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Lodging and its impact on grain yield and quality of tef [*Eragrostis tef* (Zucc.) Trotter] - A review

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Abstract

Tef belongs to the grass family, Poaceae, sub-family Chloridoideae (Eragrostoideae), tribe Eragrostidae, sub-tribe Eragrostae, and genus *Eragrostis*. Lodging can be defined as the permanent displacement of a plant from the vertical position. Lodging has the highest chances of occurring two or three months before harvesting, usually after ear or panicle emergence. It was a consequence of the use of tall varieties, of inadequate nitrogen management or of unfavorable climate conditions. In tef lodging decrease grain yield and quality, limit mechanized farm. In Ethiopia, lodging of tef is also a common phenomenon and one of the causes for the current low grain yields and leads to poor quality of tef product. The paper, therefore, aims at reviewing the lodging, its impact and the way for improving lodging as it is major constraints in tef production. Many breeding strategies have been used for lodging improvement in tef. Recently improvement of lodging resistance in tef are through modern molecular genomics approach, including tilling and eco-tilling, induced mutation, culture techniques and genetics transformation. Convectional breeding method also one method of for improving lodging in tef but there is lack of sufficient genetic variability in lodging resistance and the unfavorable correlation between lodging resistance and yield trait.

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Introduction

Tef belongs to the grass family, Poaceae, sub-family Chloridoideae (Eragrostoideae), tribe Eragrostidae, sub-tribe Eragrostae, and genus *Eragrostis*. The genus Eragrostis comprises about 350 species (Watson and Dallawitz, 1992). Although the crop species had several synonyms previously used by several authors, its presently most accepted binomial nomenclature is *Eragrostis 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.

Lodging can be defined as the permanent displacement of a plant from the vertical position (Berry et al., 2004). When stems of normally upright plants fall over and do not return to their upright position, plant is said to have lodged (Pinthus, 1973). Lodging is also regarded as an abundance disease which restricts the exploitation of yield promoting factor. Although bending at base of the peduncle has also been considered as lodging (Patterson et al., 1957). Lodging is often not distributed uniformly throughout an affected field but may be scattered over certain sections or spots. Uncertainty in climatic and weather conditions may result in lodging. Lodging, be it a consequence of the use of tall varieties, of inadequate nitrogen management or of unfavorable climate conditions is one of the main barriers on the way to higher mean yields and an enhanced quality of cereal crops (Floss, 2004).

In general, lodging was provoked due to high velocity winds in February, March and April coupled with rainfall especially in February and March at vegetative and grain filing stage of the crop (Khakwani et al., 2010). The situation further aggravated due to soil textural class, which created temporarily water logged condition and this favored the root lodging of the crop. Lodging is a most chronic constraint, which is causing tremendous yield reduction in crop plants; therefore, better understanding to control lodging-induced adversities or to enhance lodging resistance in cereals is imperative.

Lodging is a complicated phenomenon that is influenced by many factors including wind, rain, topography, soil type, previous crop, husbandry, and disease. It is frequently associated with conditions that promote plant growth such as an abundant supply of nutrients. Significant progress was made during the 1950s, 1960s, and 1970s to reduce lodging risk by the introduction of semi-dwarf varieties. These shorter varieties had a greater lodging resistance and could respond to greater amounts of fertilizers. For these reasons the introduction of semi-dwarf varieties was one of the most significant reasons for the steady improvement in grain yields starting in the late 1960s, which has resulted in cereal yields increasing by as much as 1 t ha^{-1} per decade in Western Europe and 0.5 t ha^{-1} in many American and Asian countries (Conway, 1997).

Lodging is identified as one of the constraints to the increase of the yield of tef during production. Lodging indirectly prevents the attainment of grain yield increase in tef through the use of ample amount of nitrogen fertilizers by limiting the amount to be used. This is so because the uses of nitrogen fertilizers on the current cultivars which are susceptible to lodging under the present production techniques enhance lodging which decreases yield. Lodging limits mechanized large scale production of tef by making mechanized harvesting difficult and also makes harvesting by hand in the traditional way, time consuming and tiresome. In addition lodging causes direct yield loss in tef through affecting important yield components such as 1000 seed weight and grain yield per panicle (Seyfu, 1993).

In Ethiopia, lodging of tef is also a common phenomenon and one of the causes for the current low grain yields and leads to poor quality of tef product. It increases cost of harvesting with decrease in quality because it occurs close to harvest and as tef are prone to lodging near harvest. The paper, therefore, aims at reviewing the lodging, its impact and the way for improving lodging as it is major constraints in tef production.

Type of lodging

Lodging in tef can be classified into two major and three subcategories. The two major lodging categories in tef are: Transient and permanent lodging. Permanent lodging is further divided in to three subcategories of, bend lodging; break lodging and root lodging (Seyfu, 1993).

Transient lodging

Transient lodging transient lodging occurs before heading and its temporary since the plant suffering from it are able to regain their upright position through the meristematic activity of the node. It is caused by heavy rain, strong wind or the combination of; occurring at seedling, tillering or jointing stage. It’s not critically economic importance, since the plant resumes their normal upright position.

Permanent lodging

Permanent lodging occurs after heading and is a permanent displacement of the plant from the upright position. It’s subdivided in to three.

Bend lodging –is the type of permanent lodging where the plant loses elasticity and bend without any breakage while the root are securely fixed in the soil but is unable to grow upright again because the stem tissues are now all mature.

Break lodging –Is differ from bend lodging in having a broken stem, breakage usually taking place near the base of the peduncle. In both bend and break lodging the root remain securely fixed in the soil.

Root lodging –Occurs when the whole plant is over timed or uprooted, while the stems remain straight and intact.

Bend lodging is the common and most widely occurring type of permanent lodging and is of considerable economic importance, since it cause losses in seed and straw yield, create favorable conditions for the spread of disease and insect pest and cause problem in harvesting. In contrast bend lodging is the most significant; break lodging is of minor concern and root lodging, relatively unimportant in tef.

Impact of Lodging on Grain Yield and Quality

Grain Yield

In plants, that have lodged, respiration continues in the upper parts of plants and depletes the stored carbohydrate reserve in other parts of plant. The weakest plant, following loss of stored carbohydrates become more susceptible to infection by diseases or damage by insects (Dahiya et al., 2018). It reduce cereal yield by reducing the grain size and number or through reducing the amount of crop that can be recovered at harvest. This section deals only with physiological reductions in yield associated with lodging. The greatest lodging-induced reductions in grain yield occur when crops are lodged flat at anthesis or early on in grain filling. Smaller yield losses have been observed when the angle of lodging is less than 90^0 from the vertical. Smaller yield losses also occur when lodging occurs at a later stage of development. Lodging in tef causes damage to the vegetative part of the plant, due to rotting and the fast spread of pests and diseases; it renders the straw relatively useless as fodder and also reduces grain yield. The overall loss in grain yield due to lodging is estimated to be within the range of 11-22% and an average loss of 17% (Seyfu, 1993).

Grain Quality

Lodging may cause shriveling of the grain and reduce its test weight. It may reduce milling quality of seed. In situ seed germination may occur in lodged plants due to conductive environment especially for cultivars with weak seed dormancy. As a result, lodging could cause great losses in both grain yield and quality. In addition, it also causes difficulties in harvest operations, increases demand for grain drying, and consequently results in increased production cost (Hoshikawa and Wang, 1990). In tef its significantly lowers 1000 seed weight i.e. by 35%, reduces grain yield per panicle by 51%, decreases percent of germination by 40% and rate of germination by 44% (Seyfu, 1983).

Method of lodging improvement in tef

Tef has a week stem and a shallow root system, leading to lodging (Ayele et al., 2001; Van Delden et al., 2010), which is one of the main production problems, causing yield losses of 11 to 25% (Seyfu, 1993). Lodging severely affects grain yield and straw quality (Kebebew et al., 2011). Lodging of tef is also a main constraint limiting fertilizer application. Use of nitrogenous fertilizers enhances lodging (Feyera et al., 2014; Teklay and Girmay, 2016). Presently row sowing of tef seeds is being introduced to farmers in order to reduce plant populations and hence reduce lodging. However, drilling of the small sized tef seed is difficult, tedious and expensive, as it requires much human labour, and there are no small-scale matching machines available for row sowing.

By the time wheat breeders and agronomists developed lodging resistant semi-dwarf wheat varieties that transformed food production in the developing world in what it's known as 'The Green Revolution', but scientific tef improvement was only in the inception stage and only in Ethiopia. According to a recent review by Kebebew et al., (2011), during the first phase of tef research, the emphasis was on germplasm collection/acquisition, characterization and conservation. However, as the scale and scope of research started to expand, the focus has shifted to specific production constraints.

Lodging is the major constraint to yield increases in tef, while a number of genetic and agronomic factors are involved (Kebebew et al., 2011). Tef estimated yield loss due to lodging can be as high as 30% (Seyfu, 1997). Tef breeders have screened hundreds and thousands of tef germplasm accessions and found no lodging-resistant tef types in the existing tef germplasm in spite of the existence of wide variation in lodging resistance related traits such as plant height and culm thickness. With the discovery of the conventional stereo-scope aided tef emasculation and pollination technique attempts to get recombinants with short height and thick Culm were unsuccessful due to the apparent linkage between these two traits (Kebebew et al., 2003).

Lodging Syndrome

A multi-faceted approach involving different disciplines has been suggested to combat the problem of lodging in tef. This involves: a) cultural practices such as row planting, optimum plant population density (low seed rate), optimum nitrogen fertilization, and deep seeding; b) use of chemicals that reduce the height of the plant especially of the length of the culm and thereby indirectly increase the tolerance of the plant to lodging; c) use of improved farm implements and machinery for planting; and d) breeding for lodging tolerant cultivar (Kebebew et al., 2013).

Breeding for lodging tolerant cultivars:-The latter, in turn, involves: I) direct selection for dwarf and semi-dwarf plant height, stem strength and large seed size; b) intra- and inter-specific hybridization with a view to increase the number of crosses so as to increase the chances for crossing over to get recombinants with breakage of the apparent linkage between plant height and stem thickness; c) induced mutagenesis to g et mutants with lodging resistance traits; and d) modern molecular or genomics approach including TILLING and Eco-TILLING, QTL analysis, comparative and association mapping, in vitro culture techniques, and genetic transformation (Kebebew et al., 2013).

Conventional breeding strategies

In the overall tef breeding strategies the following approaches deserve attention: a) systematic germplasm collection/ acquisition coupled with subsequent characterization and evaluation; and b) enhancement of the hybridization program. In the tef crossing program, due focus is needed to be given to: a) increasing the number of crosses to get desirable recombinants; b) divergent crossing involving intra- but especially also inter-specific crosses to harness the potentials of wide crosses and useful alleles existing in related species; c) targeted crossing addressing various desirable traits; and d) ideo-type based breeding for different desirable agronomic, and biotic and abiotic stress tolerance traits (Kebebew et al., 2013).

The challenge of improving lodging resistance by conventional approaches is the lack of sufficient genetic variability in lodging resistance. Another challenge is the apparent unfavourable correlation between lodging resistance and yield related traits such as plant height, panicle length, panicle form, grain and shoot biomass yield (Kebebew et al., 2011). In light of the foregoing situations, one of the likely options has been to create variability through induced mutation techniques using different mutagenic agents. In tef, this has been attempted since the early 1970s when the crop was considered entirely cleistogamous and not amenable to cross-hybridization.

Biotechnological approaches

In the biotechnology approaches, areas that need to be dealt with include: a) in vitro culture techniques especially di-haploid (DH) production systems; b) development of user-friendly molecular markers and sufficiently dense genetic linkage maps; c) QTL analysis and mapping; d) marker assisted selection (MAS); e) comparative genomics and association mapping; f) TILLING and Eco-TILLING; g) genome sequence and annotation ; h) genetic transformation; and i) harnessing important tef genes.

Induced mutation using gamma rays and ethyl-methanesulphonate (EMS) were employed before and after the discovery of the conventional tef crossing techniques. Subsequent screenings of the mutagenized populations under field conditions were not successful in identifying lodging-resistant/lodging-tolerant lines.

Not satisfied with the slow progress of conventional genetic improvement approaches in achieving the specific objectives, tef researchers started to look for alternative tools to complement the previous efforts, and with that studies of tef genomics started to emerge (Kebebew et al., 2013).

Agronomy and crop protection

Planting on raised beds is one of the better options to control lodging (Tripathi et al., 2005). Bed planting also reduced the wheat plant height and improved the grain yields by significantly affecting the lodging score (Sayre and Hobbs, 1998). As equally important to improving the crop to make it fit to different agro-ecologies is the manipulation of the crop-growing environment to make it fit for the crop.

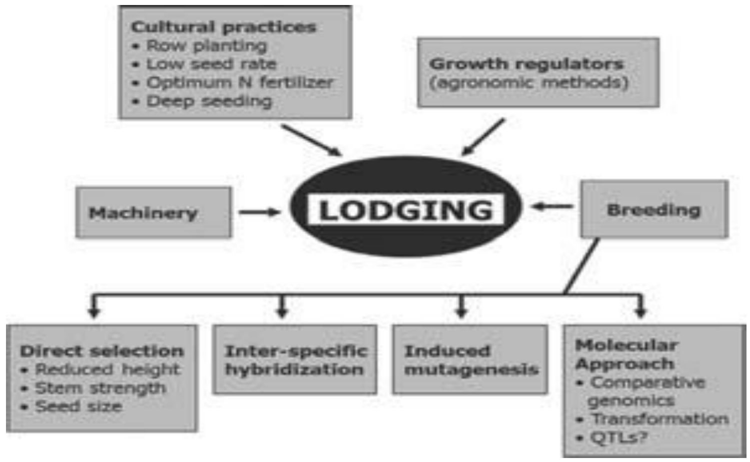

Fig. 1: The strategies toward tackling the lodging problem in tef are briefly outlined below Source- Kebebew et al., (2013).

Important areas of focus with regard to agronomy and management are: a) soil fertility management; b) research in various cropping systems; iii) improved management of problematic soils (acidity, salinity and waterlogging); iv) management of drought stress; and v) potentials of irrigation use in tef.

Tef production and quality are highly affected by lodging that result in substantial reduction in yield. It is caused by the use of tall tef varieties by farmers, inadequate nitrogen application, and high velocity of wind and soil textural class. Lodging also limit mechanized large-scale production by making mechanized weeding and harvesting difficult and forced to manual weeding and harvesting. Tef has week stem and shallow root system that result in high prone to lodging. The greatest lodging in reduction of the grain yield occur when the crop are lodged flat at anthesis or early at the grain filling. Generally, loss in grain yield due to lodging can be estimated to the range of 11-22%. Use of appropriate nitrogen fertilization, proper seed rate and row planting is an important agronomic practice used to reduce lodging in tef production area at farmer level.

Genetic diversity particularly for lodging and related trait has been not sufficient to bring about the needed improvement in lodging resistance of the crop. Many breeding strategies have been used for lodging improvement in tef. Recently improvement of lodging resistance in tef are through modern molecular genomics approach, including tilling and Eco-tilling, induced mutation, culture techniques and genetics transformation. Convectional breeding method also one method of for improving lodging in tef but there is lack of sufficient genetic variability in lodging resistance and the unfavorable correlation between lodging resistance and yield trait.

However for accelerating the improvement against lodging problem there must be integrated with the multidiscipline like agronomic, crop protection, biotechnology and other related discipline to overcome the problem.

Conflict of interest statement

Authors declare that they have no conflict of interest.

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