	4.5
Graindiameter(mm)	0.5	1
Number-related		
No.oftillers/plant(total)	4	22
No.oftillers/plant(fertile)	1	17
No.ofprimarypaniclebranches	10	40
No. of spikelet/panicle	30	1070
No. of florets/spikelet	3	17
Mass-andyield-related		
100-kernelmass(mg)	18.9	33.9
Grainyield/panicle(g)	0.1	2.5
Grainyield/plant(g)	0.5	21.9
Grainyield(kg/ha)	1058	4599
Totalphytomass/plant(g)	4	105
Shootphytomass(kg/ha)	6355	19630
Other-properties		
Harvestindex (%)	5	39
Lodgingindex	20	100

Tef is highly diverse and variable in terms of morphological and agronomic characters. The distribution of the crop in different agro-ecological zones coupled with the selection by farmers on the basis of their preferred traits has resulted in a number of varieties with unique characters. Genetic diversity analysis of tef accessions facilitates the development ofimproved varieties with high productivity and yield stability. Significant clinal diversity was reported in tef germplasm populations collected from different altitudinal zones for traits such as days to maturity, number of culm nodes, first and second basal culm internode diameter, and harvest index. Likewise, significant altitude-based diversity in tef germplasm populations was found for traits such as main shoot culm node number, days to maturity, diameters of the first and second lowest primary shoot culm internodes, and harvest index. However, no significant differences for qualitative traits (such as lemma, seed and anther colors and panicle form) were reported among the altitudinal zones. On the other hand, for the trait days to maturity, 36 heterogeneous tef populations had lower diversity levels for accessions collected between altitudes of 1800 and 2400 m, while high diversity was noted for accessions obtained below 1800 m above sea level.

Evaluations of 70 accessions of tef collected from different regions of Ethiopia showed significant variations within populations, among populations within regions, and among regions in most of the phenotypic traits. On the other hand, studies based on evaluations of 3600 tef lines representing 36 populations collected from the Central and Northern Regions of Ethiopia revealed significant regional diversity for seed color and days to maturity. Furthermore, other studies showed significant regional diversity for lemma color, number of culm internodes, and counts of basal and middle spikelet florets in tef germplasm populations from different parts of the country. An experiment at two locations using 144 accessions collected from different regions of Ethiopia showed that accessions from the same origin clustered into different classes and those from different origins also clustered into the same group. Other studies further confirmed that the level of genetic diversity is higher in tef germplasm within a region than between regions, and as a result, accessions that had originated from the same region and altitude were grouped into distinct and distant clusters. On the other hand, no significant differences were obtained among diverse altitude zones for parameters like days to panicle emergence, culm and panicle length, number of panicle branches, counts of fertile florets/spikelet, and shoot biomass. Moreover, diversity studies using 33 accessions collected from North-Western Ethiopia and four improved varieties and selected tef genotypes revealed considerable variations among the genotypes for many of the traits assessed. However, this genetic variability is rapidly declining as farmers are quickly adopting improved cultivars and using them instead of landraces. In order to reduce the expected genetic erosion, the Ethiopian Institute of Biodiversity (EIB) has made rescue collections from different agro-ecological zones (Assefa *et al*., 2015).

A yield potential experiment was conducted with one farmers' variety and 10 improved varieties released. The experiment was conducted at the Debre Zeit Agricultural Research Center, Debre Zeit, Ethiopia, on two soil types in the 1997 main cropping season. Evaluation of cultivars from different aeras in a common environment has been used to estimate breeding progress. Optimum levels of fertilizers and full weed and bird control programs were used. Netting was used to prevent lodging. Data on grain yield and its attributes were determined. Grain yield of tef was estimated to have risen for 35 years of breeding from 3425 to 4599 kg/ha. Biomass yield and kernel weight per main panicle were greater in newer cultivars, highly and linearly related to cultivar age, and positively and significantly correlated to grain yield. Number of spikelets per panicle is also greater in newer cultivars and significantly and positively correlated with grain yield. Improved plant height, panicle length and kernels per panicle were a feature of most modern genotypes. However, no change occurred in harvest index and 100-kernel weight. Results of a stepwise regression analysis of grain yield on selected yield components revealed that biomass yield was the single most important yield attribute, which accounted for 56.7% of the variation in grain yield (Teklu and Tefera, 2005). A total of 408 accessions of tef held in the Israel Gene Bank were grown in 2015 under common garden (screen-house) conditions for propagation and initial phenotyping. A diversity panel, consisting of 273 accessions representing the entire collection's range of phenotypic diversity, was assembled and evaluated in small field plots in 2016. Further evaluation was conducted in 2017, in single-plant field plots (to eliminate admixtures). A representative plant (plot) was selected from each accession grown in 2017 and its single seed descent progenies where grown in 2018 in single-plant plots. The collection exhibited a wide diversity for each of the measured phenotypic traits, across all four environments. High grain yield was associated in most cases with early flowering time, whereas higher biomass was associated with late flowering. Heritability estimates, calculated based on the 2017, 2018 data, varied between 0.11 for plant biomass and 0.75 for 1000 grain weight. This study shows that tef can successfully grow and produce under irrigated Mediterranean conditions. The wide diversity available in our germplasm collection can provide the foundations for breeding new tef cultivars that are better adapted to these conditions(Ben-Zeev *et al.*, 2018)..

Much of the national and international success of teff is due to its unique flavour and nutritional properties. Starch makes up about three-quarters of teff flour. Its amylose content (20 to 26%) is comparable to that of most cereals, but the total dietary fibre content of whole grain teff (9.8%) is higher than that of major cereals and even higher than that of quinoa (7.1%). Teff germplasm displays high variability in nutritional properties yet the highest iron and calcium contents are recorded in brown seeded varieties. Fat (2% to 3%) and protein content (8% to 11%) in teff grain is similar, in some instances better, than that of other more common cereals, with a balanced amino acid composition and relatively high concentration of lysine. In teff flour, riboflavin ranges from 0.13 to 0.14 mg/100 g, niacin from 1.7 to 1.8 mg/100 g, and thiamine from 0.3 to 0.6 mg/100 g, higher than in most common cereals. Polyphenols and phytates are also present in high concentration. This is also related to the fact that, due to its small size, the grain cannot be divided into germ, bran and endosperm during processing and it is consumed as a whole. The total phenolic content (mg GAE/gr) in teff ranges from 0.89–1.2 to 1.04–1.27 in white and brown grains, respectively. Feed traits are associated with food quality traits and yield traits, confirming the possibility of improving feed quality traits without significantly affecting grain yield ((Woldeyohannes *et al*., 2022)

BREEDING

Germplsm: Globally, 6797 tef germplasm accessions are found in gene-banks in different countries around the world. Of these, 6,000 accessions are found in the EBI gene bank while the remaining 797 accessions are found in institutions outside Ethiopia (Seyfu, 1997) (**Table** 3).

Table 3. Global holdings of tef genetic resources

Source /Institution	Number of samples/ accessions
Ethiopia, Ethiopian Biodiversity Institute (EBI), P.O.Box 30726, Addis Ababa, Ethiopia	6,000
Germany, Institute of Crop Science, Federal Research Center for Agriculture (FAL), Bundesallee 50, 38116 Braunschwelg	30
Germany, Institute for Plant Genetics and Crop Plant Research, (IPK) - Genebank, Correnstr 3, 06466 Gatersleben	5
Japan, Department of Genetic Resources, I Nat. Inst. of Agrobio. Resources, Tsukuba-gun, Ibaraki-ken 305, 1-1 Kannondai, 3- Chone, Yatabe-Machi	30
Yemen, Agricultural Research and Extension Authority, P.O.Box 87148, Dhamar, Republic of Yemen	2
Russia, N.I. Vavilov All-Russian Research Institute of Plant Industry, Bolshaya, Morskaya Str. 44, St. Petersburg, 190000, Russian Federation	14
Slovak Republic, Botanical Garden of the University of Agriculture, Trieda A. Hlinku2, Nitra	1
South Africa, Division of Plant and Seed Control. Dept. of Agric. Tech. Service, Private Bag X179, Pretoria	3
UK, Welsh Plant Breeding Station, Inst. of Grassland and Environ. Res., PlasGogerddan, Aberystwyth, Dyfed SY23 3EB	3
USA, National Seed Storage Laboratory, USDA-ARS, Colorado State University, Fort Collins, Colorado 80523	341
USA, Western Region Plant Introduction Station, USDA-ARS, Washington State University, 59 Johnson Hall, Pullman, WA 99164-6402	368
Total	6,797

The total numbers of holdings of tef germplasm accessions in the genebank of the Institute of Bio-diversity Conservation (IBC) in Ethiopia until 2000 was 4395, and of these 1497 accessions were acquired through donations and repatriations and the rest through collections (Assefa *et al.,* 2011). Ethiopia is the origin and center of diversity for tef, harboring landraces with a wide array of phenotypic diversity, and also wild progenitors and related wild species. As in any crop improvement program, tef breeding also relies mainly upon the germplasm resources existing in the genetic stock. Diverse types of accessions are available in the country, and collection, evaluation, and utilization of tef germplasm by national and international groups began in Ethiopia in the late 1950s. However, organized collection at the national level was made after the establishment of the Plant Genetic Resources Center of Ethiopia (PGRC/E) in 1976. After several changes in its name and mandate, the institute responsible for germplasm collection and maintenance as wellas distribution is currently called the Ethiopian Institute of Biodiversity (EIB). The institute with only 1067 tef accessions in Demissie (1991) has reached to 5169 accessions in 2011. This fourfold increase in the collection size in just two decades shows the presence of both a wide diversity of germplasm in the country and also the commitment of institutes and individuals to collect and preserve these germplasm forfuture use. Characterization of the accessions according to their properties such as morphology is important in order to provide information to interested researchers or other sectors of society. The first and most comprehensive detailed morphological descriptions for 35 tef cultivars were given based on phenology, plant vigor, shoot and root related traits, panicle form, spikelet size, growth habit, and lemma and caryopsis color (Assefa *et al.,* 2015). The first step generally involves germplasm enhancement through mainly collection/acquisition, characterization and evaluation, hybridization (intraspecific and interspecific) and induced mutation techniques. Ethiopia is the center of both origin and diversity of teff. In the absence of influences from abroad regarding breeding materials, the crop's genetic improvement relies heavily on the indigenous genetic resources. **Table** 4 summarizes current holdings of teff germplasm accession in the world. The Ethiopian genebank at the Ethiopian Biodiversity Institute alone presently holds a total of 5,169 accessions (Kebebew and Solomon, 2018).

Table 4. Teff germplasm accessions in gene banks in different parts of the world

Source and Institution	Number of samples and accessions
Ethiopia, Ethiopian Biodiversity Institute	5,169
Germany, Institute of Crop Science, Braunschweig	30
Germany, Institute for Plant Genetics and Crop Plant Research (IPK)–Genebank, Gatersleben	5
Japan, Department of Genetic Resources, International Institute of Agrobiological Resources	30
Yemen, Agricultural Research and Extension Authority	2
Russia, N.I. Vavilov All-Russian Research Institute of Plant Industry, Saint Petersburg	14
Slovak Republic, Botanical Garden of the University of Agriculture	1
South Africa, Division of Plant and Seed Control, Department of Agriculture and Technology Service, Private Bag X179, Pretoria	3
UK, Welsh Plant Breeding Station, Institute of Grassland and Environment Research	3
US, National Seed Storage Laboratory, USDA-ARS, Colorado State University, Fort Collins, Colorado	341
US, Western Region Plant Introduction Station, USDA-ARS, Washington State University, Pullman	368
Total	5,966

Crop germplasm collections are a key asset to support the resilience and productivity of cropping systems worldwide. In their diversity lays an oftentimes untapped reservoir of alleles that may enable breeding strategies targeting local adaptation, resulting in enhanced performance and higher varietal uptake (Woldeyohannes *et al.,* 2022)

Breeding Objectives: The overall objectives of the tef breeding program are 1) to enrich and improve the germplasm resource base; 2) to develop suitable varieties for different agro-ecologies and cropping systems and 3) to generate basic scientific information on the crop species (Assefa *et al.,* 2011; Kebebew *et al*., 2017; Kebebew and Solomon, 2018). Teff breeding should target the improvement in the following traits—grain yield, shoot biomass, lodging resistance, grain size and color, grain coat properties, nitrogen-use efficiency, osmotic adjustment root depth, tolerance to drought, salinity, and acidity, nutritional values, physicochemical, and palatability. Variability for the culm internode diameter is a key factor for improved lodging resistance (Merchuk-Ovnat *et al*., 2020

The overall objective of the tef breeding program is to develop adaptable high yielding, abiotic and biotic stress tolerant, and farmer and consumer- preferred tef varieties, and thereby contribute to improved productivity and production, food and nutrition security, and livelihood of farmers and consumers in Ethiopia (Solomon *et al.,* 2021). The specific objectives of the tef breeding program are 1) To enrich the genetic resource base; 2) To develop and promote suitable varieties for different agro-ecologies, and farming as well as cropping systems; and 3) To generate basic scientific information on the crop (Assefa *et al.,* 2011; Solomon *et al*., 2021).

Breeding Methods: Following the germplasm enhancement are generation advancement and handling of segregating populations from crossing and induced mutation, observation nurseries, series of field variety trials, and ultimately variety verification trial for release. For handling such segregating populations, the breeding methods adopted are mainly modified pedigree and bulk methods; in some cases also single-seed descent methods are used (Poehlman and Davis 1995). The following breeding methods *viz.,* 1. Pure-line selection method, 2. Mass selection breeding method, 3. Bulk Method, 4. Pedigree Method and 5. Single seed descent method have been suggested by Solomon *et al*.(2021).

Breeding: Applied breeding work to improve tef included direct selection from the landraces, interspecific and intraspecific hybridization and mutation breeding, while at the basic research level investigations were made in the area of biotechnology. The applied research attempts in the areas of mutation and interspecific hybridization programmes have not yet contributed to the development of improved cultivars. On the other hand, the direct selection from the landraces and the intraspecific hybridization programme which was employed to effect gene recombination were successful in developing several improved cultivars of tef with desired traits. In the intraspecific hybridization programmes the pedigree and modified pedigree selection methods were used to handle the segregating population. The improved cultivars developed include: cultivars that have high grain yield with wide or specific adaptation, cultivars with acceptable high grain quality, and early maturing, high-yielding varieties. All the improved cultivars were accepted by farmers and currently are in production. Direct selection from the landraces, mutation breeding and intraspecific hybridization were tried for developing lodging-resistant varietie (Ketema, 1997).

Tef or teff, a cereal crop which adapts to extreme climatic and soil conditions, is extensively cultivated in the Horn of Africa. It is also considered as nutritious and a life-style crop due to its richness in essential nutrients and health-related benefits. However, the productivity of the

crop is extremely low due to little scientific improvement made globally. It is, therefore, in the category of *orphan crops*. Together with all cereal crops, tef belongs to the Grass or Poaceae family. The improvement of tef focuses on selection and hybridization techniques. However, recently, molecular and high-throughput techniques have also been implemented to a limited scale. Forty-two tef varieties were approved for release by the Ethiopian National Variety Release Committee in the past four decades. Due to the adoption of improved varieties and technologies, the national average yield of tef has more than doubled over the last 20 years (Chanyalew *et al.,* 2019). Lodging is the most important yield limiting factor of tef in Ethiopia both directly and indirectly. Under natural conditions grain yield losses due to lodging are estimated at up to 25% with an average of 17%. Lodging also reduces the quality of the seed in terms of germination energy and capacity, colour and nutritional value. Indirectly, susceptibility to lodging hinders the use of high-input husbandry technologies such as increased nitrogen fertilization, and it interferes with both mechanical and hand harvesting operations (Assefa *et al.,* 2011). The major challenges in teff production are its low yield and high susceptibility to lodging. Efforts to conventionally breed teff towards higher yields started in the 1950s and led to an average annual increase in yield of 0.8%.[31] However, no considerable improvements concerning the susceptibility of lodging have been made, due mainly to low demand outside of Ethiopia and Eritrea (Wikipedia, 2023).

Improved Varieties: To date, a total of 35 varieties have been released in Ethiopia through the NationalAgriculturalResearchSystem. Of these, 21varieties have been Released by Debre Zeit Agricultural Research Center, while14 were released by other six centres. Of the total number of varieties released to date, only 12 varieties were developed through hybridisation, while the remaining 23 were developed using pure line selection technique from the land races (Kebebew *et al.,* 2017). Tef is the major Ethiopian cereal grown on 3.02 million hectares annually and serving as staple food grain for over 70 million people. However, the national average yield of tef is low 1.6 t ha-1. This is partially due to the use of unimproved local cultivars, and biotic and abiotic stresses. Therefore the experiment was designed to develop high yielding and desirable quality improved varieties suitable for diverse agro-ecologies, farming systems and purposes. Fourteen tef genotypes including two checks were laid out in randomized complete block design using four replications for two years at eight locations. Results of combined data analysis across locations and over the years showed that candidate variety Dagem [DZ-Cr-387 X Kay Murri (DZ-Cr-438 (RIL No 91A))] performed better than the two check and other test genotypes. Thus, Dagim was identified and released as best promising tef variety for production in the country (Chanyalew *et al*., 2017). To date, a total of 33 varieties have been released in Ethiopia through the National Agricultural Research System. Of these, 19 varieties have been released by Debre Zeit Agricultural Research Center. The remaining 14 teff varieties released were 2 by Holetta, 1 each by Melkassa and Areka, 5 by Sirinka, 3 by Adet, and 2 by Bako agricultural research centers. Of the total number of released varieties, 10 varieties were developed through hybridization, and of these, 9 were released by Debre Zeit Agricultural Research Center. Four of the released varieties, viz. Magna (DZ-01-196), Enatite (DZ-01-354), Dukem (DZ-01-974), and Quncho (DZ-Cr-387 RIL355) are widely cultivated (Kebebew and Solomon, 2018). Due to its nutritional and functional properties, the acceptance and global demand of the crop is rapidly increasing and being cultivated in many countries such as the USA, Canada, Australia, Switzerland, and the Netherlands. Tef cultivars have been distinguished and described based on the color and inflorescences, ramification of the inflorescences and the size of plants (Asefa *et al*., 2022)..

USES

Teff is mainly used for making a pancake-like bread called '*injera*'. In some cases it is used to make porridge and native alcoholic drinks called '*tella*' and '*katikala*'. Its straw is highly valued and is used as feed for cattle. In addition, the straw is incorporated with mud to reinforce it and used for plastering walls of houses (Ketema, 1991). In Ethiopia tef is traditionally grown as a cereal crop. The grain is ground to a flour which is mainly used for making a popular pancake-like local bread called enjera and sometimes for making porridge. The grain is also used to make local alcoholicdrinks, called tela and katikala. Tef straw, besides being the most appreciated feed for cattle, is also used to reinforce mud and plaster the walls of tukuls and local grain storage facilities called gotera. Tef grain, owing to its high mineral content, has started to be used in mixtures with soyabean, chickpea and other grains in the baby food industry (Ketema, 1997). The famous Ethiopian bread injera, a flat bread, very similar in appearance and texture to a pancake, is prepared with the consistency of pancake batter and baked in a skillet on a hot stove or fire. That's where the resemblance with pancakes ends, though, because injera is not a sweet bread. In fact, it is quite sour (for Ethiopians, the more sour the better), made with sourdough, wild yeast (Amare, 2014).

Tef grain is a staple food in Ethiopia. It has a high nutritive value and is used to prepare several dishes, the main one being *injera*, a popular fermented and flattened sour bread. Tef grain is one of the cereal grains used in the production of Ethiopian beer (*tela*). Due to the minuteness of tef grains, they are difficult to decorticate, and the cereal is consumed as a wholegrain. There are many varieties of tef. The Hagaiz type has white seeds, matures slowly (150 days), makes higher demands on the soil and cannot be grown above an altitude of 2500 m. The Tseddia type has brown seeds, matures early (90 days), can be grown above 2500 m and is superior for fodder production. Three major categories exist on the market: white (*nech*), red (*quey*) and mixed (*sergegna*). Wholesalers subdivide white tef into very white (*magna*) and white (*nech*), though these categorizations remain subjective. Consumers prefer white tef over darker coloured types, but red tef, which is believed to be more nutritious, is also gaining popularity among health conscious consumers in Ethiopia. In Ethiopia, a country of nearly 90 million people, approximately 6 million households grow tef. The production and consumption of tef grain are matters of national policy, since food insecurity remains a serious problem. Tef is now considered a luxury cereal and its consumption is mostly done by urban dwellers, as most rural people are unable to afford tef and rely mostly on less expensive grains to make their injera. The Ethiopian government banned the export of tef grain (but not of injera) in 2006. Demands for tef grain by African diasporas, health conscious and gluten intolerant individuals in industrialised countries have led to an increased production of tef internationally. Though there is hardly any literature on the use of tef grain as a feed for livestock, its valuable nutrient composition could make it useful in animal production (Heuzé *et al.,* 2017).

In addition to its merits in farming, the sustained cultivation of teff is also prompted by its relative merits in terms of its use over other crops. These major relative merits include the following: First, the grains of teff give the best quality and most consumer-preferred injera (traditional fermented Ethiopian pancake) in terms of water-holding capacity, long shelf-life, unique flavor (slightly sour but pleasant), pliability, and smooth and glossy texture. Second, the grains yield high returns in flour upon milling of 99 percent, compared to 60–80 percent from wheat (Ebba 1969). In other words, if 100 kilograms of wheat are used for milling, the usable flour yield is 60–80 percent and the rest is bran, while 100 kilograms of teff gives 99 percent flour yield. Upon baking, teff flour produces a large amount of injera due to its high water-holding capacity. Third, teff entails minimal postharvest losses and high storage longevity of the grains even under traditional storage conditions. Fourth, the straw is important mainly as fodder for cattle and as a binder of mud used for plastering walls of local houses. Fifth, teff offers cash crop value for farmers owing to the high market prices of both the grains and the straw (Kebebew and Solomon, 2018). The most common utilization of teff in Ethiopia is the fermented flatbread called injera. Injera mixed with other flour such as wheat or sorghum is considered inferior. Other utilizations of teff include local alcoholic beverages called *tela* and *katikala*, and porridge. Additionally, teff plant residues could be used as fodder for

livestock, and often incorporated as construction materials. Various teff-based products are developed to capture the premium market in the form of bread, porridge, muffin, biscuit, cake, casserole and pudding. The crops' potential is also explored as a thickener for soup, stew, gravy and baby food **(**Lee, 2018). Tef is a superior cereal grain crop simply produced and is considered as the noble grain of Ethiopia. The crop is also a highly valued primarily grown for its grain that is used for making "injera". Injera is a fermented pancake made from tef flour and is a sour flatbread used in Ethiopian and Eritrean cuisine that is thicker than a crepe but thinner than a pancake and has a delightfully sour taste. In Ethiopian and Eritrean cuisines, vegetable, lentil, or meat dishes are served on top of the injera, and the food is eaten with your hands, using the injera to scoop up the food (Teshome and Tesfu, 2022). Teff can be used in cooking in the same way as millet or quinoa, but cooks faster because the seeds are much smaller. It is extremely versatile in the kitchen, with uses ranging from grain salad, porridge and cereals to snack bars. It has a nutty, grainy taste and adds texture to dishes. It can be boiled like rice, quinoa and other grains by adding a 1:3 ratio of teff grain to boiling water. Teff can also be steamed. Its flour is used in baked goods and is especially popular for use in gluten- free bread, pancakes and other baked goods. In Ethiopian cooking, it is traditionally used to make *injera*, a sourdough flatbread (Agriorbit, 2022).

Teff is predominantly produced as a staple food for local consumption and an important cash crop for farm households. The grain is grounded into flour to make a pancake-like local bread called injera. It is also appreciated as a fodder crop, with nutritious straw preferentially given to cows used for traction. Moreover, its straw is the preferred binding material for walls, bricks and household containers made of clay (Dipartimenti, 2023). Teff is a multipurpose crop which has a high importance for the Ethiopian diet and culture. In Ethiopia, teff provides two-thirds of the daily protein intake. It is not only important for human nutrition, but also as fodder for livestock, or as building material. Teff is the main ingredient to prepare injera, a sourdough-risen flatbread. During meals, it is often eaten with meat or ground pulses. Sometimes it is also eaten as porridge. Moreover, teff can be used to prepare alcoholic drinks, called *arak'e* or *katikalla* or beer, called *t'ella* or *fersso*. Finally, due to its high mineral content, teff is also mixed with soybeans, chickpeas or other grains to manufacture baby foods. According to a study in Ethiopia, farmers indicated a preference among consumers for white teff over darker colored varieties. As a nutritious fodder, teff is used to feed ruminants in Ethiopia and horses in the United States. It is a source of animal feed, especially during the dry season, and it is often preferred over straw from other cereals. Teff grass can be used as a construction material when mixed with mud to plaster the walls of local grain storage facilities (Wikipedia, 2023).

Teff flour is used extensively in Ethiopia to make *injera*, a soft flatbread prepared from slightly fermented batter, and the grains are also used in stews and porridges. In some places the plant is also grown as a forage or hay crop, and the stalks are commonly fed to livestock postharvest (Petruzzello, 2023). In Ethiopia, teff is usually ground into flour and fermented to make the spongy, sourdough bread known as *injera*. As anyone knows who has eaten at an Ethiopian restaurant anywhere in the world, *injera* is used as an edible serving plate. Food is piled on a large round of *injera* on a tray in the middle of the table and different foods are served directly onto the *injera*. The diners eat by tearing off bits of *injera*, and rolling the food inside. Ethiopians also use teff to make porridge and for alcoholic beverages, including *tella* and *katikala*. Today, teff is moving way beyond its traditional uses. It's an ingredient in pancakes, snacks, breads, cereals and many other products, especially those created for the gluten-free market. You can also buy teff wraps. White or ivory teff has the mildest flavor, with darker varities having an earthier taste. Those who have only tasted teff in injera assume it has a sour taste, but when it is not fermented (made into a sourdough), teff has a sweet and light flavor (WGC, 2023). Teff is the staple grain for the majority of Ethiopians and Eritreans. Teff provides around ⅔ of the daily protein intake in Ethiopia. Teff is eaten in a variety of ways, but the most common is injera, a sourdough flatbread made of teff flour. Injera is eaten at most meals, used to scoop up vegetables, meat, and legume dishes and curries. Teff can also be eaten as a porridge or fermented into beer and other alcoholic drinks (Mann, 2023).

The word teff comes from *teffa*, the Amharic word for "lost", due to its tiny seed that is easily blown away in the harvest and threshing process. In the early 2000s, the Ethiopian government banned the export of raw, unprocessed grain and flour to keep teff affordable at home. Ethiopian teff still made it around the world, in the form of injera, enabling processing and manufacturing jobs to stay in Ethiopia. In the early 2000s, members of the Ethiopian diaspora living abroad, those who left Ethiopia during the famine and conflicts of the 1980s, were the main consumers of exported teff products. Teff farming popped up in Australia, the U.S., China, India, and South Africa in use as cattle feed and to provide the grain for the diaspora community and a growing consumer base. Slowly, teff gained prominence as a nutritional powerhouse beyond the diaspora community and the Ethiopian government implemented an agricultural development program that increased teff production by 40% through efficiency measures, mechanization, and increased research (Mann, 2023). Teff is a versatile crop of great importance to the Ethiopian diet and culture. In Ethiopia, Teff makes up two-thirds of his daily protein intake. It is important not only for human nutrition, but also for livestock feed and as a building material. Teff is the main ingredient for making injera, a sourdough-leavened flatbread. It is often eaten with meat or legumes. It is sometimes eaten as porridge. In addition, teff can also be used to make an alcoholic drink called Arake or Catikala and a beer called Terra or Ferusso. Finally, due to its high mineral content, teff is sometimes mixed with soybeans, chickpeas, or other grains to produce baby food. Studies in Ethiopia show that farmers prefer white teff over darker varieties among consumers. Teff is used as a nutritious fodder, in Ethiopia as ruminant feed and in the United States as horse feed. It is a source of animal feed, especially during the dry season, and is often preferred over other cereal straws. Tefgrass can be mixed with mud and used as plaster on the walls of local grain storage facilities and can be used as a construction material (Academic, 2023).

Ethiopians primarily use teff to make their national dish known as ''injera''. Injera is a type of sourdough-risen flatbread which looks like a flat pancake with a unique sponge-like texture. Traditionally it is eaten with a range of different toppings such as stews, salads or sauces. However, like a pancake, there are a great number of ways and possible toppings to eat injera with. Now that cultures all over the world are coming into contact with this traditional Ethiopian and Eritrean meal, the possibilities are practically endless. Some of the derivated food our customers have created so far include bread, cookies, pancakes, breakfast products (such as cereal), snack crackers, ready-made baking mixes, porridge and much more (Milletsplace, 2023). Teff is grown predominantly as a cereal crop in Ethiopia. The grain can be used to make flour or porridge or can be fermented and made into type of flatbread called *injera*, which is eaten widely in Ethiopia. Grain can also be used to brew alcoholic beverages or grown as a forage for livestock or for use in building construction. As the grain lacks gluten, it can be used to produce gluten-free specialty products for people with allergies to gluten (Plantvillage, 2023). The teff plant produces grain for human and animal nourishment. The grain is ground into flour and used to make the flat bread injera or enjera. Injera resembles a soggy pancake, and its detractors, among them a British diplomat in the 19th century, think the flavor sour. This perception may derive from the fact that the fermentation of teff produces sourness. Others are much more enthusiastic, deeming the flavor akin to molasses, though not as sweet. Much depends on the grain sampled. Light-colored grain yields a comparatively bland flavor, one akin to chestnut. Darker grains are more robust in flavor, tasting like hazelnuts. Despite its blandness, light- colored grain fetches the higher price, and throughout history the elites ate it, relegating dark grains to commoners. Teff is also eaten as porridge or fermented into alcohol. Some recipes substitute teff for sesame seeds. Because teff grains are so small, one cup of them substitutes for two cups of sesame seeds. Cooks and bakers add teff to pudding, pie, soup, stew, gravy, biscuits, cookies, cake, stir-fry

preparations, casseroles, and pancakes that are apparently different from injera. Teff may be combined with herbs, seeds, or other crops, beans, tofu, garlic, and onion to make a meatless teff burger. Sprouts a few days old may be added to salad and sandwiches. Uncooked seeds should be kept in a cool, dry, dark place. Once cooked teff may be refrigerated, though it should be eaten in a few days. Ethiopians eat teff as often as thrice daily and may rely on it for two-thirds of their protein. Injera is a food of the well-to-do. The poor usually cannot afford it. Because teff grains are so small they are mostly bran and germ, the structures packed with nutrients. Beyond its value in human sustenance, teff has for centuries fed livestock, which relish both seeds and straw. Ethiopians rank teff straw above the straw of other grains in feed value. South Africans prefer teff straw for cattle, sheep, and horses. Teff is a livestock feed elsewhere in Africa, India, and South America (Cumo, 2023).

Teff is grown as a cereal crop primarily in Ethiopia. The grain is ground into flour, fermented and made into Injera, a sourdough-type flat bread. Teff can also be eaten as porridge or used for home-brewed alcoholic drinks. Teff straw from threshed grain is considered to be excellent forage, superior to straw from other cereal grains. The straw is also utilized to reinforce mud or plaster in the construction of buildings. Teff can serve as a temporary ground cover and a non-weedy, annual grass for erosion control (Echocommunity, 2023). Teff has as much or more food value than the major grains of wheat, barley and maize. This is probably because being a small grain; it is normally used in the whole grain form, which retains the germ and bran covering. Teff flour contains little or no gluten therefore it cannot be used alone in baked products that require rising as in yeast breads. The most popular use of Teff is in the making of Injera, a sourdough type of flat bread. It is recommended as a good thickener for soups, stews, and gravies, and its mild, molasses-like sweetness makes Teff easy to include in porridge, pancakes, biscuits, cakes, stir fry dishes and soups. Persons with severe allergies to wheat gluten should try to useTeff as it contains no gluten, or at least none of the type found in wheat (Echocommunity, 2023). Products developed from teff is given in **Fig.9.**

		
Flour	**Flour**	**Flour**
		
Flakes	**Injera**	**Injera**
		
Injera	**Injera**	**Roll of Injera**
		
Teff Soup	**Teff Kheer Porridge**	**Teff porridge**

Fig. 9 . Products developed from Teff

NUTRITIONAL VALUE

The amino acid composition of tef is excellent, its lysine content is higher than that of all cereals except rice and oats, it has good mineral content and its straw is nutritious. The fractional composition of the protein in tef indicated that glutelins and albumins were the major protein storage components and their order of fractional importance was: glutelins 44.55% > albumins 36.6% > prolamin 11.8% > globulins 6.7%. In tef seed the distribution of protein, percentage of ash and mineral elements is higher in the pericarp than in the endosperm. Tef is reported to have a higher iron content. However, they confirmed that tef has a relatively high iron content owing to its contaminants, which peak during threshing on the ground. It was reported that non-tef consumers have a lower level of haemoglobin, and hookworm anaemia develops in non-tef eaters if they are infested with hookworm. On the other hand, since tef eatershave higher levels of haemoglobin in their blood, they do not suffer from hookworm anaemia even when infested. In addition, according to the same study, malaria is frequently 'found in the groups with lower haemoglobin levels. Moreover, consuming tef is reported to prevent the anaemia related to pregnancy. Tef contains more calcium, copper, zinc, aluminium and barium than winter wheat, barley and sorghum (Ketema, 1997). Teff is well known by Ethiopians and Eritreans for its superior nutritional quality. It contains 11% protein, 80% complex carbohydrate and 3% fat. It is an excellent source of essential amino acids, especially lysine, the amino acid that is most often deficient in grain foods. Teff contains more lysine than barley, millet, and wheat and slightly less than rice or oats. Teff is also an excellent source of fiber and iron, and has many times the amount of calcium, potassium and other essential minerals found in an equal amount of other grains. When teff is used to make engera, a short fermentation process allows the yeast to generate more vitamins. Teff is nearly gluten-free, and is gaining popularity in the whole food and Health food industry in the U.S. as an alternative grain for persons with gluten sensitivity. Teff may also have applications for persons with Celiac Disease (Piccinin, 2010). For a food to be a staple in any part of the globe, it must be sufficient to sustain life. Teff is such a food, having very high calcium content, complete proteins (all eight essential amino acids), carbohydrates and other minerals such as phosphorous, magnesium, iron and zinc. It is also a rich source of dietary fiber. Unlike regular grains, it also has vitamin C. Something that will especially endear it to many is that it is totally lacking in the protein gliadin, making it gluten-free and suitable for celiac sufferers. It has been receiving worldwide attention not only for its benefits to humans but also as a nutrient-rich foraging crop for livestock. Locals even use the straw, mixed with mud, for building purposes (Amare, 2014).

Nutritionally, 100 g of teff grains have 357 kcal, similar to that of wheat and rice. Yet, its grains are comparably rich in iron, calcium, and fiber. Teff with 11% of protein is an excellent source of essential amino acids, especially lysine: the amino acid that is most often deficient in grains. Teff grains are low on the glycemic index, which makes them suitable for people with Type 2 diabetes. The grains are also gluten-free. This, in particular, attracts individuals who suffer from gluten intolerance or celiac disease; a study of 1,800 people with celiac disease reports that regular consumption of teff significantly reduced their symptoms. With an increasing number of health-conscious consumers across the world, teff has started generating a similar phenomenon with quinoa, the nutritious grains native to South America for global prominence (Lee, 2018). Teff is a very nutritious cereal grain. Its nutritional content is generally comparable to that of the major world cereals like wheat, barley, rice, maize, and sorghum. In fact, teff is superior in many aspects, particularly in such minerals as iron, calcium, magnesium, and zinc. In recent years teff has become popular as a health and performance food in the global market. Since the grains are gluten-free, it is useful as food for humans suffering from the gluten protein allergy ailment known as celiac disease. Its low glycemic index characterized by slow-release-type starches make it particularly suitable for diabetic people. Moreover, its high iron content is associated with the low prevalence of hook worm and pregnancy-related anemia in people consuming teff as a staple food. Details on the nutritional aspects of teff are gtven in **Table 5** (Kebebew and Solomon, 2018).

Table 5. Nutritional composition (%) of teff grains compared with other major world cereals

Nutritional item	Teff	Wheat	Rice	Maize	Sorghum	Barley
Protein	11.0	11.0	9.7	9.4	8.6	8.5
Fat	2.6	1.9	1.6	4.4	3.8	1.5
Fiber	3.5	1.9	5.8	2.2	1.9	4.5
Carbohydrates	73.0	69.3	64.7	69.2	71.3	67.4
Mineral ash	3.0	1.7	5.0	1.3	2.4	2.6

Food products of teff are rich in crude fiber as the whole grain flour of the crop incorporates the bran of the grain. The grain of the crop provides relatively higher protein content with an excellent balance and a complete set of essential amino acids. The grain is also high in iron content and other minerals such as calcium, copper, and zinc compared to other cereal grains consumed as whole grain flours such as wheat, maize, barley, and sorghum. It was also recently proven to be a significant source of bioactive compounds including polyphenols, especially very rich in flavonoid derivatives which are rare in the other common grains (Gebru *et al*., 2020). Different teff varieties have different mineral concentrations. Red teff has a higher content of iron and calcium than mixed or white teff varieties, and in contrast, white teff has a higher copper content than the red and mixed teff varieties (Merchuk-Ovnat *et al.,* 2020).

Teff has been the secret of strength behind athletic endurance, stamina and successes owing to its dense amino acid content lysine which is mostly lacking in other cereals. It is a gluten-free grain packed with amino acids, essential fatty acids, dietary fibre and phytochemicals. Teff is bestowed with a high protein profile and well-balanced set of eight essential amino acids, which is valued as an endurance building food. It is mainly high in lysine, an amino acid that is often lacking in other grains, that supports hormones, enzymes, and collagen and elastin production and also promotes energy production and immune function. Being intrinsically rich in iron, copper, calcium and zinc fortifies bones, pump up iron stores, regulates diabetes, and prevents cancer. It is a perfect grain for those suffering from celiac disease and other digestive disorders. Furthermore, studies also reveal that teff is an abundant source of polyphenol compounds flavonoids, which are not found in other common cereals (Binu, 2021). 100 g teff grains contain 11.0 per cent protein, 2.5 per cent fat, 70.2 per cent carbohydrate, 3.0 per cent fiber, 10.5 per cent moisture, 2.8 per cent ash, calcium (165.2 mg), iron (15.7 mg), copper (2.6 mg), magnesium (181.0 mg), manganese (3.8 mg), phosphorous (425.4 mg), potassium (380.0 mg), sodium (15.9 mg), potassium (380.0 mg) and sodium (15.9 mg (4.8 mg). Teff is gluten-free and can be used to avoid celiac disease when used as a substitute for wheat. It has a higher nutritional content than other cereal grains, containing all necessary amino acid composition, notably lysine and greater mineral content (mostly iron, calcium, phosphorus and copper). It is high in fiber and includes the B1 vitamin. Teff is richer in lysine than most other cereals and can reduce iron deficiency which causes anaemia diseases. It also has a complete set of essential amino acids with excellent composition (Sridhara *et al*., 2021).

According to the South African National Research Foundation (NRF), teff is high in dietary fibre, iron, protein and calcium. A 100g serving of teff contains 336kcal, 58,9g iron, 10,5g protein, 73,1g carbohydrates, 157g calcium, 3,1g ash, 3,1g fibre, 2,7g fat and 366g phosphorus. Furthermore, its popularity also stems from the fact that teff is a gluten-free grain that can be used to replace wheat. It can be enjoyed as a wholegrain or in various baking goods as flour (Agriorbit, 2022). Tef is highly nutritious crop riched with different minerals, carbohydrates and vitamins and the eight Essential Amino Acids (isoleucine, leucine, methionine, lysine, phenylalanine, threonine, tryptophan and valine). The protein digestibility is high because the main protein fractions are the most digestible types, and the absence of gluten makes it an alternative food for people suffering from celiac disease (Teshome and Tesfu, 2022).

Nutritional value of 100 g cooked teff is given in **Table 6** (Wikipedia, 2023).

Table 6. Nutritional value per 100 g of cooked teff grains

Energy	422 kJ (101 kcal)
Carbohydrates	19.86 g
Dietary fiber	2.8 g
Fat	0.65 g
Protein	3.87 g
Vitamins	Quantity %DV†
Thiamine (B1)	16% 0.183 mg
Riboflavin (B2)	3% 0.033 mg
Niacin (B3)	6% 0.909 mg
Vitamin B6	7% 0.097 mg
Folate (B9)	5% 18 µg
Minerals	Quantity %DV†
Calcium	5% 49 mg
Iron	16% 2.05 mg
Magnesium	14% 50 mg
Manganese	136% 2.86 mg
Phosphorus	17% 120 mg
Potassium	2% 107 mg
Sodium	1% 8 mg
Zinc	12% 1.11 mg
Other constituents	Quantity
Water	74.93 g

The grains have a mild, nutty flavour and are a good source of dietary fibre and protein and are high in magnesium, calcium, and other minerals. Teff has increased in popularity as a gluten-free health food in developed countries and has potential as an alternative food crop (Petruzzello, 2023). Teff is a good source of iron, vitamin B1, manganese, magnesium, phosphorus, and zinc. Teff contains concentrations of all 18 essential amino acids, making it a complete protein. Cooked teff contains a 1:5 ratio of protein to carbohydrates. Teff's fiber content beats that of most other cereals. The small grain of teff size allows it to cook quickly, saving fuel resources (Mann, 2023). Teff contains a higher amount of essential amino acids, including lysine. The total seed average protein content range from 8 to 11%, slightly higher than sorghum, maize or oats, but lower than wheat. (Dipartimenti, 2023) .

Nutritional value of 100 g of uncooked teff grains is given in **Table 7** (Wikipedia, 2023).

Table 7. Nutritional value of 100 g of uncooked teff grains

Energy	1,536 kJ (367 kcal)
Carbohydrates	73.13 g
Dietary fiber	8.0 g
Fat	2.38 g
Protein	13.30 g
Vitamins	Quantity %DV†
Thiamine (B1)	34% 0.390 mg
Riboflavin (B2)	23% 0.270 mg
Niacin (B3)	22% 03.363 mg
Vitamin B6	37% 0.482 mg
Minerals	Quantity %DV†
Calcium	18% 180 mg
Iron	59% 7.63 mg
Magnesium	52% 184 mg
Phosphorus	61% 429 mg
Potassium	9% 427 mg
Sodium	1% 12 mg
Zinc	38% 3.63 mg
Other constituents	Quantity
Water	8.82g

Uncooked teff is 9% water, 73% carbohydrates, 13% protein, and 2% fat. Cooked teff is 75% water, 20% carbohydrates, 4% protein, and less than 1% fat. A 100-gram (3+1⁄2-ounce) reference serving of cooked teff provides 420 kilojoules (101 kilocalories) of food energy, is a rich source of protein, dietary fiber, and manganese, and contains moderate amounts of thiamin, phosphorus, iron, magnesium, and zinc **(Table).** The fiber content in teff is also higher than in most other cereals. While teff is gluten free, a method has been developed to process teff into a flour with a wider range of baking applications, such as for bread and pasta (Wikipedia, 2023).

Uncooked teff is 9% water, 73% carbohydrates, 13% protein and 2% fat. Cooked teff is composed of 75% water, 20% carbohydrates, 4% protein and less than 1% fat. A reference serving of 100 grams of cooked teff provides 101 kilocalories of dietary energy, is a rich source of protein, dietary fiber and manganese, and contains moderate amounts of thiamine and phosphorus, iron, magnesium, zinc. The fiber content in teff is also

higher than most other cereals. Although teff is gluten-free, methods have been developed to process teff into flour suitable for a wider range of baking applications, such as bread and pasta (Academic, 2023). Apart from being gluten-free, teff is known as a very healthy grain. It is rich in minerals (such as iron and calcium) and vitamins (such as B1, B3, B6 and B9) as well as protein, carbohydrates and fiber. The carbohydrates in teff are complex, slow-processed carbohydrates, meaning that they get broken down by the body at a slower rate than other grains so you feel satisfied for a longer time. Teff is a great source of nutrition for everyone, especially physically activate people. Famous Ehtiopian athletes Haile Gebrselassie and Kenenisa Bekele name teff as the main source of their success (Milletsplace, 2023). Nutritionists value teff, which has all eight essential amino acids and is 9.6 percent protein. Teff has more of the amino acid lysine than do wheat and barley but less than rice and oats. Having little gluten, teff is ideal for people allergic to it. In addition to protein, 100 grams of teff have 11 grams of water, 336 calories, 73 grams of carbohydrates, 2 grams of fat, 0.3 milligram of thiamine, 0.18 milligram of riboflavin, 2.5 milligrams of niacin, and 88 milligrams of vitamin C. Minerals include 159 milligrams of calcium, 13 milligrams of chlorine, 0.7 milligram of copper, 5.8 milligrams of iron, 170 milligrams of magnesium, 6.4 milligrams of manganese, 378 milligrams of phosphorus, 401 milligrams of potassium, 47 milligrams of sodium, and 2 milligrams of zinc (Cumo, 2023).

Samples tested have shown protein levels between 14-15%. The iron (11-33 mg) and calcium (100-150 mg) contents are also higher than most grains. The relative absence of anemia in Ethiopia is presumed to be due to the grain's high content of iron (Echocommunity, 2023). Teff has a high concentration of different nutrients. This grain has a very high calcium content, and contains high levels of phosphorus, iron, copper, aluminum, barium, and thiamin. A big advantage is the fact that the iron from teff is easily absorbed by the body. It could be used for top sports because of this. Teff is high in protein. It is considered to have an excellent amino acid composition (including all 8 essential amino acids for humans) and has lysine levels higher than wheat or barley. Because of this variety, it stimulates the flora of the large intestine. Teff is high in carbohydrates and fiber. It contains no gluten, so it is appropriate for those with gluten intolerance or Celiac disease **(**Academickids, 2023**).**

Teff Flour Nutrition: Because teff grains are so small, it's hard to remove the bran and germ during milling. Because of this, teff flour is almost always whole grain flour. Teff's nutritional content can be different, depending on the variety we use.

Protein: Whole grain teff is 11% protein. This is similar to wheat, maize, barley, and pearl millet. The protein in whole grain teff is higher than rye, sorghum, and brown rice.

Amino acids: Since teff is high in protein, it has lots of essential amino acids. Protein and amino acids are important as the building blocks of your tissues. It's specifically high in lysine, which is low in other grains. Your body can't make lysine, so you must get it from foods. Lysine helps your body convert energy, lowers cholesterol, forms collagen, and may help your body absorb calcium.

Fiber: Teff is higher in fiber than other grains. This is because the bran and the germ are usually intact. Getting lots of fiber can help prevent chronic diseases like heart disease, bowel disease, kidney disease, and type 2 diabetes.

Minerals: Teff has more calcium and iron than most grains. There are conflicting reports about how much iron it has, but 100 grams of teff bread has about 3.3mg of iron. This is 45% of your daily recommended iron intake.

HEALTH BENEFITS

Health Benefits of teff grains (Binu, 2021). Gluten-free grain: Gluten is a type of protein found in wheat and other grains that gives an elastic texture to the dough. However, people with celiac disease cannot consume gluten, as the body's immune system attack the lining of their intestine. This can lead to impairment of nutrient absorption leading to anaemia, weight loss, diarrhoea, constipation and bloating. Teff flour is naturally gluten-free and it's an excellent alternative to wheat flour.

High on dietary fibre: Teff is high in crude dietary fibre than most other grains that packs 12.2 grams of dietary fibre per 100 grams. It contains both soluble and insoluble fibre, where insoluble fibre adds bulk to stool, regularise bowel movements and prevents constipation. While soluble fibre softens stools, feeds gut bacteria and promotes carbohydrate and fat metabolism. A diet high in fibre is linked with a lower risk of diabetes, cardiovascular disease, hypertension and other digestive problems.

Boost iron stores: Teff is loaded with immense volumes of iron, an essential mineral that supplies oxygen and nutrients to all the cells in the body. Adding this grain as a part of a diet regimen is known to decreased rates of anaemia in pregnant women and also helps others with iron-deficiency anaemia to improve their iron stores.

Promotes growth: Teff is blessed with eight essential amino acids, including lysine that can deliver potential support for normal growth and development. It holds a significant role in the regeneration of new cell, tissue repair, and development of muscle mass. It is a must-to-have cereal for vegetarians that helps to meet their protein demands.

Manages diabetes: Teff helps to control blood sugar spikes because of its low glycaemic index and high fibre content. It is loaded with resistant starch that delays the gastric emptying time, keep you satiated, control unwanted hunger pangs, shed extra kilos and effectively regulate blood glucose levels.

Health Benefits of teff flour (Binu, 2021). Gut health: Teff is naturally gluten-free. One of the common problems with gluten-free foods is that they're often missing vitamins, minerals, and nutrients. Since teff is packed with nutrients, this might be a safe and more nutritious option to add to your diet. Teff is high in dietary fiber, with high levels of insoluble fiber in particular. This type of fiber stays mostly undigested in your gut. This causes your stool to bulk up and can help with regular bowel movements. The insoluble fiber in teff can feed the bacteria in your gut. This is called a prebiotic. A healthy balance of gut bacteria is important for good health.

Higher iron levels: Iron helps carry oxygen throughout your body and it is an essential mineral. Eating teff can help you get enough iron and avoid iron deficiency. In one study, eating teff helped pregnant women avoid low iron levels. Another study showed exercising women had better iron levels from eating teff.

Health risks of teff flour: While teff has lots of good nutrients, it also has a lot of phytic acid. This is a plant chemical that can bind to its nutrients and stop you from absorbing them. Fermenting teff can help lower some of the phytic acid.

Teff with a grainy texture adds a great crunch to any dish and cooks much faster than most grains. This versatile nature of the flour can be used in making several dishes such as roti, dosa, bread, pancakes, cookies, muffins and cakes. It is easy to add grain to any diet. Teff is indeed a superfood that has to be included in a balanced diet regimen to reap its wellness incent (Binu, 2021). Iron deficiency anemia is the most common type of anemia, affecting millions of people around the world by causing extreme fatigue and other health issues. Consumption of teff can be used to prevent iron deficiencies, especially for those with diets low in red meat (Mann, 2023).

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