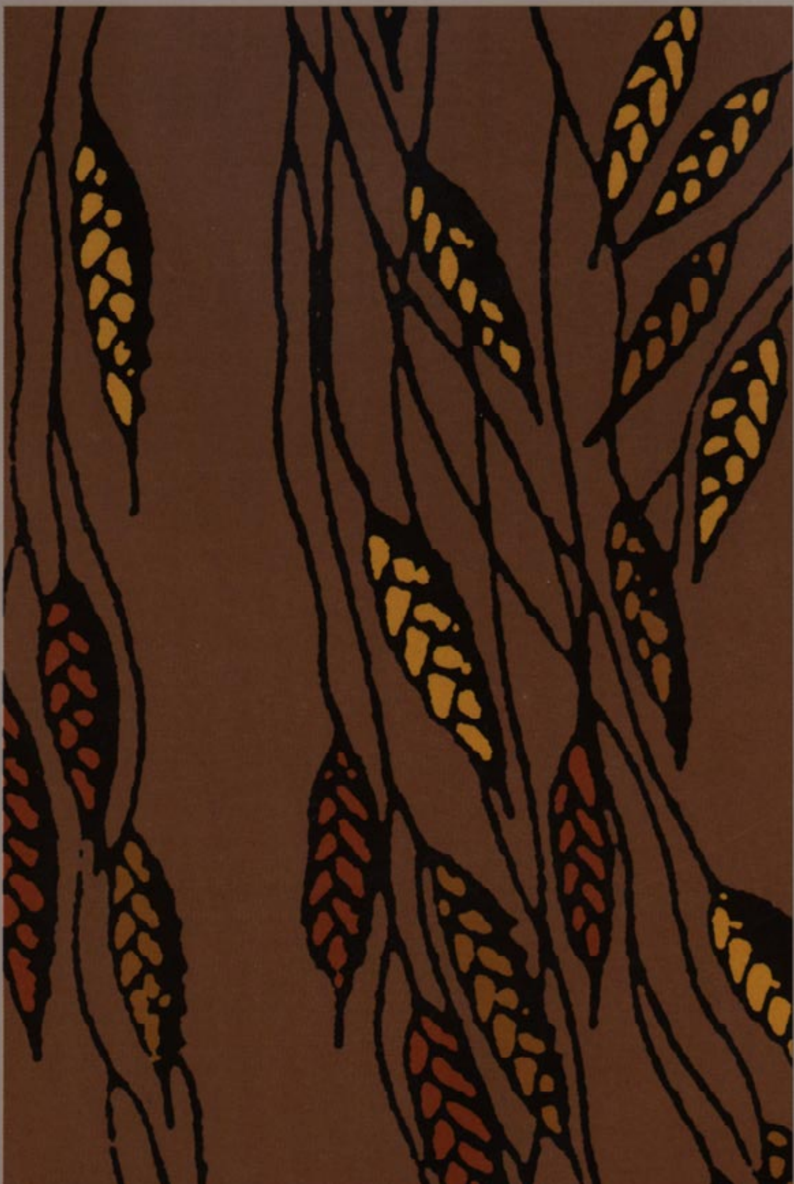
Promoting the conservation and use of underutilized and neglected crops. 12.

Tef

Eragrostis tef (Zucc.) Trotter



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International Plant Genetic Resources Institute IPGRI

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Biodiversity Institute
Addis Abeba, Ethiopia

International Plant Genetic Resources Institute
IPGRI

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Contents

Foreword

Humanity relies on a diverse range of cultivated species; at least 6000 such species are used for a variety of purposes. It is often stated that only a few staple crops produce the majority of the food supply. This might be correct but the important contribution of many minor species should not be underestimated. Agricultural research has traditionally focused on these staples, while relatively little attention has been given to minor (or underutilized or neglected) crops,, particularly by scientists in developed countries. Such crops have, therefore, generally failed to attract significant research funding. Unlike most staples, many of these neglected species are adapted to various marginal growing conditions such as those of the Andean and Himalayan highlands, arid areas, salt-affected soils, etc. Furthermore, many crops considered neglected at a global level are staples at a national or regional level (e.g. tef, fonio, Andean roots and tubers, etc.), contribute considerably to food supply in certain periods (e.g. indigenous fruit trees) or are important for a nutritionally well-balanced diet (e.g. indigenous vegetables). The limited information available on many important and frequently basic aspects of neglected and underutilized crops hinders their development and their sustainable conservation. One major factor hampering this development is that the information available on germplasm is scattered and not readily accessible, i.e. only found in 'grey literature' or written in little-known languages. Moreover, existing knowledge on the genetic potential of neglected crops is limited. This has resulted, frequently, in uncoordinated research efforts for most neglected crops, as well as in inefficient approaches to the conservation of these genetic resources.

This series of monographs intends to draw attention to a number of species which have been neglected in a varying degree by researchers or have been underutilized economically It is hoped that the information compiled will contribute to: (1) identifying constraints in and possible solutions to the use of the crops, (2) identifying possible untapped genetic diversity for breeding and crop improvement programmes and (3) detecting existing gaps in available conservation and use approaches. This series intends to contribute to improvement of the potential value of these crops through increased use of the available genetic diversity In addition, it is hoped that the monographs in the series will form a valuable reference source for all those scientists involved in conservation, research, improvement and promotion of these crops.

This series is the result of a joint project between the International Plant Genetic Resources Institute (IPGRI) and the Institute of Plant Genetics and Crop Plant Research (IPK). Financial support provided by the Federal Ministry of Economic Cooperation and Development (BMZ) of Germany through the German Agency for Technical Cooperation (GTZ) is duly acknowledged.

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Seyfu Ketema
Addis Abeba, Ethiopia
4 October 1996

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Introduction

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.

Identifying, maintaining and using crop types that can grow under various stress and limiting conditions is essential. It is in this context that tef (*Eragrostis tef* (Zucc.) Trotter), a traditional crop that grows very well under various stress conditions and is extensively used in Ethiopia, but little known elsewhere, is the subject of this monograph.

Tef is an important cereal crop in Ethiopia. The area under tef cultivation is over one million hectares of land each year. During the 1994/95 cropping season tef occupied 32% of the cultivated land under cereals, while maize occupied 19%, sorghum 16%, barley 15%, wheat 13%, millet 4% and oats 1% (CSA 1995); this is similar to previous production years and clearly shows the importance of tef in Ethiopia.

Outside Ethiopia there is a growing interest in using tef. For example, small-scale commercial production of tef has begun in a few areas of the wheat belts of the USA, Canada and Australia. Tef has been introduced to South Africa and cultivated as a forage crop, and in recent years cultivated as a cereal crop in northern Kenya.

1 Names of the species and taxonomy

Tef *(Eragrostis tef* (Zucc.) Trotter) belongs to the family Poaceae, subfamily Eragrostoideae, tribe Eragrosteae and genus *Eragrostis.* The genus contains about 300 species (Costanza 1974).

Accepted synonyms of *Eragrostis tef* (Zucc.) Trotter, Bull. Soc. Bot. Ital. 1918 no. 4 (1919) 62, are presented below (Costanza 1974):

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.

The common vernacular name of the crop in Ethiopia is *tef.* It is also known by the vernacular names *tafi* in Oromigna and *taf* in Tigrigna.

According to Ponti (1978), “several wild species of *Eragrostis* are used in Africa today for food and other purposes. In West Africa, Dalziel(l937) notes the use of *E. cilianensis, E. pilosa, E. gangetica, E. ciliaris* and *E. tremula* as cereals, the first species regularly and the others in time of scarcity Gast *et al.* (1972) describe the importance of *E. pilosa* to nomads of the Central Sahara: these people harvest grains from plants growing on ants’ nests, and they even pillage the ants’ grain reserves within the nests. *E. pilosa* grains have apparently been harvested by tribes of the Eastern Sahara since the 12th century AD (Haudricourt 1941). Many species of *Eragrostis,* then, are obviously attractive food plants: they produce abundant seeds; they are free-threshing; and, above all, they are weeds, inhabiting land disturbed by human activity. The transition from gathering seeds of a selection of readily available weeds to encouraging and cultivating them seems an easy and logical process.”

During drought years when food scarcity prevails, *tefe tafo (Eragrostis tenella)* is collected and used for food in Ethiopia. According to Costanza (1974); Streetman (1963) stated: “Species of *Eragrostis* were first introduced into the United States in the early 1930s and several of these have been used extensively for reseeding the arid and semi-arid range lands of the southwest. The species of particular interest are *E. chloromelas* Steud., *E. curvula* (Schrad.) Nees, *E. lehmanniana* Nees and *E. superba* Peyr. Most of the lovegrasses are prolific seed producers, a characteristic almost indispensable for successful range revegetation. Their ability to green up earlier in the spring and remain green in the fall later than the common native grasses also enhances their usefulness.”

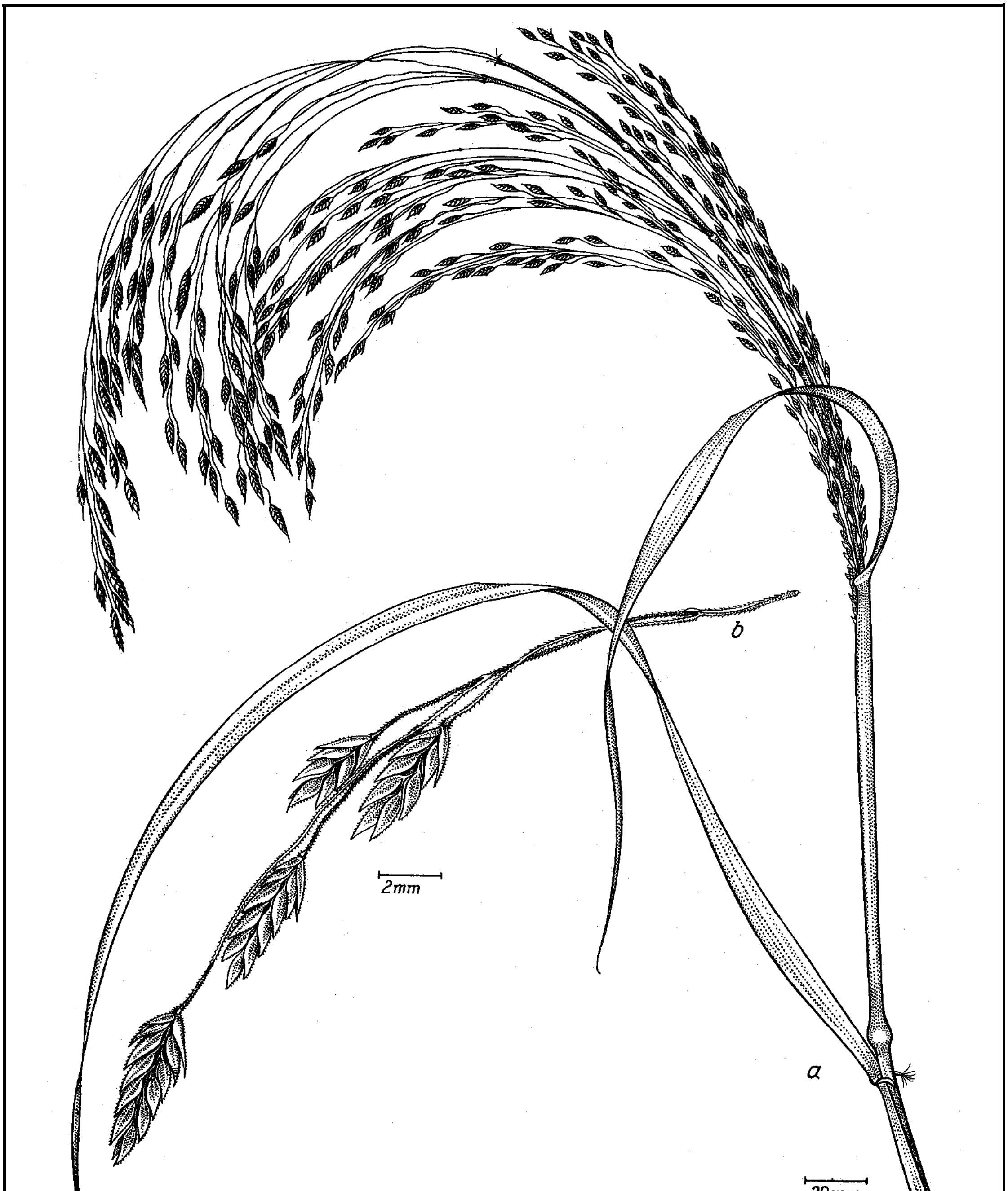


Fig. 1. *Eragrostis tef* (Zucc.) Trotter. (a) Inflorescence, (b) branch of panicle with floret. (drawing: R. Kilian in Schultze-Motel 1986, reprinted with permission of the Gustav Fischer Verlag, Jena).

2 Brief description of the crop

Tef is a C_4, 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 (Figs. 1 and 2). 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 (Tadesse 1975).

Tef is an allotetraploid plant with a chromosome number of $2n$ =40 and the basic chromosome number of the genus *Eragrostis* is x =10 (Tavassoli 1986). This is based on a genetic study that resulted in disomic inheritance patterns for different characters of tef (Tareke 1981) 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 (Tavassoli 1986). 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 (Tavassoli 1986).

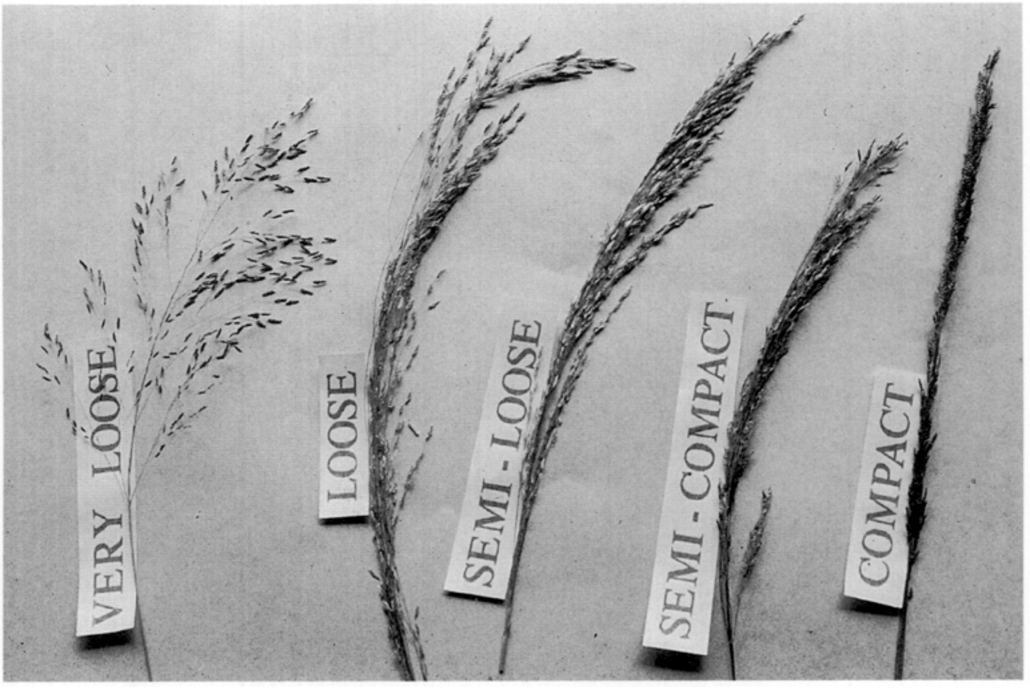


Fig. 2. Types of panicles(very loose, loose, semi-loose, semi-compact, compact).

Melak Hail and Guard (1966) studied the development of the embryo sac and embryo of tef. They reported that 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% (Kemal Ali, 1996, pers. comm.).

3 Origin and centre of diversity

Centre of diversity

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.

According to Ponti (1978) tef was introduced to Ethiopia well before the Semitic invasion of 1000 to 4000 BC. It was probably cultivated in Ethiopia even before the ancient introduction of emmer and barley According to Tadesse (1975) tef seeds found by Unger (1866) 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.

According to Costanza (1974), Haudricourt (1941) suggested that the word tef might have been derived from the Semitic *thaf* applied in Yemen to a wild harvested cereal. However, according to the same source, Porteres (1958) "listed definitions of 'thaf' given in an Arabic dictionary: 'Thaf' is a plant growing in Yemen, whose grains resemble those of red mustard which are eaten during famine. A bread made of Dourra flour." Among other things Porteres concluded the following:

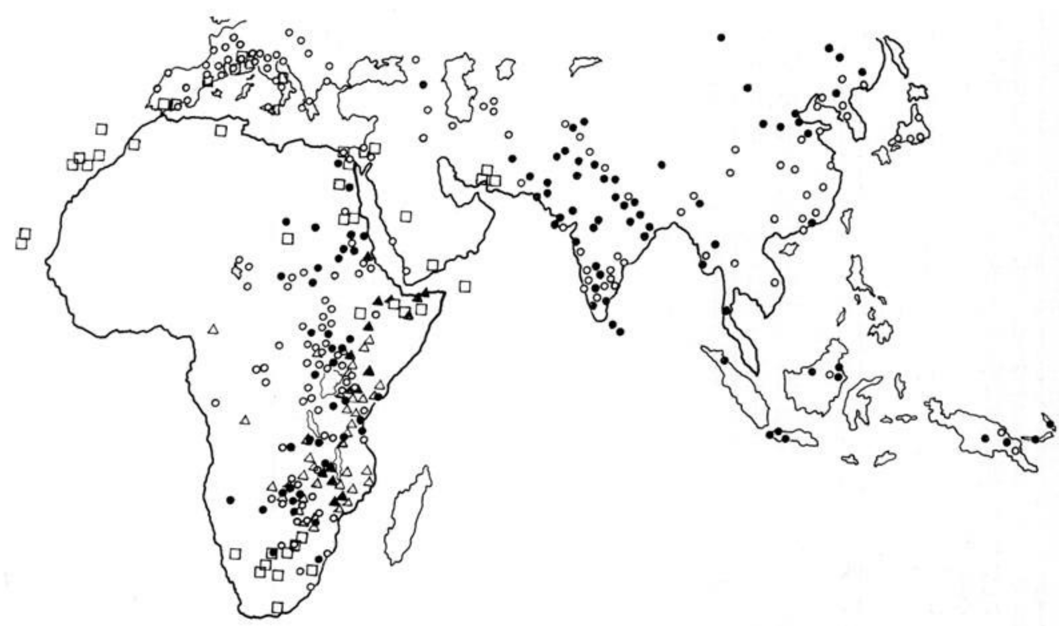
- The word tef does not seem to have been introduced into the Abyssinian plateau by the Semitic people who already used the supposed derivative *thaf*. Instead, tef might be from an Egypto-Cushitic base. Like the cereal, the name scarcely spread beyond northeastern Africa, the only centre known for the crop.
- The Abyssinian Semites probably borrowed the name from the populations they found on the plateau who were already cultivating tef, when they invaded them. If the Semites had started tef cultivation, one would expect to find evidence of its cultivation in central Asia and by the European Aryan people. It would be found across to the Indian Ocean in the mountain regions.
- No word in Indian languages, or in the languages of Arabia or in the Mesopotamian area, resembles tef in sound or in connoting nourishment.
- 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.

Distribution of the genus and some species related to tef

Within the genus *Eragrostis* 43% of the species seem 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 (Costanza 1974). Of the 54 *Eragrostis species* listed in Ethiopia, 14 (or 26%) are endemic (Cufodontis 1974).

The fact that several endemic and nonendemic species of *Eragrostis*, some of which are considered the wild relatives of tef, are found in Ethiopia and, in addition, the fact that the genetic diversity for tef exists nowhere in the world except in Ethiopia, indicates that tef originated and was domesticated in Ethiopia. Vavilov (1951) has identified Ethiopia as the centre of origin and diversity of tef.

In a study to trace the origin and domestication of tef and identify the species related to it, Ponti (1978) stated 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 Ponti made a survey of the collections of *E. pilosa, E. aethiopica, E. cilianensis, E. minor* and *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. 3). 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."



Glandular plants
● *E. pilosa*
▲ *E. aethiopica*

Eglandular plants
o *E. pilosa*
Δ *E. aethiopica*

Sparsely glandular Plants
□ *E. barrelieri*

Fig 3. Geographical distribution of *Eragrostis pilosa, E. aethiopica* and *E. barrelieri* determined from exsiccate in the herbarium of the Royal Botanic Gardens, Kew, UK (source: Ponti 1978, modified)

Wild relatives of tef

Tef is considered an allotetraploid crop (Tareke 1981; Tavassoli 1986). 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, as the ancestors and contributors to the origin of tef or as species closely related to tef:

- Species suggested as ancestors of tef (Costanza 1974) are *Eragrostis pilosa*, *E. macilenta*, *E. aethiopica*, *E. pseudo tef*, *E. longifolia* and *E. atrovirens.*
- Species suggested as contributors to the origin of tef (Endeshaw 1978) are *E. pilosa, E. curvula, E. aethiopica, E. cilianensis, E. mexicana* and *E. bicolor.*
- Species suggested as very closely related to tef (Ponti 1978) are *E. pilosa* and *E. aethiopica; E. mexicana, E. cilianensis, E. minor* and *E. barrelieri* sufficiently related; while *E. macilenta* and *E. aegyptica* are suspected to be close enough but need further investigation. Among perennials, *E. papposa, E. heteromera* and *E. bicolor* are more closely related to tef than others.
- Species suggested as closely related to tef based on cytological evidence (Tavassoli 1986) are *E. aethiopica 2x, E. pilosa 2x, E. mexicana 6x, E. barrelieri 6x, E. minor 2x, 4x* and *E. cilianensis 2x, 4x, 6x.*

Geographic distribution

Most of the Ethiopian farmers use traditional landraces of tef and these are distributed all over the country. Local cultivars such as Gea-Lamie, Dabi, Shewa-Gimira, Beten and Bunign, which are early maturing varieties (<85 days), are widely used in areas that have a short growing period due to low moisture stress or low temperature. The same varieties are also used in areas with adequate rainfall and where double cropping is practised. In the highly productive and major tef-producing regions of Gojam and Shewa, and in other regions where environmental stress is not severe, the local cultivars such as Alba, Ada and Enatit are used. Modem varieties are used in many regions but in very small areas within each region. In the regions of Gojam and Shewa, which are located in the central highlands of Ethiopia and are also the largest and major tef-production areas in the country modern varieties are used as well as traditional landraces and local cultivars. The most widely used modern varieties in these regions are:

- DZ-01-354, has very wide adaptation, a cream-white seed colour and high grain yield;
- DZ-01-196 is not as widely adapted and high yielding as DZ-01-354 but is very popular with farmers because of its very white seed colour which fetches the highest market price for its grain-quality in the country;
- DZ-01-787 has specific adaptation, cream-white seed colour, better tolerance to rust and high grain yield;
- DZ-Cross-37 has wide adaptation, cream-white seed colour, medium maturity (<90 days) and is suitable to areas having a short growing period. In the region of Welo, Tigray, many areas of the rift valley and other areas that suffer from low moisture stress, DZ-Cross-37 is used.

Tef has been introduced to different parts of the world through various institutions and individuals. The Royal Botanic Gardens, Kew, imported seed from Ethiopia in 1866 and distributed it to India, Australia, the USA and South Africa. According to Tadesse (1975), Burt Davy in 1916 introduced tef to California (USA), Malawi, Zaire, India, Sri Lanka, Australia, New Zealand and Argentina; Skyes in 1911 introduced it to Zimbabwe, Mozambique, Kenya, Uganda, Tanzania; Horuitz in 1940 to Palestine.

4 Properties

The composition of tef is similar to that of millet, although it contains generally higher amounts of the essential amino acids, including lysine, the most limiting amino acid (Jansen *et al.* 1962). 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 (Tables 1, 2 and 3). 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% (Mulugeta 1978). In tef seed the distribution of protein, percentage of ash and mineral elements is higher in the pericarp than in the endosperm (Mulugeta 1978).

According to Melak Hail (1966), compared with other cereals tef is reported to have a higher iron content. But Abraham *et al.* (1980) disagreed with Melak Hail's (1966) conclusions and reported that the iron content of tef is not more than that of other common cereals. However, they confirmed that tef has a relatively high iron content owing to its contaminants, which peak during threshing on the ground. According to Tadesse (1969), Molineaux and Biru (1965) 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 eaters have higher levels of haemoglobin in their blood, they do not suffer from hookworm

Table 1. Amino acid content of tef (g/16 g N) compared with other cereals, the FAO pattern and whole egg

Amino acid	Tef	Barley	Maize	Oats	Rice	Sorghum	Wheat	Pearl millet†	FAO Pattern‡	Whole eggs§
Lysine	3.68	3.46	2.67	3.71	3.79	2.02	2.08	2.89	4.2	6.6
Isoleucine	4.00	3.58	3.68	3.78	3.81	3.92	3.68	3.09	4.2	7.5
Leucine	8.53	6.67	12.5	7.26	8.22	13.3	7.04	7.29	4.8	9.4
Valine	5.46	5.04	4.85	5.10	5.50	5.01	4.13	4.49	4.2	7.2
Phenylalanine	5.69	5.14	4.88	5.00	5.15	4.90	4.86	3.46	2.8	5.8
Tyrosine	3.84	3.10	3.82	3.30	3.49	2.67	2.32	1.41	2.8	4.4
Tryptophan	1.30†	1.54	0.70	1.26	1.25	1.22	1.07	1.62	1.4	1.4
Threonine	4.32	3.31	3.60	3.31	3.90	3.02	2.69	2.50	2.8	4.2
Histidine	3.21	2.11	2.72	2.10	2.50	2.14	2.08	2.08	-	2.1
Arginine	5.15	4.72	4.19	6.29	8.26	3.07	3.54	3.48	-	6.9
Methionine	4.06	1.66	1.92	1.68	2.32	1.39	1.46	1.35	2.2	3.8
Cystine†	2.50							3.19	2	2.4

† Jansen et al. (1962).
‡ Amount of amino acid content considered adequate by FAO standards.
§ Alemayehu (1990).

Table 2. Chemical composition of tef seed compared with that of spring wheat, winter wheat, winter barley, and sorghum (Melak Hail 1966)

Chemical element	Purple tef	White tef	Spring wheat	Winter wheat	Winter barley	Sorghum
K (%)	0.36	0.20	0.37	.33	0.44	0.44
P (%)	0.44	0.46	0.51	0.40	0.48	0.52
Ca (%)	0.18	0.17	<0.1	<0.1	<0.1	<0.1
Mg (%)	0.18	0.19	0.15	0.12	0.13	0.18
Mn (ppm)	21.2	30	53	36	12	29
Fe (ppm)	196	115	78.5	40	35	66.5
B (ppm)	14	13	12	11.5	11	16.5
Cu (ppm)	53	36	20	11	14	23.5
Zn (ppm)	67	67.5	60	39.5	45	44
Al (ppm)	83	0.12	<0.1	<0.1	<0.1	<0.1%
Sr (ppm)	<0.1	<0.1	<0.1	<0:1	<0.1	<0.1%
Mo (ppm)	0.78	0.74	0.6	0.55	0.4	0.45
Co (ppm)	0.52	0.64	0.6	0.55	0.3	0.3
Na (ppm)	220	212.2	195	168.5	392	141.5
Ba (ppm)	19	23.5	7.5	6	7	<0.1
SiO_2 (%)	0.31	trace	trace	trace	trace	<0.1

Table 3. Yield and chemical composition of various crop residues on dry matter basis (Lulseged and Jamal 1989)

Crop residue	Yield (t/ha)	Composition [†]			
		DM	Ash	CP	NDF
Barley straw	10	92.6	8.4	4.7	71.5
Tef straw	5	92.6	8.4	5.2	72.6
Wheat straw	9	93.1	9.0	3.9	79.8
Faba bean	3.8	91.7	10.4	7.2	74.3
Field pea	5	91.9	6.1	6.7	73.6
Natural pasture (hay)	4.1	92.2	9.5	6.6	73.8

[†] DM = dry matter; CP = crude protein; NDF = neutral detergent fibre.

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 (Tareke Berhe, 1996, pers. comm.). Tef contains more calcium, copper, zinc, aluminium and barium than winter wheat, barley and sorghum (Melak Hail 1966).

5 Uses

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 alcoholic drinks, 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.

Enjera made from tef is traditionally consumed with *wot*, a sauce made of meat or ground pulses like lentil, faba bean, field pea, broad bean and chickpea. This indicates that the traditional way of consuming tef with *wot*, is wise, since the *wot*, supplements the lysine deficit in tef and provides a better balanced diet.

Tadesse (1969) and Beyene (1965) suggested that fenugreek *(Trigonella foenum-graecum)* is a good supplement if used with tef. In some regions of Ethiopia, e.g. Welo, women usually prepare *enjera* by adding some fenugreek to tef to improve its baking quality. Because of this, the *enjera* becomes softer and has a shiny appearance. Thus women should be encouraged to continue this traditional practice and be made aware that their practice not only has the benefit of improving the baking quality of the *enjera* but also of supplementing its protein content, especially lysine.

The most popular and widely preferred form of *enjera* is prepared from unmixed pure tef flour. The next preferred *enjera* is the one prepared by mixing tef flour with the flower of other cereals such as barley, wheat, maize or sorghum.

Tef is predominantly grown in Ethiopia as a cereal crop and not as a forage crop. However, when grown as a cereal, farmers highly value the straw of tef and it is stored and used as a very important source of animal feed, especially during the dry season. Farmers feed tef straw preferentially to lactating cows and working oxen. Cattle prefer tef straw to the straw of any other cereal and its price is higher than that of other cereals. According to Lulseged and Jamal (1989), the quantity and quality of residues from various cereal crops vary greatly depending on the crop species. Wheat and barley usually give high straw yields, though of inferior quality. Among cereals, tef straw is relatively the best and is comparable to a good natural pasture. The same source indicated that the performance of animals on residue diets is also known to vary depending on the crop species. The highest daily weight gain was obtained using tef straw. Table 4 shows the weight gains of steers fed for 116 days on a ration composed of 50% residue, 20% molasses, 25% niger cake *(Guizotia abyssinica)*, 4% bonemeal and 1% salt (IAR 1975). Dry-matter intake and daily weight gain were lowest for wheat straw, 5.0 kg and 352 g/head respectively. Daily feed intake was the highest for tef.

According to Burt-Davy (1913), the chief value of tef as a hay crop lies in its palatability, high nutritive value, narrow albumin ratio (for a grass hay), high yield, rapid growth, drought resistance and ability to smother weeds. In South Africa tef is grown as a forage crop. According to Taddesse (1969), tef produces more than

Table 4. Weight gains of steers fed on crop residue-based diets for 116 days, Holetta (1974/75) (Lulseged and Jemal 1989, citing IAR 1975)

Roughage source	Initial weight	Final weight	Daily feed intake	Feed per kg of liveweight gain	Daily gain (g)
Tef straw	186.0	258.8	6.9	11.0	628
Wheat straw	185.0	225.9	5.0	14.2	352
Oats hay	182.0	231.9	5.5	12.8	430
Native hay	184.3	239.6	5.9	12.4	477

twice as much forage as weeping lovegrass *(Eragrostis curvula)*, producing an average of 14.5 t/ha of green material in 3 months. This again shows that tef has a great potential to serve as a forage crop. Hence it can be used as a dual or multipurpose crop, i.e. for both cereal and forage.

Tef straw costs 40-50 Ethiopian birr/l00 kg (6 Ethiopian birr = US$l), while the price of wheat straw is 30-40 Ethiopian birr/l00 kg in Ada region. The national average grain yield of tef is nearly 1 t/ha. With a national average of total biomass production of 4.1 t/ha and a harvest index of 24.4% on 1.38 million hectares of land the country produces 4.3 million tonnes of tef straw annually. The price of tef straw varies depending on region as well as season. However, taking the price in Ada region as a base price, it is possible to roughly estimate that nationally the price for tef straw is between 129 and 172 million Ethiopian birr annually. Both the amount of tef straw produced as well as its price clearly indicate the important role that tef straw plays as a crop-residue livestock feed in Ethiopian agriculture.

6 Genetic resources

Existing genetic variation

As part of the routine characterization programme of germplasm at PGRC/E, Dawit and Hirut (1995) characterized 506 tef accessions (13%) of the total collection for some morpho-agronomic characteristics. Frequency of occurrence of some qualitative characters in tef is presented in Table 5. Fifty-four percent of the 506 collections showed an intermediate type of panicle and 21% were a fairly loose type. Extremely compact and semi-compact panicle types were observed on 13 and 9% of the accessions, respectively. Among the characters, light colours of panicle, glume and seed appeared to be dominant. Concerning glume hairiness, low level of hairiness was found to be dominant. Variability of some agronomic characters of tef germplasm was found to be high (Table 6).

Table 5. Frequency of occurrence of some qualitative characters of 506 tef accessions (Dawit and Hirut 1995)

Characters	Frequency of occurrence (%)[†]			
	1	2	3	4
Panicle colour	50	39	11	0
Glume colour	44	25	6	25
Seed colour	49	21	30	0
Glume hairiness	18	81	1	0

[†] 1 indicates light colour and absence of characters for other characteristics; 4 indicates black or dark colour and intensity of other characters.

Table 6. Variations in some agronomic and morphologic characters of 506 tef accessions (Dawit and Hirut 1995)

Characters	Min.	Max.	Mean	SD	CV(%)
Days to 50% flowering	43	83	49	9.5	17
Plant height (cm)	25	135	99	14	14
Culm diameter (cm)	1	5	2.3	0.45	20
Spikelets panicle	190	1410	604	227	38
Days to 50% maturity	93	130	104	8.5	8
Panicle length (cm)	11	63	39	7.5	19

Apart from the studies made at the PGRC/E, Seyfu (1993) characterized 2255 pure line accessions of tef germplasm for 15 morphological and agronomic traits. All the traits studied showed a wide magnitude of variation and had statistically significant differences. This elucidates the existence of a great wealth of genetic diversity in tef which could be utilized in the improvement programme of the crop (Table 7).

Table 7. Descriptive statistical values for phenological traits, components of height, shoot biomass, harvest, index, flag leaf area and culm thickness for 2255 pure line accessions of tef (Seyfu 1993)

Character	Min.	Max.	Mean	SD	SE	CV (%)
Days to germination	4	12	5	0.70	0.01	13
Days to heading	26	54	37	3.80	0.08	10
Days to maturity	62	123	93	7.36	0.16	8
Days heading to maturity	29	76	56	6.23	0.13	11
Culm length (cm)	11	82	38	7.57	0.16	20
Peduncle length (cm)	7	42	19	4.54	0.09	23
Panicle length (cm)	14	65	41	6.99	0.15	17
Plant height (cm)	31	155	98	12.97	0.27	13
Grain yield/panicle (g)	0.3	3.0	0.9	0.34	0.01	38
Grain yield/plant (g)	4	22	8	4.01	0.08	48
Straw yield/plant (g)	20	90	41	15.83	0.33	39
Total shoot biomass/plant (g)	26	105	49	18.58	0.39	38
Harvest index (%)	7.0	38.0	17	5.51	0.12	33
Flag leaf area (cm^2)†	2.0	26.0	12	6.22	0.62	52
Culm of first internode (mm)‡	1.2	5.0	3	1.12	0.17	37
Culm of second internode (mm)‡	1.2	5.0	3	1.10	0.16	38

† Data taken for 100 germplasm accessions
‡ Data from 45 germplasm accessions.

Out of the 15 traits studied, maximum genetic diversity was observed in the flag leaf area, grain yield per plant and straw yield per plant.

Wild relatives of cultivated crops play an important role as sources of useful and transferable genes. They enrich and broaden the available genetic base in crop improvement programmes and assist in developing superior genotypes. Thus, the wild relatives of tef should be considered for improvement work, identified, collected, conserved, characterized and utilized. So far, no systematic collecting or any activity related to the germplasm of the wild relatives of tef has been conducted by PGRC/E. Several studies were made to identify the wild *Eragrostis* species that are related to tef (Costanza 1974; Endeshaw 1978; Ponti 1978; Tavassoli 1986). However, there are no study results which identified specific economically important traits such as tolerance to diseases, drought, waterlogging or low temperature in the wild *Eragrostis* species, and thus no recommendations have been made for an interspecific hybridization programme. Only Endeshaw (1978) studied the protein content of 11 cultivars of tef and 14 *Eragrostis* species and stated that the accessions of tef were lower in total protein content than that of other wild *Eragrostis* species. Thus, he suggested the possibility for improving the protein content of tef through an interspecific breeding programme.

Several attempts were made to investigate the possibility of crossing tef with other wild *Eragrostis* species. However, the attempt to make a cross between *E. tef* and *E. curvula* was not successful. Also, interspecific hybridization attempts using three tetraploids, i.e. *E. tef* x *E. cilianensis (4x); E. tef* x *E. pilosa (4x);* and *E. tef* x *E. minor (4x)* were not successful (Tavassoli 1986). Some barrier to gene exchange was suspected where it was not possible to develop a plant from the hybrid seed formed by crossing *E. tef* with *E. minor* (Tavassoli 1986).

Conservation

The Plant Genetic Resources Centre of Ethiopia (PGRC/E), now called the Biodiversity Institute, is actively engaged in collecting, conservation and characterization. Utilization of the germplasm for the tef improvement programme is mainly done in cooperation with the Institute of Agricultural Research. Currently the PGRC/E has a total of 3842 accessions of tef out of which 187 accessions are repatriations, 357 selections, 1310 accessions collected by other institutes and 1988 accessions collected by the PGRC/E. The passport data for the materials collected by the PGRC/E include accession number, collection number, local name, place of collecting, longitude, latitude, altitude, period of collecting and sample type. Other institutions maintaining duplicate accessions of tef germplasm are the Institute of Agricultural Research and the Debre Zeit Agricultural Research Centre. Few accessions are kept outside Ethiopia. The FAO - World Information and Early Warning System on Plant Genetic Resources reports the major ones as follows: 368 accessions kept at Western Region Plant Introduction Station USDA-ARS, Washington State University; 341 accessions kept at the National Seed Storage Laboratory USDA-ARS, Colorado State University; 30 accessions kept -at the Department of Genetic Resources, Japan, and 30 accessions kept at the Institute of Crop Science, Germany (Table 8).

In a study conducted by Zewdie and Ellis (1991a), regarding the upper-moisture-content limit to negative relations between seed longevity and moisture in niger and tef, they concluded the following. Increase in seed moisture content above 22.1% and 24.1-27.7% moisture content (fresh weight basis) had little or no effect on seed longevity (time taken for normal germination to decline to 50%) in one seedlot of tef when stored hermetically at 20°C. These estimates of the upper limit to negative relations between longevity and moisture content in air-dry storage are equivalent

Table 8. Institutions with collections of tef germplasm (FAO - World Information and Early Warning System on Plant Genetic Resources. 1995, updated)

Country†	No. of samples	Sample availability‡	Passport data§	Storage¶	Year of updating
Ethiopia	3842	R	A	L; M	1989
Germany, Braunschweig	30	F	A	L; M	1993
Germany, Gatersleben	5	F	A	L; M	1993
Japan	30	F	A	nd	1991
Republic of Yemen	2	nd	nd	nd	1992
Russian Federation	14	nd	nd	nd	nd
Slovak Republic	1	nd	nd	S; F	1993
South Africa	3	F	nd	L	1984
UK	3	F	A	L; M	1994
USA, Nat. Seed Storage Laboratory	341	F	A	L	1990
USA, Western Reg. Plant Introd. Station	368	F	A	M	1992

† For full addresses see Appendix II.
‡ nd = no data, the institution did not provide the information; sample: F=freely available, R=restricted.
§ Passport data: A=available.
¶ Storage: L=long-term storage, M=medium-term storage, S=short-term storage, F=field collection.

to seed water potentials of about -14 MPa and -20 MPa to -16 MPa, respectively In another study made by Zewdie and Ellis (1991b), on the survival of tef and niger seeds following exposure to subzero temperatures at various moisture contents, they concluded that tef seeds stored at 4.4-22.9% moisture content showed more than 96% normal germination through storage at -18°C. In contrast, some 75% of those at 26.1% moisture content failed to germinate following exposure to -18°C, with no further damage to germination occurring during the following 100 days of storage. The germination of seeds of tef at 22.5 and 24.4% moisture content was reduced to 92 and 10%, respectively, following immersion in liquid nitrogen for 3 days. In addition, a smaller effect of liquid nitrogen storage was detected at lower moisture contents by probit analysis, normal germination being reduced from 99.1 to 98.1%. This decline in germination for tef seeds stored in liquid nitrogen for 3 days at 4.4-19.9% moisture content was significant ($P<0.005$), but neither an effect of seed moisture content was detected within this range ($P>0.25$) nor was there a significant interaction between the effect of seed moisture content and liquid nitrogen storage ($P>0.25$).

At the PGRC/E tef germplasm is conserved *ex situ* using a cold store. Tef seeds are dried to a level of 3-7% moisture content and then stored in laminated aluminium foil bags at -10°C for long-term storage and at 4°C for short- and medium-term storage. Duplicate tef germplasm samples at the other institutes are kept in bottles at room temperature and rejuvenated every 3 years.

The accessions that are currently conserved at the PGRC/E are from altitude ranges of 950 to 2950 m asl. No samples were obtained from altitudes below 950 and above 2950 m asl. Figure 4 shows the distribution of samples over different altitude ranges, while Figure 5 shows geographical distribution of collected tef accessions. The highest number of collections came from altitudes ranging from 1750 to 1950 m and 1951 to 2150 m (temperature 15-20°C, annual rainfall 900-1400 mm), the least were from 950-1150 m (20-28°C, 350-900 mm) and 2750-2950 m (l0-15°C, 900-1800 mm) (Dawit and Hirut 1995).

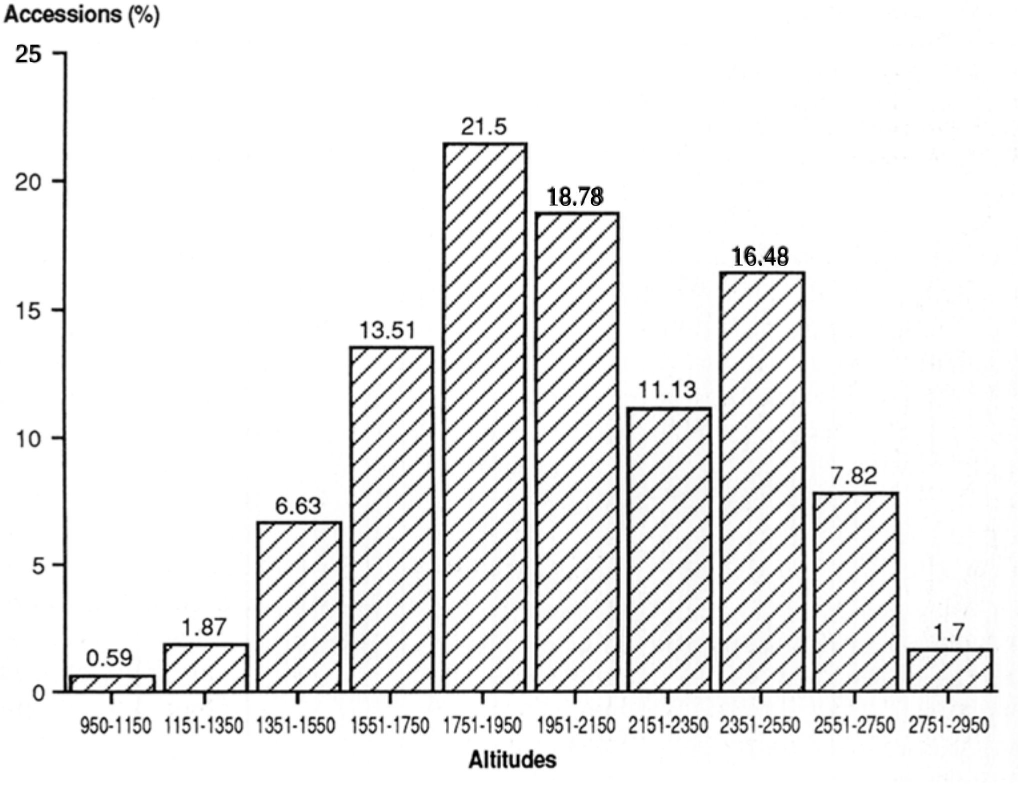


Fig. 4. Distribution of tef germplasm accessions in a range of altitudes.

1. Arsi
2. Bale
3. Eritrea, now independent state
4. Gamo Gofa
5. Gojam
6. Gonder
7. Harerge
8. Ilubabour
9. Kefa
10. Shewa
11. Sidamo
12. Tigray
13. Welega
14. Welo

⋆ PGRC/E Collections
⊕ Collections by other Institutes
⦿ Addis Abeba

Fig 5. Collecting sites of tef.

Gaps in collections and recommended plan of action

The following points are among some of the major gaps in the present tef germplasm work and the collection held at the PGRC/E. Most of the accessions held at the PGRC/E were acquired before the establishment of PGRC/E; hence they were not collected in a systematic way – following appropriate sampling procedures and taking into consideration various ecogeographic regions and environments of special interest. Over 55% of the accessions lack adequate passport data details. Thus, it is not possible to make correlation studies with the environment or other factors. In addition, the accessions at the PGRC/E have not been adequately characterized for several traits of economic importance such as tolerance to drought, waterlogging, high and low temperatures in order to be useful for the tef improvement programme. So far no collecting of the wild relatives of tef has been done. The system for germplasm data storage, retrieval and dissemination needs improvement, through updating the software and hardware used within the PGRC/E as well as generally improving the germplasm information system within the country.

The following points could be taken into consideration in a plan of action. The study made on the 2255 accessions of tef for 15 morphological and agronomic traits has indicated the availability of significant genetic diversity, thus demonstrating the high potential that exists for the improvement of tef (Seyfu 1993). Improvement could be achieved through direct selection out of the existing 2255 pure line accessions or by effecting gene recombination between parental lines selected from them, to create genetically superior cultivars through conventional breeding or biotechnology techniques, if they are made available for tef in the future. Thus, further characterization and evaluation work on the established line is necessary for additional economically important traits, to develop genetically superior cultivars.

Other activities to be considered are:

- Determining the geographic distribution of the wild relatives of tef within the country
- Assessing the genetic diversity of tef both within and between regions with regard to morpho-agronomic and molecular characteristic, to effectively utilize the germplasm.
- Making systematic collections with comprehensive passport data, taking into consideration various ecogeographic regions and targeted environments of specific interest.
- Making ethnobotanical studies to find out more about the crop.
- Further characterization and evaluation of the existing accessions fo economically important traits such as tolerance to drought, waterlogging, diseases, insects, etc.
- Updating and making efficient the information system on tef germplasm.

There are no major constraints noted so far in the *ex situ* conservation of tef. Both the total number of improved varieties released so far (only eight) and the amount of improved seed distributed to farmers each year are low. Most farmers (>80%) use their own landraces as their seed source for production. Thus, one could say that tef is currently being conserved on-farm by farmers. The use of landraces will diminish in the future with the modernization of agriculture and the wider use of improved cultivars. In addition, other sources for genetic erosion such us drought, population growth, habitat destruction and environmental degradation will result in changing the existing farming system and have a negative impact on the genetic resources of tef. Thus, as the need arises in the future *in situ* conservation should be considered.

Although on a limited scale, researchers on tef have always used tef germplasm in their improvement programmes. The limited use was imposed by the lack of comprehensive characterization data for various essential traits. Prior to 1993 characterization data were not available for more than 200 accessions (Seyfu 1991). As indicated above, a more systematic and comprehensive use of tef germplasm in tef breeding and other research work has commenced (Seyfu 1993).

7 Breeding

Breeding activities

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 varieties. However, so far no success has been achieved. Lodging is still one of the production constraints and therefore the breeding programme has the development of lodging-resistant varieties as one of its objectives. Other production constraints are: low-yielding cultivars, low moisture stress resistance, waterlogging, frost, weeds, poor soil fertility, diseases and insects. Generally the crop improvement programme in tef attempts to solve these production constraints through a multidisciplinary research approach. Specifically, the breeding programme should overcome the problems of low grain yield, and also develop cultivars that are resistant to low moisture, waterlogging and disease as there is a wealth of genetic diversity within tef germplasm.

Hybridization technique

The small size of the floret, its autogamous nature and its unique pollination habit - pollination occurs only during the early hours of the morning - require the employment of an appropriate artificial hybridization technique. Under Ethiopian climatic conditions, tef flowers open and pollinate only between 6:45 and 7:45 a.m. (Tareke 1976). Techniques for delaying flower opening were developed to control pollination and to effect hybridization whenever required during the late hours of the day. These included putting potted plants overnight under cold temperature (5-10°C) or under complete darkness at temperatures of 14-22°C (Seyfu 1983). The process of initial flower opening to anther dehiscence takes about 30-40 minutes and once pollination is effected the pollen grains take only 3-4 minutes to germinate on the stigmas (Seyfu 1983). The suggestion of Tareke (1981) to use pollen from stigmas as a source for hand-pollination for an hour and a half is not recommendable. This is because pollen grains taken off the stigma are useless after 3-4 minutes since they would have already germinated and sent their pollen tubes down the style and thus will not be viable and functional for pollinating another stigma. Detaching the florets, which contain the anthers and their pollen intact, from a spikelet when they just begin to open for natural self-pollination, and keeping them in moist vials could prolong the viability of the pollen grains for use in pollination (Seyfu 1983). Anther dehiscence can also be delayed by removing undehisced anthers with jeweller's forceps from florets as the flowers open under the influence of light conditions and increased temperature and transferring them to damp filter paper in a petri dish. The humidity here delays dehiscence for a considerable time (Ponti 1978).

During artificial crossing, the state of the stigma assists in identifying the receptive and ready florets for pollination. The receptive florets have fluffy, feathery and turgid stigmas, while the nonreceptive ones have sticky and nonturgid stigmas (Seyfu 1983).

The following procedure for the artificial hybridization of tef is suggested by Seyfu (1983):

- Grow, one or two plants of each parent in separate pots of about 13-cm diameter.
- Put the female plant and the pollen donor plant into separate light-tight dark boxes at about 2:00 p.m., 8-18 days after anthesis begins on the central or any other tiller. Keep the boxes away from direct sunlight at a temperature well below 28°C; lower temperatures improve the degree of control over flowering. Next day, crossing may be done any time before early afternoon.
- Take the pollen donor plant out first and wait for 3-5 minutes. As soon as it starts to open its flowers, detach the spikelets with open florets using forceps and attach them to the moistened inner wall of a vial. Label the vial with a code number of the plant (these can be used as the pollen source later).
- Take out the female plant, lay it horizontally under a binocular microscope (x15), and begin to emasculate as soon as the flowers start to open and before the anthers dehisce. Only the basal florets should be emasculated, the other florets on the spikelet being removed. This enables identification of the treated flowers.
- Keeping the emasculated flowers under observation, remove a spikelet from the vial. Detach an individual anther with forceps while observing beneath the binocular microscope or while the anther is still attached to the flower; gently squeeze out the pollen directly onto the stigma of the emasculated floret.
- Label each plant for crossing records.

A skilled operator can avoid hand-emasculation by applying the donor pollen before the anthers in the flowers of the female parents dehisce, although this procedure involves some risk.

Hybrid identification

One of the following means can be used to identify successful hybrids from accidental selfs after artificial hybridization in the F_1 generation: dominance is displayed by loose panicle, coloured lemma and coloured seeds over compact panicle, yellowish white lemma and white seed, respectively. Therefore seed colour, lemma colour and panicle form can serve as the useful genetic markers on mature F_1 tef plants (Tareke 1975). In addition, the following techniques can help distinguish the hybrids from the accidental self-pollinated seeds in a very short time, mainly because the techniques do not require growing mature plants. Plants with florets having red lemmas have red coleoptiles when their seeds are germinated under direct sunlight. These show dominance over plants that have florets with yellowish white lemmas and green coleoptile during germination. Hence coleoptile colour can serve as a genetic marker at earlier growth stages (Seyfu 1983). Similarly, the dark embryo that develops only in mature caryopsis and shows dominance over the pale embryo can serve as a marker to identify the F_1 hybrid seeds (Ponti 1978).

Inheritance of characters and selection

The inheritance patterns of tef for the following three traits (Tareke 1981) were:

- lemma colour - purple, grey, red, and yellowish brown
- seed colour - dark brown, medium brown, yellowish white and greyish white
- panicle form - loose and compact.

Four pairs of genes were found to be involved in the inheritance pattern of the lemma colour. Gene action and interactions of dominance, codominance, complementarity and epistatic nature have been observed on tef plants. Thus the following genotypes were given to the four cultivars having different colours: *fesho* (purple) = *CCPPP2P2GG; bursa* (grey) = *ccPPP2P2GG; key murri* (red) = *CCppp2p2gg;* and *Trotteriana* (yellowish-white) = *ccPPP2P2gg.* Duplicate pairs of genes were identified in the inheritance of seed colour and the gene action between these genes and their alleles was simple dominance with additive effects. Panicle form was conditioned by duplicate pairs of genes for degree of looseness and another pair of genes for branching pattern.

The fact that tef showed a disomic inheritance pattern for lemma colour, seed colour and panicle form indicates that it is an allotetraploid; thus the quantitative genetic theory developed for diploids, including the procedures used to estimate the genetic variance and heritability of diploids, is applicable to tef.

A preliminary genetic experiment using the F_2 and F_3 generations of a single cross indicated that gene actions for most agronomic traits of tef were not simple additive/dominance only (Hailu *et al.* 1992). For example, in the case of yield and yield components of tef, the effect of nonadditive genes has been verified (Hailu 1993).

A study on two sets of crosses indicated that additive and dominance by dominance gene effects control the inheritance of grain yield. The magnitudes of the additive terms were lower than the dominance by dominance interaction term, which signals that selection based on grain yield *per se* might be difficult. Triple test cross analysis also revealed the presence of epistasis for grain yield in this crop. Nonallelic gene interactions were also reported for yield per panicle, panicle weight, tiller number, harvest index, plant weight, plant height, panicle length, culm thickness, kernel weight, days to heading and days to maturity using different mating designs (Hailu 1993).

Epistasis has been found to be part of the genetic architecture of grain yield and other agronomic traits of tef and has been detected by different procedures unequivocally. Previously, gene interaction in tef was reported for some traits (Tareke *et al.* 1989a, 1989b, 1989c) and therefore it is not surprising to detect the same for more complex quantitative traits. Therefore, future quantitative genetic analysis in the tef plant must consider procedures that may allow the detection of epistasis to avoid biased estimates of additive and dominance components.

In small cereals, several researchers have reported that traits like kernel weight, number of kernels per head and tiller number have a strong association with grain yield. These characters are widely accepted as yield components. In the tef plant, Melak Hail *et al.* (1965) computed a positive correlation between seed yield and panicle length at Purdue in the USA. Under an Ethiopian environment, Hailu (1988) observed kernel weight per main panicle and productive tillers positively associated with grain yield. In a study using early generations of a single cross, Hailu *et al.* (1992) obtained panicle weight per plant (a trait closer to true grain yield) positively associated with panicle weight per primary tiller and productivity index.

Subsequent studies confirmed that yield per panicle and panicle weight showed strong correlation with grain yield per plant (Hailu 1993). These traits have high heritability compared with grain yield *per se* and therefore they are useful criteria for grain yield selection in tef.

Biotechnology

All of the cytological literature on tef and other *Eragrostis* species reports the difficulties in studying tef chromosomes because of their small size (0.2-l µm) and their refractory nature to staining techniques, and recommends improvement in the technique before any useful result can be expected. The meristems of the main roots are small and divisions are relatively few; the small roots of seedlings grown in petri dishes were also studied but were not suitable. Meiosis is difficult to observe owing to the few pollen mother cells in each anther. This suggests that detailed studies of the genome composition of tef and other *Eragrostis* species to obtain meaningful results are not possible at this stage. However, the more efficient techniques now available (image analyis, flow cytometry and banding techniques) coupled with molecular techniques should make it possible to analyze individual chromosomes and the genome architecture of tef more accurately

Establishment of plant cell and tissue culture techniques for tef is a prerequisite to successful plant transformation and regeneration. Embryogenic cell lines in particular can provide a suitable source of embryogenic protoplasts for culture and regeneration, and the development of a single cell system which is a *sine qua non* for direct gene transfer techniques such as electroporation and micro-injection. Somaclonal variation has potential as a new option to generate additional genetic variability in co-adapted, agronomically useful cultivars without the need to resort to hybridization and so far has provided breeders with new sources of variability to incorporate into conventional breeding programmes. Agronomically useful traits such as increased tolerance to physiological stress and pests and diseases have been recovered from such materials. *In vitro* mutation techniques can be useful to identify lodging-resistant tef lines.

Tesfaye (1991) reported preliminary results in cell and tissue culture and genetic transformation and also outlined biotechnological approaches for tef research. According to Tesfaye (unpublished), embryogenic callus from leaf explant and seeds was induced with 1.0-2.5 mg/L of 2,4-D in the culture media. Similarly, Firew (1991) regenerated tef plantlets through somatic embryogenesis originating from cultured leaf explants. Appropriate culture media for zygotic embryos were studied for use for embryo-rescue in tef (Cheverton 1985). Callus was obtained from the fusion product of tef and sorghum (Endeshaw 1992). *In vitro* manipulation of the spikelets of tef showed that tef spikelets develop successfully in Wheat Spikelet Medium (WSM) (Hailu 1993). Furthermore, spikelets of the F_1 (varieties: Fesho x Kaye Murri) showed good early development.

The transient expression of the ß-glucuronidase (GUS) gene in embryogenic callus and the antibiotic sensitivity of cultured tissues of tef to Kanamycin and Gentisin (antibiotics), which lays a foundation for the future selection of transgenic tef using these markers, was studied (Tesfaye 1991). Introduction of a foreign gene through the incubation of seeds with plasmid DNA for various lengths of time was not successful for tef.

Nugent and Gaff (1989) reported electrofusion of protoplasts of tef and other desiccation-resistant species in the genus *Eragrostis*. Protoplasts were obtained by enzymatic degradation of the cell wall from desiccation-tolerant ‘resurrection grasses’ *(Eragrostis* and *Sporobolus* spp.). The highest protoplast yield was achieved by using young tissue of leaves still enclosed in the sheaths of older leaves. Electrofusion was successfully applied to achieve fusion between protoplasts of desiccation-sensitive and tolerant species *(S. pyramidalis* and *S. pellucidus, E. tef* and either *E. hispida* or *E. paradoxa* and between two desiccation-tolerant species *(E. invalida* and *E. nindensis).*

Wide hybridization between related but distinct species normally fails because of fertilization, embryo lethality or disruption of embryo-endosperm relations (Simmonds 1979). If embryo-endosperm relations is the block, then embryo culture can be very valuable, and indeed such embryos of several plant species have been rescued. Interspecific crossing of tef with related wild species requires the support of this technique.

Protoplast fusion has long been proposed as an innovative and extensive method for producing hybrid plants that cannot be obtained by sexual means. The best use of protoplast fusion will be in the production of hybrids which contain the nuclear and cytoplasmic genome of one parent and only the cytoplasmic genome of the second parent (Vasil 1983). These can be of particular advantage in the transfer of cytoplasmic male sterility, an important trait in breeding, as yet not discovered in tef.

The development of rapid screening techniques for identifying germplasm with economically important traits such as tolerance to drought, waterlogging, low temperature, etc. will be essential for the optimum utilization of the germplasm and the development of superior genotypes.

Currently there are neither sufficient basic and applied research results in tef biotechnology to be put to practical use in the improvement of tef nor are there sufficient funds to indulge in large-scale tef biotechnology research, and thus conventional breeding remains the appropriate. option to improve the crop.

8 Production areas

Within Ethiopia the administrative regions of Shewa, Gojam, Gonder Wello and Welega are the major tef-production areas. It is widely grown in both high-potential and marginal production areas. These areas include most parts of the Vertisols that suffer from waterlogging and other non-Vertisol parts of the country that suffer from low moisture stress. Tef is grown in almost all regions of the country for home consumption since it is a preferred grain, and for local market since it fetches the highest grain price compared with other cereals and is used as a cash crop by farmers. A small amount of the tef produced for local markets is also exported. No specific production areas are targeted for export. Major and minor tef-production areas in Ethiopia are presented in Figure 6.

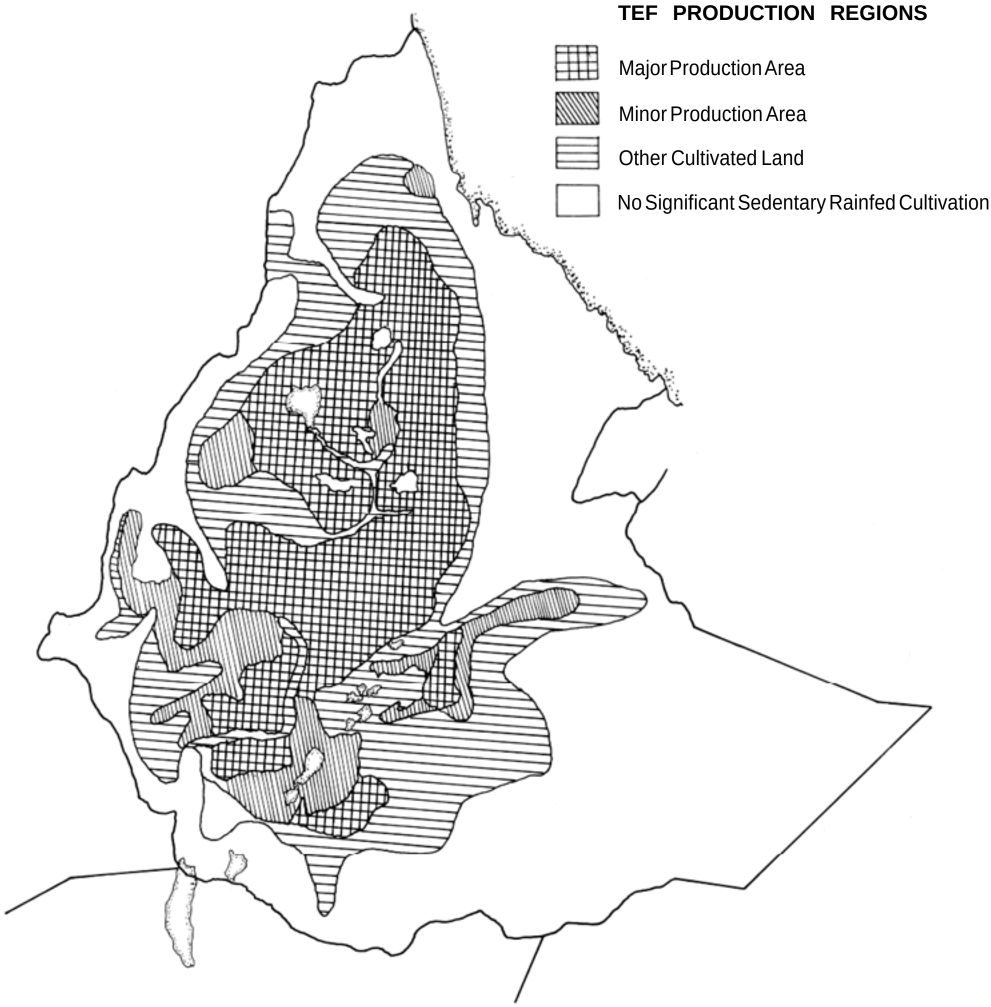


Fig. 6. Production regions of tef.

Table 9 shows the production of tef in relation to other crops in Ethiopia. The average annual production is estimated to be 1.38 million tonnes. With an average grain price of 2000 birr/t the average annual trade value of tef could be estimated to be 2.76 billion birr or US$460 million at the 1995 rate of exchange (6 birr = US$l). Outside Ethiopia, small-scale tef grain production has started in the USA and Canada. Approximately 200 acres of tef are grown commercially by Wayne Carlson in Idaho (National Research Council 1996).

Table 9. Area under cultivation, yield and production of major crops in Ethiopia

	Sept.1990-Sept.1991			Sept.1991-Sept.1992		
Crop	Area ('000 ha)	Yield (kg/ha)	Production (t)	Area ('000 ha)	Yield (kg/ha)	Production (t)
Tef	1279.1	1420	1813 870	1368.4	870	1184 550
Maize	1121.4	1200	1347 920	986.5	1530	1510 620
Barley	712.3	1130	803 350	736.0	1070	785 140
Sorghum	508.1	1340	679 660	460.4	1230	564 730
Wheat	506.6	1400	711 240	559.9	1350	755 670
Millet	167.7	1320	221 860	152.1	840	128 340
Horse beans	244.9	1500	367 300	296.8	1100	326 160
Field peas	124.8	1420	176 870	144.0	740	106 420
Chickpeas	117.6	1280	150 760	110.5	690	76 400
Haricot beans	105.4	1310	137 950	53.4	870	46 330
Lentils	44.0	1440	63 540	48.1	580	27 860
Niger	159.0	1280	203 700	139.1	370	51 200
Linseed	63.5	1330	84 150	58.9	460	27 270

Source: Central Statistical Authority. 1992. Ethiopia Statistical Abstract.

9 Ecology

Tef is adapted to a wide range of environments and is presently cultivated under diverse agroclimatic conditions. It can be grown from sea level up to 2800 m asl, under various rainfall, temperature and soil regimes. However, according to experiences gained so far from national yield trials, conducted at different locations across the country, tef performs excellently at an altitude of 1800-2100 m, annual rainfall of 750-850 mm, growing season rainfall of 450-550 mm and a temperature range of 10°C-27°C. A very good result can also be obtained at an altitude range of 1700-2200 m and growing-season rainfall of 300 mm.

According to experiences from Debre Zeit, which is one of the best tef-growing regions known for its production of the best preferred and high-quality tef called ‘magna tef’ (DZ-O1-196) as well as for its high production level per unit area of different varieties of the crop, tef suffers less from diseases, gives better grain yield and possesses higher nutrient contents, especially protein, when grown on Vertisols rather than on Andosols. However, proper management on Vertisols calls for using different seedbed preparation methods to overcome the problem of poor stand establishment that is encountered either because of soil crusting and cracking during growing seasons with low moisture stress or because of waterlogging during very wet growing seasons. This problem can partially be alleviated by using better practices such as packing the seedbed during the dry season and making drainage furrows during the wet season, as well as other cultural practices such as determining sowing dates.

Tef is sensitive to daylength, since its vegetative and flowering habits were found to be affected when plants of the same lines grown in Ethiopia were grown during the summer and the winter in England (Seyfu 1983). The plants performed best in Ethiopia, where there is approximately 12 hours of daylight. When the same cultivars were grown in England in heated glasshouses during winter under short-day conditions (ca. 8 hours), their height was very short, around half their size when grown in Ethiopia. Flowering also was greatly affected: the flowers remained open for longer periods, most of the anthers never produced pollen grains, and seedset was extremely low, perhaps because many florets became male-sterile. Their vegetative stage was lengthened and they took more than 6 months to reach maturity. The number of florets per spikelet was greatly reduced. The summer-grown plants in England were affected by long day conditions (ca. 16 hours); however, much less than the winter grown plants. The plants grew taller, they had a longer vegetative period, but not as long as the winter-grown ones. Flower opening was not much affected, but the number of sterile flowers compared with the ones grown in Ethiopia was high, but lower than the English winter-grown ones, and there were many spikelets where more than one floret opened on the same day. The number of florets per spikelet was more or less the same as the ones grown in Ethiopia but the seedset was somewhat lower (Seyfu 1983).

10 Agronomy

In Ethiopia tef is cultivated in much the same way as wheat and barley. Depending on the location and maturity period of the cultivar it is grown during the main growing season between July and November, and also during the small rainy season between March and June. It is mainly cultivated as a monocrop, but occasionally under a multiple cropping system. In such cases it is usually grown as an intercrop with rapeseed *(Brassica napus)*, safflower *(Carthamus tinctorius)* and sunflower *(Helianthus annuus)* or relay-cropped with maize *(Zea mays)* and sorghum (Sorghum bicolor). It is also cropped sequentially in a crop-rotation system in the mid- and high-altitude areas after chickpea *(Cicer arietinum)*, field pea *(Pisum sativum)*, faba bean *(Vicia faba)* and grass pea *(Lathyrus sativus)*; while at low-and some mid-altitude areas it is 'grown after haricot bean *(Phaseolus vulgaris)*. Usually a 4-5 year rotation cycle is practised. In a 4-year rotation cycle the sequence followed would be: pulse/tef/tef (or another cereal, for example, wheat or barley)/pulse. In a 5-year rotation cycle the sequence would be: pulse/tef/tef/other cereal/pulse.

Seedbed preparation and sowing

Under current farmers' practices, a tef field is ploughed two to five times depending on the soil type, weed conditions and waterlogging. Heavy clay soils need ploughing more frequently than loam or sandy soils. Fields with high weed populations receive more ploughings than those with fewer weeds. Vertisols in areas where there is a problem of waterlogging are ploughed more than those without, to open drainage furrows. Traditionally, farmers alleviate the problems of waterlogging through preparing a raised seedbed, similar to a cumber-bed, by a hand-or oxen-pulled broad bed maker after the land has been well ploughed. The fourth and fifth ploughings are usually made for opening drainage furrows; the last is called *derdaro*.

In a study conducted to evaluate effect of tillage and weed control practices on yield and yield components of tef, it was reported that ploughing more than once may not be necessary provided nonselective herbicides are applied to control weed flush before ploughing, suggesting that tef can be produced under reduced tillage. In this study, although nonselective herbicides were applied before ploughing, it was found that additional weeding (hand or chemical) once at the early tillering stage of tef increased yield (Aberra 1992).

Under the current farmers' production system, tef seeds are sown on the surface of the soil and left uncovered or sometimes covered very lightly by pulling woody tree branches over the field using oxen. It has been observed that covering tef seeds thinly or pressing them lightly just after sowing or packing the seedbed before sowing under moisture stress conditions promotes germination and increases grain yield through increasing stand establishment on both Andosols (light clay loam soils) and Vertisols (heavy clay soils). Particularly if there is moisture stress or rainfall interruption incidence at the beginning of the growing season, moderate packing of the seedbed is useful to enhance stand establishment on Vertisols that suffer from soil crusting. Farmers pack the seedbed using oxen, donkeys, goats, sheep and other farm animals. Seedbed packing is done before sowing tef to make the seedbed firm, prevent the soil surface from drying quickly, assist germination of seeds and minimize the damaging effect of low moisture during late onset of rain. Packing of the seedbed is also practised to free the seedbed from weeds by turning them tinder. Otherwise, during years of sufficient rainfall, in areas where sometimes there is a shortage, or in areas where there always is a reliable and sufficient amount of rainfall with good distribution, packing the seedbed does not have any additional positive advantage in promoting germination and stand establishment.

In a study conducted to investigate the effect of planting depth and soil type on germination and emergence of tef, using two tef cultivars (DZ-01-354 and Dabi), it was observed that emergence from surface planting and from greater than 20 mm depth was significantly lower than either 5, 10, 15 or 20 mm depth. There was no significant difference between crop emergence from 5 and 20 mm depths. Plant height was not affected by a planting depth of between 5 and 15 mm. However, seedlings that emerged from surface and planting depths of greater than 15 mm had significantly reduced height while seedlings that emerged from clay loam were taller than those from sandy loam (Aberra 1992).

Tef can be sown during a season when the rainfall is reliable and well distributed. For most cultivars, 300-500 mm of rainfall per growing season is adequate. Early maturing varieties (60-75 days) can do with less than 300 mm of seasonal rainfall. Tef germinates and establishes faster on Andosols than on Vertisols.

About 15-55 kg of tef seeds are sown per hectare under different conditions. If a manually or motor-driven broadcaster or drill is available, a lower seed rate (about 15 kg/ha) is recommended. If sowing is to be done by hand-broadcasting, it would be difficult to evenly distribute the 15 kg/ha of seeds because of the small seed size – l000-seed weight is only 265 mg. Therefore, 25-30 kg/ha seeds are recommended for broadcast sowing. Farmers' traditional practice is to broadcast tef at the rate of 40-50 kg/ha.

Fertilization

Systematic studies on the fertilizer requirements of tef under varying conditions and in various regions need further investigation. However, currently the following recommendations are made:

Recommendations from Debre Zeit Agricultural Research Centre: On heavy clay soils (Vertisols): 60kgN and 26kgP_2O_5 per ha. On sandy clay loam soils (Andosols): 40kgN and 26P_2O_5 per ha. Urea is generally recommended to be applied in split applications.

Alkämper (1973) has made the following conclusions regarding the response of tef to fertilizers:

- High rates of fertilizers can be applied at sowing together with the seeds on the bare land without any harm to the germination rate of tef.
- Nitrogen produces more straw while phosphorus encourages good grain production.

- Potassium is of minor importance to tef production.
- The figures concerning the uptake of the main elements by tef are relatively low.
- Split applications of nitrogen may result in increases in grain yield without influencing the straw yield.

Weeding

It is best to start with a weed-free and clean field that has been ploughed in the appropriate season and frequently enough to kill the weeds. The work should also start with clean tef seeds that are free of weed seeds. Hand-weeding once at early tillering stage (25-30 days after emergence) is ideal and adequate, if the weed population is low. However, if the infestation is high, a second weeding should be done at the stem-elongation stage. On the other hand, hand-weeding after heading is not recommended, since it may result in heavy damage to the plants.

Weed competition causes about 52% crop losses, but with hand-weeding (even at the wrong time), crop loss is 8% (Berhanu 1986). Pre-sowing and post-emergence herbicides available for the control of weeds in tef are indicated in Table 10.

Table 10. Recommended rates of herbicides and their time of application (Berhanu 1986)

Herbicide	Rate (kg a.i./ha)
Pre-sowing	
Gesatan 500 FW (Ametryne + Prometryne)	1.2
Post-emergence	
2,4-D amine 480	0.8-1.2
2,4-D ester 720	0.7-1.3
MCPA 415	0.9-1.3
MCPA 625	0.8-1.3
Dichloprop 620 (2,4-DP)	2.0-2.5
Bromuron 60% (Mecoprop + MCPA)	2.5
ARD 12131 50 % (Bromoxynil + cmPP)	1.5-2
2,4-D 36% + MCPA 31%	0.5-0.7
Brittox 50.5 % (Mecoprop + Bromoxynil + Ioxynil)	1.0-1.3

Berhanu (1986) has stated that the pre-sowing herbicides should be applied 1-2 weeks before planting while the post-emergence herbicides should be applied at early tillering (4-5 weeks after sowing). The pre-sowing herbicides have shown an acceptable control level for annual broadleaf and grass weeds, though they did not satisfactorily control the perennial weed species. All the post-emergence herbicides listed in Table 10 had good control for only the broadleaf weeds and not for the grasses and sedges.

Diseases

Diseases are not a serious problem. In the major tef-growing areas of Ethiopia tef suffers less from diseases than most other cereal crops in the major production areas of Ethiopia (Stewart and Dagnachew 1967).

Tef rust *(Uromyces eragrustidis* Tracy) and head smudge *(Helminthosporium miyakei* Nisikado) have been reported as the most important diseases on tef (Stewart and Dagnachew 1967; Tareke 1981). According to Tadesse (1969, citing Castellani *et al.* 1939), rust causes an average loss of l0-25%.

Damping-off caused by *Drechslera poae* (Baudis) Shoemaker has been found to be severe and even damaging when higher rather than lower seed rates and early rather than late sowing dates were practised.

Spraying tridemorph has decreased helminthosporium leafspot *(Helminthosporium* spp.) from a 25-30% infection level to a l-2% level.

Insect pests

The control methods of the most important insect pests of tef are presented below.

Welo bush-cricket *(Decticoides brevipennis* Ragge), locally known as *degeza,* is new to science; it is a major pest existing only in Ethiopia with its distribution being recorded in the altitude range of 1550-2516 m in Tigrai, Welo, Gonder, Gojam and Shewa, but not in Welega (Stretch *et al.* 1980). As the early instars of *D. brevipennis* are flower feeders, slashing of weeds in the field margins before cereals have headed would deprive this pest of food and reduce its population near crops. Early sowing of cereal crops would also enable them to mature before the natural food sources of this potential pest dry completely As *D. brevipennis* has only one generation a year, one well-timed application of insecticide can almost eliminate it from an area, especially since migration is minimal (Stretch *et al.* 1980). The application of 8-10 kg/ha of 2.6% BHC as dust has been found effective in controlling Welo bush cricket.

For control of central shootfly *(Hylemya arambourgi)* a seed dressing before sowing with 40% Aldrin WP at the rate of 50 g/kg of seed is recommended.

Red tef worm *(Mentaxya ignicollis* Walker) was first reported as a pest of tef in 1970 south and west of Addis Abeba on black clay soils. Since then, losses from red tef worm were estimated to be l0-30% in five regions of Ethiopia. Repeated crop losses have been observed in Becho area of Shewa. Preliminary study results indicate that *Digitaria scalarum* and *Phalaris* spp. were the important alternate wild hosts of red tef worm. Some of the insecticides found useful to control red tef worm are (Tadesse, 1996, pers. comm.): Cypermethrin, 25% e.c. (187.5 g a.i./ha, 750 ml/ha) or Fenitrothion, 50% e.c. (625.0 g a.i./ha, 1.25 ml/ha). Spraying should be done when, on the average; 25 larvae/m^2 of red tef worm are counted.

Harvesting

Tef is harvested when the vegetative parts turn yellowish. This depends on the maturity period of the varieties, which varies from 60 to 120 days. Harvesting before the plant gets too dry helps prevent losses from shattering. It is threshed by trampling the harvested crop either with oxen or by using threshers. The grain is stored outside the house in a granary made of wood or bamboo plastered with mud mixed with tef straw to reinforce it, or stored in the house using other storage containers. Tef seed is stored very easily for several years under local storage conditions because it is not attacked by weevils or other storage pests and chemicals are not required to control storage pests. Tef straw is nutritious feed. It is piled up and stored outside the house after threshing for animal feed.

11 Limitations of the crop

The small size of tef seed poses problems during sowing, and indirectly during weeding and threshing. At sowing the very small seed size makes it difficult to control population density and its distribution. This remains true whether one broadcasts the seed by hand, uses a broadcaster or a seed driller.

The uneven plant stand after germination has an impact on nutrient use efficiency of the crop and crop yield. Owing to the scattered plant stand, farmers find it difficult to use mechanical weeding implements and are forced to either hand-weed or use chemical herbicides.

Threshers or combine harvesters are used to thresh tef. However, seed loss is incurred because tef seed is very small and light and gets blown away with the chaff. Harvesting of the crop is difficult because of lodging. Since tef lodges heavily it is not advisable to use higher rates of fertilizer to increase yield. The current landraces and cultivars used are not lodging resistant and the development of genetically lodging-resistant cultivars is essential.

Landraces and current cultivars give low yield. At present the national average grain yield of tef is 910 kg/ha. Improved varieties of tef give a grain yield of 1700-2200 kg/ha on farmers’ fields and 2200-2800 kg/ha under research-managed large farms. However, no comprehensive study has been conducted to assess the yield potential of the crop.

The study of 2255 accessions of tef has demonstrated the high yield potential of the crop (Seyfu 1993). Thus, it is not fair at this point to state that low yield is one of the genetic limitations of the crop. The personal opinion of the author is that the crop has great potential for improvement and could give more than 6 t/ha if it receives adequate research attention. Low grain yield, and production constraints such as lodging, drought, waterlogging, heat and frost might be overcome through a comprehensive plant breeding programme since there exists genetic variation in tef germplasm for these traits. In addition to using the existing genetic variation to overcome some of the production constraints, development of improved and appropriate agronomic practices (seed rate, sowing dates, seedbed preparation, fertilizer type, rate and time of application) and cropping systems (crop sequence, relay cropping, intercropping, etc.) would greatly contribute to overcoming production constraints and improving, the productivity of the crop.

12 Prospects and research needs

Ethiopian farmers prefer to grow tef because of the following advantages (Seyfu 1991):

- It can be grown in areas experiencing moisture stress.
- It can be grown in waterlogged areas and withstands anaerobic conditions better than many other cereals including maize, wheat and sorghum.
- It is suitable for use in multiple-cropping systems such as double, relay and intercropping.
- Its straw is a valuable feed during the dry season when there is an acute shortage. It is highly preferred by cattle over the straw of other cereals and demands high prices in the markets.
- It has acceptance in the national diet, has high demand and high market value and hence enables farmers to earn more than with other crops.
- It is a reliable and low-risk crop.
- In moisture-stress areas, farmers use it as a rescue crop. For example, around Kobo and Zeway, which are areas with low and erratic rainfall, farmers first plant maize around April. If this fails after a month or more because of moisture stress or pest problems they plough it under and plant sorghum. If this also fails after a month or more then they sow tef as a last resort, which often survives on the remaining moisture in the soil and yields some grain for human consumption and straw for feed.
- It is not attacked by weevils and other storage pests and therefore is easily and safely stored under local storage conditions. This results in reduced post-harvest management costs.
- Compared with any other cereals growing in Ethiopia it has fewer disease and pest problems (Stewart and Dagnachew 1967).

It was stated earlier that the ability of tef to tolerate and grow under waterlogged conditions is one of its advantages and a characteristic that makes it preferred by farmers. Experimental results have shown that under undrained conditions without fertilization, tef gave a 106% grain yield advantage over wheat and 70% under undrained conditions with fertilization (Hiruy 1986). This indicates that tef is relatively more tolerant to waterlogged conditions than wheat.

The other advantage of tef for farmers is its suitability for easy storage under local storage conditions (using *goteras),* without incurring much loss; this has been substantiated by various study results.

Results of experiments conducted in Ethiopia under natural environmental conditions and traditional storage systems indicate that tef does not incur any loss as a result of damage by any storage insect pests (Yemane and Yilma 1989).

Currently diseases are not a serious problem in tef in the major tef-growing areas of Ethiopia. Tef suffers less from diseases than most other cereal crops in the major production areas of Ethiopia (Stewart and Dagnachew 1967).

Jansen *et al.* (1962) reported that tef has an excellent balance among the essential amino acids that makes it comparable to that of egg, except for its somewhat low lysine content, which can be supplemented by the use of fenugreek, pulses and soyabean, which can be locally grown.

The characterization work done by Seyfu (1993) has shown that among the 2255 pure line accessions there is a high variability for grain yield per plant, straw yield per plant and harvest index. The potential has been shown for the development, through direct selection as well as gene recombination, of cultivars that are either mainly forage or dual-purpose types with acceptable levels of both grain and straw yield.

Tef has its own unique qualities and advantages, and thus its introduction to other parts of the world could be of benefit to many nations. Its benefit as a forage crop to South Africa has been described by Burt-Davy (1913).

The crop has a wealth of genetic diversity which could be utilized to overcome present constraints through proper germplasm conservation and utilization efforts. The gaps in current germplasm collections and suggestions made for future action, both of which were indicated earlier, need to be addressed in order to utilize the germplasm and overcome present constraints. Targeted collecting of germplasm from stress areas such as waterlogged areas, low-temperature and drought-prone areas, etc. would be useful. Development of rapid and cheap screening techniques to identify various stress-tolerant cultivars and identify and utilize efficient breeding or biotechnology techniques for developing superior cultivars are essential for overcoming present constraints.

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Appendix I. Research contacts, centres of crop research and breeding of tef in Ethiopia

Name	Area of expertise	Address
Abebe Demissie	Germplasm Collecting	Biodiversity Institute†
Seyfu Ketema (PhD)	Breeding/Agronomy	Biodiversity Institute
Hirut Kebede (PhD)	Plant Physiology	Biodiversity Institute
Mehari Zewdie (PhD)	Plant Physiology	Biodiversity Institute
Tesfaye Mengiste (MSc)	Cytogenetics	IAR‡
Zerihun Taddele (MSc)	Agronomy	IAR
Abohaye Takle (MSc)	Plant Physiology	IAR
Lekelesh Gugsa (MSc)	Cytology	IAR
Hailu Teferra (PhD)	Plant Breeding	AUA§
Kibebew Asefa (MSc)	Agronomy	AUA
Mulu Ayele (MSc)	Agronomy	AUA

† Biodiversity Institute (former PGRC/E), PO Box 30726, Addis Abeba, Fax: +251-1-613722/ 654976. (Plant genetic resources and related research)

‡ Institute of Agricultural Research (IAR), PO Box 2003, Addis Abeba, Fax: +251-1-611222. (Crop research, including breeding)

§ Alemaya University of Agriculture, PO Box 138, Alemaya, Dire Dawa, Tel.: +251-05-111399/ 111400, Fax: +251-05-114008. (Crop research, including breeding)

Appendix II. Centres maintaining collections of tef

Centre	No. of accessions
Ethiopia Biodiversity Institute PO Box 30726, Addis Abeba Fax: +251-1-613722/654976	3842
Germany Institute of Crop Science, Federal Research Centre for Agriculture (FAL), Bundesallee 50, 38116 Braunschweig	30
Institute for Plant Genetics and Crop Plant Research (IPK) - Genebank, Corrensstr. 3, 06466 Gatersleben Fax: +49-39482-5155	5
Japan Department of Genetic Resources, I Nat. Inst. of Agrobio. Resources, Tsukuba-gun, Ibaraki-ken 305, l-l Kannondai, 3-chone, Yatabe-machi	30
Republic of Yemen Agricultural Research and Extension Authority, PO Box 87148, Dhamar	2
Russian Federation N.I. Vavilov All-Russian Research Institute of Plant Industry, Bolshaya Morskaya Str. 44, St. Petersburg, 190000 Fax: +7-812-311-8762	14
Slovak Republic Botanical Garden of the University of Agriculture, Trieda A. Hlinku 2, 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., Plas Gogerddan, Aberystwyth, Dyfed SY23 3EB	3

USA

Western Reg. Plant Introd. Station USDA-ARS, Washington State University, 59, Johnson Hall, Pullman, WA 99164-6402,	368
National Seed Storage Laboratory USDA-ARS Colorado State University, Fort Collins, Colorado 80523	341

Related IPGRI publications

Promoting the conservation and use of underutilized and neglected crops.

1.	Physic nut *(Jatropha curcas* L.)	1996
2.	Yam bean *(Pachyrhizus* DC.)	1996
3.	Coriander (Coriandrum *sativum* L.)	1996
4.	Hulled wheats	1996
5.	Niger (Guizotia *abyssinica* (L. f.) Cass.)	1996
6.	Pili nut *(Canarium ovatum* Engl.)	1996
7.	Safflower *(Carthamus tinctorius* L.)	1996
8.	Chayote *(Sechium edule* (Jacq.) Sw.)	1996
9.	Bambara groundnut *(Vigna subterranea* (L.) Verdc.)	1997
10.	Breadfruit *(Artocarpus altilis* (Parkinson) Fosberg)	1997
11.	Cat's whiskers *(Cleome gyandra* L.)	1997

Coffee Genetic Resources	1980
Genetic Resources of Tree Species in Arid and Semi-arid Areas	1980
Genetic Resources of Amaranths	1981
Genetic Resources of Cocoa	1981
Genetic Resources of Tomatoes and Wild Relatives	1981
Genetic Resources of *Allium* Species	1982
Genetic Resources of Citrus	1982
Genetic Resources of Sugarcane	1982
Genetic Resources of *Vigna* Species	1982
Genetic Resources of *Vitis* Species	1983
Genetic Resources of *Capsicum*	1983
Genetic Resources of Cucurbitaceae	1983
Genetic Resources of Cassava and Wild Relatives	1983
Genetic Resources of Soyabean	1983
Genetic Resources of *Abelmoschus* (Okra)	1984
Genetic Resources of *Hevea*	1984
Genetic Resources of Wheat: A Survey and Strategy for Collecting	1984
A World Survey of Sorghum and Millets Germplasm	1984
Genetic Resources of Tropical and Sub-Tropical Fruits and Nuts (Excluding *Musa)*	1986

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