Vol. 13(21), pp. 1042-1052, 24 May, 2018
DOI: 10.5897/AJAR2018.13163
Article Number: C3AA4D657183
ISSN 1991-637X

http://www.academicjournals.org/AJAR

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African Journal of Agricultural Research

Full Length Research Paper

Major biotic maize production stresses in Ethiopia and their management through host resistance

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Received 1 April, 2018; Accepted 7 May, 2018

Biotic stresses are recently evolving very rapidly and posing significant yield losses of maize production in Ethiopia. A number of high yielding maize hybrids, initially developed as tolerant/resistant, have been taken out of production due to their susceptibility to major maize diseases. Furthermore, recent disease and insect pest epidemics have clearly shown the importance of breeding maize for biotic stresses and study the genetics of resistance to the major maize disease pathogens, insect pests and parasitic weeds. This paper gives the general perspective of the major biotic maize production stresses in Ethiopia and the interventions made locally and globally to control these stresses using host resistance. More emphasis was given to grey leaf spot (GLS), turcicum leaf blight (TLB), common leaf rust (CLR), maize streak disease (MSD), maize lethal necrosis (MLN), maize weevil, stalk borers, fall armyworm and *Striga.* Approaches to conducting genetic analysis and achieving durable host resistance to these stresses, where applicable, are discussed. This information will be used for breeders, private and public maize seed and grain growers who are targeting to operate in Ethiopia and Eastern Africa.

Key words: Striga, biotic stress, diseases, host resistance, host - pathogen interaction, maize, pests.

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important staple food crops in sub-Saharan Africa (SSA), predominantly produced and consumed directly by the smallholder farmers (Shiferaw et al., 2011). In Ethiopia, maize is one of the principal cereal crops ranking first in total production and productivity, and second to tef (*Eragrostis*

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tef) in area coverage. A total of 7.8 million tons of maize (31% of the total cereal) was produced on 2.1 million hectares (21% of the total area planted cereals) of land by nearly 11 million small households (31% of the total cereal) in 2016 (FAO, 2017). Maize is everything for the Ethiopian maize farmers. Three forth of the maize produced is consumed at the house hold level by the small-scale producers themselves (CSA, 2017). The grain is consumed in different forms of food; the stover is used as feed, fuel and construction material. Besides, it serves as a major source of income and means of employment for tens of millions of farming and business communities. Due to its widespread significance in the country, maize is one of the strategic field crops targeted to ensure food security in Ethiopia.

Despite the importance of maize as a principal food crop, its average yield in Ethiopia (3.6 tons ha^{-1}) is still lower than that of the world's average (5.6 t ha^{-1} in 2016) (FAO, 2017). A significant portion of this yield gap is attributable to biotic and abiotic stresses, slow turnover of varieties tolerant or resistant to these stresses and low level use of improved management and other inputs (Worku et al., 2012; Abate et al., 2017). Some of the main abiotic factors affecting maize production and productivity are drought, heat, soil acidity, frost and poor soil fertility mainly in N and P. Biotic stresses hindering maize production in Ethiopia are diseases (e.g., Grey Leaf Spot, TurcicumLeaf Blight, Common Leaf Rust, Maize Streak Virus, Maize Lethal Necrosis), parasitic weeds (mainly *Strigahermontica*), and insect pests (such as the maize stem borer, maize weevils and the newly emerged fall armyworm).

While more food is needed to feed the ever-increasing world population (Clover, 2003; van Ittersum et al., 2016), the effects of climate change is becoming a great challenge threatening global food security (Godfray et al., 2010). It is now well understood that agriculture faces many threats from climate change, drought, heat, irregular weather and emergence of new diseases and pests among other environmental challenges. The impact of climate change is likely to be more severe in Sub-Saharan Africa (SSA) due to the high dependence of the region on rain-fed agriculture (Cooper et al., 2008; Fisher et al., 2015). The spread of insect pests, plant diseases and invasive alien plant species to new regions, as the world's climate changes, is a threat to farmers globally, especially in Africa where climate change effects are projected to be the most severe in the world (Swaminathan and Kesavan, 2012; Biber-Freudenberger et al., 2016; Early et al., 2016). It is anticipated that the spread of diseases, insect pests and weeds will potentially cause the loss of more than 40% of the world's food supply. Of the many countries in SSA, Ethiopia is one of the climate change vulnerable countries due to its agriculture led economy (Conway and Schipper, 2011).

In this paper, the general perspective of major biotic maize production constraints in Ethiopia and the associated host resistance interventions employed locally and globally to control these constraints were reviewed. The areas of research gaps and the approaches followed to conduct genetic analysis of host-pathogen interaction were also outlined in detail. Finally, viable future research directions towards climate smart management of maize biotic stresses were suggested.

THE BIOTIC DISEASE CONSTRAINTS OF MAIZE IN ETHIOPIA

Diseases of economic significance in maize production systems of Ethiopia are TLB (caused by *Exserohilum turcicum*), GLS (caused by *Cercospora zeae-maydis*), streak disease of maize (maize streak virus), CLR (caused by *Puccinia sorghi*) (Vivek et al*.,* 2001; Mosisa et al., 2012; Tilahun et al., 2012) and the recently emerged viral disease, MLN caused by the combination of maize chlorotic mottle virus (MCMV) and sugar cane mosaic virus (SCMV)(Mahuku et al., 2015).These diseases are known to cause significant yield losses in favorable environments; especially, when the combinations of these two or more diseases affect maize.

Grey leaf spot

Grey leaf spots (GLS), caused by *C. zeae-maydis*, is an important foliar disease of maize worldwide. The disease was originally described from southern Illinois in 1925 (Tehon and Daniels, 1925; Carson and Goodman, 2006). GLS is a major economic concern in many maize growing regions of the world (Gevers et al., 1994; Nutter et al., 1999; Guo-hui, 2009). The disease was reported as a threat to maize production in the USA in the 1980s (Latterell and Rossi, 1983; Zhang et al., 2012), in South Africa in the 1990s (Latterell and Rossi, 1983; Gevers et al., 1994), and currently known to have widespread distribution in maize production areas worldwide, including South America (Pozar et al., 2009), China (Zhang et al., 2012) and Ethiopia (Wegary et al., 2001).

In Ethiopia, the disease was first reported in 1999 (Tefferi, 1999) on a few maize farms. Later, the disease was spread to all major maize producing mid altitude sub-humid agro-ecology of the country. A major epidemic occurred in early 2000s which caused considerable maize grain yield losses (Wegary et al., 2001; Tilahun et al., 2012). To date, the disease is one of the most important threats to maize production in the country, causing yield losses as high as 29.1% (Wegary et al., 2004).

No major resistance genes are known for GLS in

Table 1. Responses of parental lines of some released hybrids to turcicum leaf blight (TLB) and grey leaf spot (GLS) diseases in Ethiopia.

Inbred line	TLB (1 - 5)	Reaction type	Sources	GLS (1 - 5)	Reaction type	Sources
CML202	2.0	R	Abera et al., 2016	2.50	R	EIAR, Unpublished data
BKL004	2.0	R	Abera et al., 2016	1.8	R	EIAR, Unpublished data
144-7-b	1.9	R	Abera et al., 2016	1.2	R	Tilahun et al. 2012
BKL001	2.0	R	Abera et al., 2016	1.5	R	EIAR, Unpublished data
142-1-e	2.0	R	Abera et al., 2016	1.3	R	Tilahun et al., 2012
A7033	2.9	S	Abera et al., 2016	2.8	S	EIAR, Unpublished data
SC22	2.8	S	Abera et al., 2016	2.5	R	Tilahun et al., 2012
124-b (109)	2.9	S	Abera et al., 2016	2.7	S	Tilahun et al., 2012
CML197	3.4	S	Tilahun et al. 2012	3.2	S	Tilahun et al., 2012
CML395	2.1	R	EIAR, Unpublished data	3.0	S	EIAR, Unpublished data
CML144	1.8	R	Tilahun *et al*. 2012	2.0	R	Tilahun et al. 2012
BKL003	2.25	R	EIAR, Unpublished data	2.0	R	EIAR, Unpublished data
CML444	2.0	R	EIAR, Unpublished data	3.1	S	EIAR,Unpublished data

R, resistant; S, susceptible, GLS, grey leaf spot; TLB, turccicum leaf blight; EIAR, Ethiopian Institute of Agricultural Research. Disease scores are on a 1 to 5 scale where 1 is being highly resistant and 5 is being highly susceptible.

maize. Although there was an initial report of major genes for GLS resistance (Gevers and Lake, 1994), this was later disproved by Gordon et al*.* (2004). Resistance to GLS in maize is quantitatively inherited and is controlled primarily by additive gene action (Clements et al*.,* 2000; Menkir and Ayodele, 2005; Gordon et al., 2006; Benson et al., 2015). Many QTLs underlying GLS resistance have been identified across the 10 maize chromosomes in various mapping populations (Bubeck et al., 1993; Maroof et al., 1996; Clements et al., 2000; Lehmensiek et al., 2001; Juliatti et al., 2009; Pozar et al., 2009; Zwonitzer et al., 2010; Shi et al., 2014; Berger et al., 2014).

Some elite maize inbred lines, for example, CML444 (Okello et al., 2006; Berger et al., 2014) carry QTL conferring resistance to GLS. This inbred line is in the pedigree of high yielding and drought tolerant maize hybrid, MH140, released in many African countries including Ethiopia. However, CML444 have been found to be susceptible to GLS in Ethiopia under artificial inoculation (Table 1). This could be due to the variability in the *Cercospora species* causing the diseases, or differences in the races of the pathogen. On the other hand, there are maize inbred lines derived from 'Ecuador573' and CIMMYT germplasm which are resistant to the most prevalent foliar disease of maize in Ethiopia (GLS, TLB and CLR). For example, the hybrids and parents of recently released drought tolerant varieties, such as BH546, BH547 and BH661, are resistant to these three fungal diseases. These inbred lines could be used as potential sources of resistance against these major foliar diseases of maize in Ethiopia. The host-pathogen interaction, diversity and the prevalent species of *Cercospora* in Ethiopia has not been determined.

Turcicum leaf blight

Turcicum leaf blight (TLB) caused by *Exserohilum turcicum* (Pass.) is known to infect maize from the seedling stage to maturity. The initial symptoms are small elliptical spots on the leaves as grayish green with water-soaked lesions parallel to leaf margins. Later, the spots turn greenish with age and increase in size, and finally attaining a spindle shape with long elliptical grayish or tan lesions. It causes premature death of blighted leaves, if the disease starts at an early stage (Chandrashekara et al., 2014). The disease can cause loss of the nutritive value of maize as fodder (Payak and Renfro, 1968). Reductions of germination capacity, vigor, grain yield and total sugar content (Ferguson and Carson, 2004), and restriction of starch formation (Cuq et al., 1993; Henry and Kettlewell, 2012) by the pathogen have also been reported. The disease has a wide host range and a high pathogenic variability with several races already reported in different parts of the world (Pratt, 2003; Agrios, 2005). The disease has been reported throughout the world wherever maize is cultivated (Atac, 1984; Leonard et al., 1985; Adipala et al., 1993; Shiferaw et al., 2011). TLB can be severe in mid-altitude tropical regions where high humidity, low temperature and cloudy weather prevail during the maize growing season (Harlapur et al., 2000; Singh et al., 2004).

Severe grain yield losses as high as 28 to 91% due to TLB have been reported in several parts of the world

(Gowda et al., 1992; Harlapur et al*.,* 2000). The genetic nature of TLB resistance has been determined to be quantitative which can be exploited for development of resistant cultivars (Kumar et al., 2011; Abera et al., 2016; Debela et al., 2017).

TLB is one of the major maize diseases having wide distribution and high economic importance in Ethiopia. The disease is prevalent from low land humid through highland humid agro-ecologies during the wet rainy seasons. There are maize cultivars that have been made obsolete (put out of production) due to their susceptibility to TLB. For example, 'Beletech', an open pollinated variety released in 1990 for lodging resistance, and 'BH541', a high yielding hybrid variety released in 2002, were withdrawn from production due to their susceptibility to TLB (Tilahun et al., 2012). Another very recent example is 'BH543', a high yielding and N-efficient hybrid released in 2005, which is being withdrawn from most maize producing areas due to its susceptibility to this disease. There is no documented information on the existence of different races of TLB causing pathogen in Ethiopia. However, the variable reaction of maize inbred lines like '142–1–e' and '144–7–b', derived from 'Ecuador573', to the diseases when planted in different regions may imply the presence of different races of the causative pathogen within the country. These inbred lines, although known to be immune to TLB in the western maize belt of Ethiopia, are susceptible to the disease in the southern part of the country. This clearly indicates the need to study the pathogen's diversity and host–pathogen interactions under different maize growing environments, in order to develop stable maize cultivars that are more resistant to the disease than the currently available TLB tolerant/resistant hybrids (Debela et al., 2017).

Previous screening works under artificial inoculation against the disease showed that some of the commercial parental inbred lines are susceptible to TLB (Table 1). However, the national breeding program of EIAR has elite inbred lines that are resistant to the disease. Efforts have been made to introduce resistance gene(s) to a good combiner, TLB susceptible inbred line, CML197, through backcrossing with TLB resistant line, 142-1-e. The efforts were unsuccessful as the number of resistance genes carried by the donor line and their mode of inheritance was not well defined prior to the start-up of the backcrossing program. Some investigators have reported single dominant and recessive genes as well as QTLs for resistance to TLB in maize (Welz and Geiger, 2000; Poland et al*.,* 2011). When the resistance gene in the donor parent is recessive, there should be a selfing stage after backcrossing as the backcross progenies are heterozygote susceptible. This was not followed in the previous backcrossing of 142-1e and CML197. Again, when the resistance is controlled by polygenic, the backcross method may not be an efficient method. It is therefore, important to first determine the mode of inheritance of the genes involved in conferring TLB resistance to the elite inbred lines using classical Mendelian genetics. In addition, tests of allelism needs to be done to determine whether the genes carried by each of the elite inbred lines co-segregate or are independent.

Maize streak disease

Maize streak disease is caused by Maize streak virus (MSV). It is a major viral disease of maize in sub-Saharan Africa (Ininda et al., 2006; Magenya et al., 2008; Martin and Shepherd, 2009; Karavina, 2014). There are reports of serious epidemics in more than 20 African countries including Angola, Benin, Burkina Faso, Cameroon, Democratic Republic of Congo, Ghana, Kenya, Malawi, Mozambique, Nigeria Uganda, South Sudan and Zimbabwe (Wambugu and Delpuech, 2000; Lagat et al*.,* 2008; Magenya et al*.,* 2008). Similar epidemics had occurred in south western Ethiopia in 2013, which caused yield losses of 50 to 100% on farmers' fields (EIAR, unpublished data).

Eleven strains of MSV are known to exist; named from MSV-A to MSV-K (Shepherd et al., 2010; Monjane et al., 2011). Of these strains MSV-A is known to cause the most severe and economically important form of maize streak virus disease. There are also five strain variants of MSV-A; viz. MSV-A1 to MSV-A4 and MSV-A6. Among these, MSV-A1 is the most widely distributed variant (Karavina, 2014). No information is available regarding which strains and variants are prevalent in Ethiopia.

In Ethiopia, this disease was formerly known only in Gambella (the western low land sub-humid plains bordering South Sudan). But in recent years, the disease is becoming very important in the mid-altitude agro-ecology of Ethiopia and posing a significant threat to maize production in the country (personal observation). Most commercial varieties currently under production are found to be susceptible to the virus. Figure 1 depicts MSV susceptibility of BH540, the most popular hybrid that had 36% maize seed market share in 2013 (Abate et al., 2017).

A number of options have been recommended for management of maize streak disease including cultural, chemical and host plant resistance. The most effective, environmentally friendly and economically viable method of MSV management is by the use of host plant resistance (Lagat et al., 2008). To date, a gene responsible for conferring resistance to MSV is identified as *msv1* (Kyetere et al*.,* 1995; Nair et al., 2015).This gene has been fine mapped (Nair et al., 2015) to chromosome 1 and thus can be a suitable candidate locus for introgression into susceptible germplasm using

Figure 1. A popular maize hybrid, BH540, highly infected by MSV on farmers' field in Benishangul Gumuz, Western Ethiopia.

marker assisted selection (MAS) (Pratt et al., 2003; Nair et al., 2015). One of CIMMYT's elite inbred lines, CML202, is known to harbor this gene (Welz et al., 1998). This inbred line is well adapted to the Ethiopian condition; and is in the pedigrees of two high yielding drought tolerant hybrids (BH546 and BH661). CML202 can, therefore, be used as a potential source of resistance for introducing the gene into the susceptible germplasm using MAS.

There are two open pollinated maize cultivars released for MSV prone areas (Gambella Regional State); namely, 'Gambella Composite' and 'Abo–Bako'. These cultivars were developed by selecting for tolerance to the disease under natural hotspot screening. However, these cultivars were not sufficient to satisfy the recently increasing demand for hybrid maize by the emerging private sector grain and seed producers in this area. This emphasizes the need for targeted MSV tolerant/resistant hybrid maize adaptation and development endeavor in the country. Research and breeding efforts targeted to develop MSV resistant/tolerant germplasm through artificial inoculation will, however, be challenged by the requirement for well-developed insect rearing and inoculation facilities, which could be established in the long run.

Another approach is to introduce MSV resistant cultivars and breeding materials, especially from International Institute of Tropical Agriculture (IITA) where maize genotypes are specifically bred for MSV tolerance, followed by evaluation of the materials in Gambella, the area that represents MSV prone lowland sub-humid agro-ecology, for further evaluation and possible commercialization within that region. This, however, entails establishment of a quarantine site within these MSV affected areas.

Maize lethal necrosis

Maize lethal necrosis disease (MLND) is a result of a combination of two viruses, Maize Chlorotic Mottle Virus (MCMV) and any of the cereal viruses in the *Potyviridae* group, such as Sugar Cane Mosaic Virus (SCMV), Wheat Streak Mosaic Virus (WSMV) or Maize Dwarf Mosaic Virus (MDMV). The double infection of the two viruses gives rise to what is known as MLN (http://mln.cimmyt.org/mln-overview/)

In Africa, the disease was first reported in Kenya in September 2011 (Wangai et al., 2012). Since then, the disease has spread rapidly into other east African countries. To date, the presence of MLN has been confirmed in Rwanda (Adams et al., 2014), Tanzania, Uganda and South Sudan (Isabirye and Rwomushana, 2016), Democratic Republic of Congo (Lukanda et al., 2016), and Ethiopia (Mahuku et al., 2015; Isabirye and Rwomushana, 2016). In Ethiopia, although its first epidemics was reported in the Central Rift Valley in 2014 main season (Mahuku et al., 2015), MLN attack has now been confirmed in all major maize growing areas of the country at varying level of severity (Demissie et al., 2016). Predictions made using genetic algorithm model estimated that Ethiopia has the potential to lose its entire maize area (Isabirye and Rwomushana, 2016) unless effective preventive measures and all available disease management options are taken. In addition to threatening food security directly, MLN has the potential to negatively impact human health and wellbeing via secondary fungal infections which lead to the production of mycotoxins.

Gowda et al.(2015) and Beyene et al. (2017) identified candidate SNPs that confer resistance to MLN. The same study identified inbred lines carrying resistance to the disease that could be used as donors for improving the susceptible germplasm by using MAS or genomic selection. Since the disease can potentially bring the maize sector in Ethiopia to a halt, there is an urgent need to search for resistant maize germplasm to use as source of resistance and/or for direct use as parents of commercial hybrids.

There is an ongoing attempt to evaluate MLN tolerant maize introduced from CIMMYT-Kenya after three years ban of any maize seed introduction from Kenya. In addition, a number of inbred lines from IITA and CIMMYT (other than Kenya) known to be tolerant to MLN are being evaluated and used in the mid-altitude maize breeding program. The recent study by CIMMYT on the inheritance of resistance to MLN in maize (Beyene et al., 2017) will enhance effective quick use of the available MLN tolerant maize germplasm in Ethiopian maize breeding program.

To determine the availability of MLN tolerant germplasm locally, the Ethiopian breeding program has sent the locally available elite maize germplasm to Kenya and screened against MLN at the Naivasha MLN screening facility in collaboration with CIMMYT. The screening included elite breeding lines, commercial OPVs, pipeline and released hybrids, and their parents. The result of screening over two years showed none of the commercial hybrids released for mid-altitude agro ecology (the high potential maize production area in the country) of Ethiopia and their parents are resistant/tolerant to MLN (unpublished data). One of the three pipeline hybrids were tolerant to the disease (average score of 4.5 across two years), however, the parental inbred lines of this hybrid were highly susceptible. While the genetics of inheritance behind such phenomenon is yet to be determined, the pipeline hybrid can hardly be recommended if the seed production is aimed in MLN prone areas.

Out of the released OPVs screened, Gibe2 (a variety tolerant to GLS and drought) and Gibe3 (a high yielding, GLS and TLB resistant variety) were found to be relatively tolerant to MLND (with an average score of 5.0 over two years) (data not shown).

Common leaf rust

Common leaf rust (CLR), caused by *Puccinia sorghi* Schwein, is another important disease of maize in Ethiopia that is widely distributed throughout the major maize growing regions of the country. However, the importance varies from place to place. It is more severe in the southern mid-altitude and the highland sub-humid maize growing agro-ecologies of the country. The first quality protein maize (QPM) hybrid variety registered in Ethiopia, 'BHQP542', was short-lived in the commercial production and seed systems due to this disease.

In maize, major race-specific resistance genes (*Rp*genes) have been used to control common rust (Pataky et al., 2001; Wisser et al., 2006). To date, eight different common rust resistance genes have been mapped (*viz. Rp1, Rp3, Rp4, Rp5, Rp6, Rp7, Rp8* and *Rp9*) (Sucher et al., 2016). However, race-specific resistance is not durable as opposed to quantitative resistance. Pyramiding these genes with the aid of molecular markers linked to the race-specific resistant loci is needed to effectively control the diseases. This approach has been effectively used in other crops to control various crop diseases (Joshi and Nayak, 2010).

MAJOR INSECT PESTS OF MAIZE IN ETHIOPIA

Insect pests are more destructive in the tropical than in the temperate environments because of the favorable climatic conditions that are more conducive for accelerated insect development with numerous overlapping generations leading to high infestation levels and losses.

Maize weevil

The maize weevils, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae), the Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) and the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) are the most important postharvest pests of stored cereal grains (Abate et al., 2000; Demissie et al., 2008; Mwololo et al., 2012). The maize weevil is usually prevalent under warm and humid conditions (Barney et al., 1991); which are mostly manifested under tropical and sub-tropical climates.

Weevils attack in maize can cause both quantity and quality losses (Barney et al., 1991; Sone, 2001; Kaaya et al., 2005). Secondary grain infections by ear rot fungi that develop after weevil attack can also lead to mycotoxins accumulation (Sone, 2001).

Grain resistance against weevil infestation and damage is one of the most sustainable and cheapest methods of minimizing weevil damage in maize especially at smallholder farmer level. Weevil resistance traits have been identified and deployed in maize germplasm to enhance grain resistance against weevil damage (Tipping et al., 1989; Arnason et al., 1993; Dhliwayo and Pixley, 2003).

In Ethiopia, grain losses due to maize weevil are estimated to be 30 to 100% (Demissie et al., 2012b). Different management options including the use of chemicals, botanicals, cultural, host resistance and integrated pest management (IPM) have been recommended (Demissie et al., 2012b). Previous screening works identified a number of maize germplasm with moderate to high level of resistance to this insect pest (Demissie et al., 2012b, 2015). On the other hand, some of the popular commercial hybrid cultivars like 'BH140' and 'BH540' are susceptible to the maize weevil and farmers usually suffer from huge losses in their maize grain storage. The nature of resistance and mode of inheritance to weevil in maize remains ambiguous.

Figure 2. Picture showing typical damage by fall armyworm on maize.

Stem borers

Stem borers are major insect pest constraints to maize production in SSA causing significant yield losses and grain quality degradation. They are most damaging in the larval stages when they tunnel inside the maize stem after hatching; and therefore, very difficult to control. Successful infestation of these borers into plants, and their feeding may cause death of growing points, reduction in number of harvestable ears or may cause structural damage that increases the likelihood of lodging. These pests can also attack maize ears making the cob and the kernels vulnerable to ear rots due to fungal attacks which produce harmful mycotoxins.

There are four species of stem borers that attack the maize plant (Demissie et al., 2012a). In Africa, they are mainly the African stalk borer (*Busseola fusca* Fuller), the spotted stem borer (*Chilo partellus* Swinhoe), the pink stem borer (*Sesamia calamistis* Hampson) and the sugarcane borer (*Eldana saccharina* Walker) (Mailafiya et al., 2009). Yield losses as high as 91% due to stem borers are recorded at hot spot areas in Ethiopia (Abate, 2012). Three species of stem borers (*viz*. *B. fusca*, *C. partellus* and *S. calamistis*) are known to be distributed across maize growing agro-ecologies in Ethiopia (Abate, 2012). However, *B. fusca* and *C. partellus*are the most predominant and economically important stem borers in Ethiopia (Demissie et al*.,* 2012a).

Fall armyworm

Fall armyworm (FAW) (*Spodoptera frugiperda*) is another newborn challenge and pandemic to Africa's crop production (Goergen et al., 2016). The Fall Armyworm is a migratory insect pest known to cause massive destruction of maize crops under warm and humid conditions in America (RAMIREZ-CABRAL et al., 2017). The pest was first detected in Africa in 2016 in Nigeria and subsequently in southern Africa (Goergen et al., 2016). In just one year, the insect moved all the way to East Africa and reached Ethiopia in March 2017; and is now confirmed in more than 30 countries on the continent (Prasanna et al., 2018). There exists a natural variability in maize to FAW attack (Widstrom et al., 1972; Ni et al., 2011,. 2014). Owing to the fact that FAW is a new pest to Ethiopia, the responses of the commercial maize varieties widely cultivated in the country and their parental inbred lines to this pest is yet to be known. Figure 2 depicts a typical damage caused by FAW on leaves, stem and cobs of maize plant.

STRIGA, THE MAJOR PARASITC WEED OF MAIZE IN ETHIOPIA

Striga is a parasitic weed that is rapidly expanding its territory in Ethiopia. Previously, it was known to have economic importance in the Eastern (Hararghe) and Northern (Tigray and Wollo) parts of the country. However, it is now becoming a major maize production issue including the western (Benishangul Gumuz), central-western (East Wollega) and north-western (West Gojjam and Metekel) parts of the country. This parasitic weed could probably be moved to East Wollega (where it had not been known before) from the neighboring farmers in West Gojjam through informal seed exchange. Another likely introduction of *Striga* to this area is with the settler families from Hararghe and Wollo during the drought famine of 1974 and 1984 (Abate et al., 2015). It is likely that during this period the families unintentionally carried *Striga* seeds with their sorghum seed introducing the weed to the new areas. In East Wollega, the high potential maize production area with 4.5 tons ha^{-1} average productivity in 2016 (CSA, 2017), the weed has already invaded two districts and it will potentially invade the major maize belt unless immediate control measures are taken. Fasil et al. (2010) indicated the likely presence of different races of *S. hermonthica* adapted to a wide range of environments and host ranges. There have also been reports that *S. hermonthica* is going beyond its host range and affecting crops that have previously known to be unaffected (Haylom, 2014).

Host-plant resistance is the most economically feasible and environmentally friendly method of *Striga* control. Screening methodologies for the identification of sources of resistance to *Striga* in host plants has been developed (Menkir et al., 2012). And genetic resistance to *Striga* has been reported in maize (Menkir et al., 2012). IITA has been successfully developing *Striga* resistant/tolerant hybrids and open pollinated varieties and released in different western African countries (Nigeria, Benin and

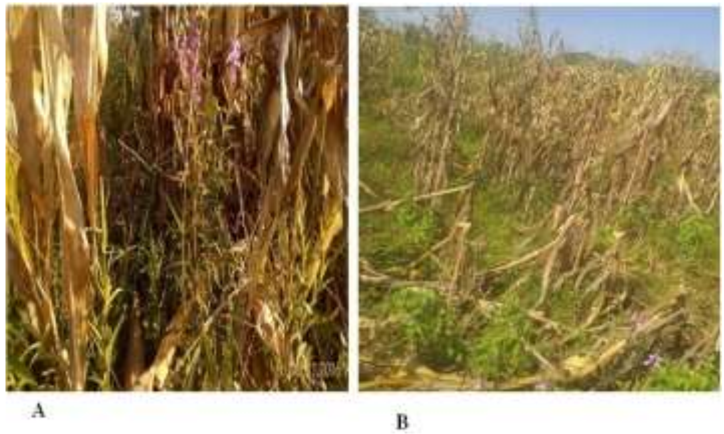

Figure 3. A, Strigainfested maze field in Pawe District (North western Ethiopia) Photo by ZigijuMesenbet; and B, Striga infested maize field in Kemashi (Western Ethiopia). Photo: By AlemuDadi.

Mali). The resistant germplasm from IITA should be exploited as sources of resistance by introgeressing into the locally adapted genotypes and/or for direct commercialization in *Striga* prone areas. Screening the currently available germplasm to this parasitic weed is also important as the reaction of the available germplasm to *Striga* has not been fully explored. In addition, incorporating herbicide resistance gene into maize varieties is another alternative to control *Striga* in maize fields (Menkir et al., 2010) (Figure 3).

CONCLUSION AND FUTURE DIRECTIONS

Maize has a versatile use in Ethiopia serving as food, feed, fuel wood and source of income, among many others. Developing biotic stress resistant maize cultivars is very important to feed the ever-increasing population in the country in the present context of climate change. Concerted research efforts have been made in developing a number of maize varieties that highly contributed to the maize productivity revolution in Ethiopia (Abate et al., 2015). These efforts should be further strengthened to develop varieties resistant to multiple biotic stresses. Stress resistant cultivars can play an important role in coping with climate variability and thus sustainably enhancing the productivity of maize in the country.

The effect of climate change in sub-Saharan Africa is becoming evident with the emergence of invasive plant diseases and insect pests. In just half a decade, Africa gave a reception to two new major pests of maize, MLN in 2011 and FAW in 2016. These pests can individually cause up to a total loss of maize yield unless appropriately managed. The pests can be controlled by application of pesticides but this will incur additional production costs to the farmers. It is also well known that application of chemical pesticides is not environmentally safe. Our understanding of the risk of pathogen and insect pest introductions is either still limited or overlooked and there is a need to improve surveillance and quarantine strategies. However, reducing the threats and impacts of such cross-boundary plant diseases and insect pests will require novel approaches to integrated research and long-term commitments from scientists and policy makers.

To effectively tackle the prevailing biotic maize production stresses and sustainably increase the rate of genetic gain, the existing breeding strategy should be transformed with the integration of modern tools and approaches. Traditional methods of crop improvement alone are not sufficient to keep abreast with the rapidly growing population and the escalating climate change threats which can potentially aggravate the biotic constraints of maize production in Ethiopia. Therefore, ways of introducing and integrating recent advances in biotechnology with the conventional maize breeding approaches should be explored and implemented. This will facilitate maize breeding for resistance to the major biotic stresses in Ethiopia through rapid and well-designed introgression of specific biotic stress tolerance genes into the already available elite maize germplasm, thus ensuring pronounced genetic gain. The conventional approach of maize germplasm screening against major biotic stresses will enable identifying sources of biotic stress tolerance genes, which can then be utilized in the breeding programs through MAS. In this paper the major biotic stresses of maize in Ethiopia and efforts in tackling this problem through genetic improvement over the years has been summarized and presented. This information will be used for breeders, private and public maize seed and grain growers who are targeting to operate in Ethiopia and Eastern Africa.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

This work was supported by the Ethiopian Institute of Agricultural Research (EIAR).

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