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SUMMARY OF DOCTORAL THESIS

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Title: A genome-wide association study on lodging resistant related traits in the Ethiopian germplasm collections of teff (*Eragrostis tef*)

（ エチオピアのテフ（*Eragrostis tef*）遺伝資源における倒伏耐性関連形質に関するゲノムワイド関連解析 ）

Teff (*Eragrostis tef*) plays an important role in the food and nutrition security of about half of the population in Ethiopia. The crop is rarely known in the other world as a food crop for long time. Due to its gluten freeness and high in minerals and dietary fiber, however, it is attracting other consumers in the world and seen as a potential component of healthy food and beverage production in the future. In addition to the nutritional importance, teff has an ecological advantage over other cereal crops. Adaptiveness to extreme growing conditions particularly tolerant to water logging Vertisol areas where other cereals might fail is consistently mentioned as one of the top merits of the crop. On the other hand, teff is tolerant to storage pests such as weevils and has higher seed longevity even under traditional storage facilities. In Ethiopia where drought and climate variability affect crop production, teff continues one of the main cash crops as both the grain and straw fetch high price. Despite the merits, the productivity of teff is very low which is about 1.76 t/ha. Lodging is the major yield and quality limiting factor of teff production directly and it also hinders farmers from applying optimum fertilizer rate fearing it could aggravate lodging.

Efforts have been carried out to search and utilize dwarfing genes in teff lodging resistance cultivar development. The attempt however, was not successful mainly due to strong association of reduced plant height with weak culm and lower grain yield potential. On the other hand, the smaller floret size limits the efficiency of hybridization and trait inheritance studies. Consequently, mutation more recently TILLING (Targeting Induced Local Lesions in Genomes) becoming an option to source new variabilities for lodging resistance. Lack of scientific knowledge is the key problem in the breeding program of teff particularly sources of culm mechanical strength, the genetic diversity and responsible genomic regions that govern lodging resistant related traits is either limited or yet not explored. Phenotyping and genotyping studies were carried out using three hundred twenty teff genotypes under the field and screenhouse conditions with the objectives of (i) to evaluate the yield potential and determine the variabilities of teff genotypes under lodging controlled and non-controlled growing conditions, (ii) to examine the variability of stem mechanical properties and agro-morphological traits with their associations with lodging, and (iii) to explore the genetic diversity, population structure and trait-marker associations using next generation sequencing (NGS) method.

The first chapter outlines the general introduction of the thesis. It presents the botanical description, its origin and distribution, the importance, production constraints, the lodging effect, previous research undertakings and the statement of the problem and research gaps. The general and specific objectives and the overall structure of the thesis are also included.

Chapter two presents the grain yield potential, heritability, and genetic advance under selection of diverse teff genotypes under intensive and field growing condition. It also outlined trait relationships at the phenotypic and genotypic levels. Under the intensive growing condition when lodging was

artificially controlled with support, wider range of harvest index was observed than the field growing condition. On the other hand, high coefficient of variation, heritability and expected genetic advance for grain yield were observed in both experiments. The harvest index showed strong positive relationship with grain yield under the intensive management but weak positive correlation with grain yield and a negative correlation with biomass under the field experiment, in which lodging was relatively higher. These suggests the presence of wide genetic potential in the teff gene pool and its opportunity to enhance the productivity.

The third chapter characterizes teff germplasm collections for lodging resistance in terms of the biomechanical properties of the culm and lodging related agro-morphological traits using three hundred twenty teff genotypes. This study revealed the presence of wide variability in both biomechanical and agro-morphological traits among the accessions. It is also noted that lodging index, failure moment, pushing resistance and lodging related traits such as culm diameter had a strong positive correlation with plant height. This suggests the shorter the plant height the lower the material strength of the teff culm. In contrast, tiller number showed a significant negative correlation with lodging index. The peduncle–panicle length, which generally accounted for 59% of the plant height, should be a target when breeding for semi-dwarfism. Root system development, which reached a depth of more than 1 m in tall and 57 cm in dwarf teff accessions, signifies the presence of genetic variabilities for future root lodging studies in teff, and it may also explain why teff performs well in drought-prone areas of Ethiopia. The observations indicated that stem failure account more likely than root failure for lodging in teff. However, our observations that the tillers initially grew mainly laterally and start to hold upright later in the growth stage further implies space competition at the crown, and teff has a relatively narrow root–shoot jointing point (crown). Thus, root failure could not be ruled out and needs detailed investigation in the future.

The fourth chapter outlines the genetic diversity, population structure and dissect the genetic basis controlling lodging resistant related traits of 179 teff genotypes through genome-wide association study (GWAS) using double digest Restriction site Associate DNA sequencing (ddRADseq) derived single nucleotide polymorphisms (SNPs). The admixture model bar chart of a STRUCUTURE program, neighbor-joining phylogenetic tree and the PCA scatter plot of TASSEL program consistently showed the presence of three sub-populations. The dendrogram based on biomechanical and agro-morphological traits contributing to lodging resistance also showed reasonable level of similarities among the members of each sub-population. The analysis of molecular variance showed only 1% of the variations was due to genetic variability among the sub-populations, whereas 99% of the variation was within populations. Further the low value of F_{ST} which is about 0.025, implies smaller population differentiation in the teff population panel. Significant SNP-trait associations were identified for stem strength, lodging index, stem diameter and tiller number. Therefore, the information generated here will help to prioritize breeding targets, and to commence advanced molecular research such as genomic selection and marker development for efficient selection.

The fifth chapter is about the general conclusions and future directions. The observed high grain yield performance, wider range of harvest index in the intensive management condition coupled with the moderate to high coefficient of genetic variation, heritability and genetic advance witnessed the genetic potential of teff for further improvement. The analysis for biomechanical and agro-morphological traits revealed significant variation among the genotypes. Higher stem strength, wider stem diameter, and reduced tiller number found important lodging related traits, all of which were found in the tall plant stature. The GWAS also identified significantly associated SNPs for stem strength, stem diameter, and tiller number. Thus, strong hybridization program focusing desirable trait recombination and selection based on the lodging resistant related traits could benefit the future teff breeding.