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Review on Breeding Maize (*Zea mays* L.) for Drought and Low- N Stresses

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Drought and low N are the most important a biotic factors that affects maize production. Drought affects maize at different stages of development starting from crop establishment up to grain filling. Maize grain yield is affected to some degree at almost all growth stages; however, the crop is more susceptible during flowering. Nitrogen is the most important mineral nutrient for plant development and is the most limiting nutrient in maize production, as it is the most mobile in the soil and the nutrient needed in the largest amounts by the crop. Accordingly, nitrogen deficiency results in decreased crop leaf-area, photosynthetic assimilation and seed growth which in turns affect the yield. In this review there were more research conducted to see the effects of drought and low N on maize crop and breeding strategies and techniques used by plant breeders to develop new cultivars that are able to resist a biotic stresses particularly, drought and low-N in their new environment. Generally, three selection strategies used by plant breeders to overcome these problems are selecting under optimum conditions, under stress conditions, and selecting in a combination of stressed and unstressed environments. Of these selections under stressed environments are the most common to develop drought and low N tolerant maize varieties.

Keywords: Maize, Drought, Low N

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INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops in world agricultural economy. It is ranked first among the cereal with an annual global production of one billion metric tons (FAOSTAT, 2016). Due to higher caloric and nutritive values, it is a valuable food for human beings as well as good feed for livestock and poultry. Maize grows in most parts of the world over a wide range of environmental conditions, with altitudinal ranges of 0 to 3000 meters above sea level (Dowswell *et al*., 1996). The maize produced in the developed world is mostly used as a feed for livestock (70%) and only a small percentage (5%) used for food. Conversely, in developing countries, 34% of the maize produced is used for food and the remaining 62% for feed. The remaining quantity is used for varied industrial uses and as seed (Felix *et al*., 2010).

In Ethiopia, maize grows from moisture stress areas to high rainfall areas and from lowlands to the highlands (Kebede *et al.,* 1993). Despite the large area under maize, the national average yield of maize is about 3.39

t/ha (CSA, 2016). This is by far below the world's average yield which is about 5.4t/ha (FAO, 2016). The low productivity of maize is attributed to many production challenges including drought, declining of soil fertility, disease and insect pests such as Maize lethal necrosis (MLN), Maize Streak Virus (MSV), Turcicum Leaf blight (TLB), Gray leaf spot (GLS), southern leaf rust, blight, stalk borers, and the parasitic weed Strigahermonthica (FAOSTAT, 2015). Drought and low soil fertility are the most important a biotic stresses challenging maize production. Nutrient deficiency, particularly N is a wide spread problem in the country due to the low use of purchased inputs and also the lack of soil fertility enrichments in maize producing areas of the country Edmeades *et al*., 2006; Meseka *et al*., 2008). Drought affects maize at different stages of development starting from crop establishment up to grain filling however, the crop is more susceptible during flowering (Banziger *et al*., 2000). Drought is responsible for approximately fifteen percent of maize yield losses worldwide (Listman *et al*., 2005).The threat of yield loss due to drought is even more severe in developing countries of the tropical regions, where rainfall can be erratic and poverty is most prevalent.

Nitrogen (N) is the most important mineral nutrient for plant development and is the most limiting nutrient in maize production, as it is the most mobile in the soil and the nutrient needed in the largest amount by the crop. In developed countries, where the availability and price of inorganic fertilizer is not a problem,nitrogen deficiency is alleviated by the addition of inorganic fertilizer. This, however, is impossible in developing countries because, either fertilizers are unavailable or are very expensive for small scale subsistent farmers (Mkhabela and Pali-Shikhulu, 2001).

The genetic control of both stress tolerance and resource-use efficiency is quantitative and involves many loci distributed in different regions of the genome in cultivated species (Wu *et al*. 2011). To achieve this, plant breeders use various strategies and techniques (e.g., genetic modification, introgression of traits from adapted relatives) to develop new cultivars that are able to resist a biotic stresses particularly, drought and low-N in their new environment. The use of genetics to improve drought tolerance and low N tolerance to provide yield stability is an important part of the solution to stabilizing global production. That is why the development of maize varieties with enhanced tolerance to drought stress and low N tolerance has become a high priority goal for major breeding programs.

OBJECTIVES

- ✓ To review the effects of drought and low N on maize plants
- ✓ To review the breeding strategies for drought and low N stresses

LITERATURE REVIEW

Origin and Uses of Maize

Maize originated in Central America and was introduced to West Africa in the early 1500s by the Portuguese traders (Dowswell *et al*., 1996). Two locations have been suggested as possible centers of origin for maize, namely, the highlands of Peru, Ecuador, and Bolivia, and the region of southern Mexico and Central America. Several theories have been formulated to account for the origin of maize, but the exact relationship between Teosinte, Tripsacum, and early pod maize found in archaeological ruins has not yet been fully resolved (Poehlman, 1987).

Maize is used in more ways than any other cereal. Though grain is the most important component for which maize is grown, all parts of the plant such as leaves, stalk, tassel, husk and cob are all employed for different purposes. It is one of the most productive species of food plants and utilized directly as a source of food for human consumption, animal feed or feed for livestock and currently as fuel for vehicles (FAOSTAT, 2010).

Constraints of Maize Production:

Maize productivity is limited due to a number of biotic and a biotic stresses. In Ethiopia, One of the major constraints affecting maize production and productivity in the major maize growing agro-ecologies are lack of sufficient widely adopted, high yielder, tolerant to different environmental stresses (particularly, drought and low N) and resistant to major disease and insect pests. In addition, the weather condition varying between seasons and locations within the major growing season is another limitation (Mosisa *et al*., 2012). Low nitrogen and drought stress jointly occur frequently in major growing regions. This results in substantial yield losses or complete crop failure under severe conditions. Nitrogen deficiency is highly affecting the maize yield. Ear and grain development is severely inhibited by N deficiency (Below, 1996).

Effects of low N and drought stress on maize production:

Poor soil fertility, particularly low N deficiency and recurrent droughts are wide spread in SSA. Consequently, crop yields are low which affect food security (Kamara *et al*., 2004). About 50% potential yield losses are caused due to a biotic constraint (Edmeades *et al* 2006). The effects of low N and drought on maize production make stress tolerant cultivars more desirable (Betran *et al*., 2003d).Tolerance of maize to stress from low N and drought is partly related to the development of the root system, which in turn influences water and nutrient uptake by crop plants (Moll *et al*., 1982; Kamara *et al.,* 2004). In general, however, the amount of grain yield recorded from maize genotypes fall with the severity of low N and moisture stress (Betran et *al*., 2003e).

Drought Stress:

The major causes of drought stress in the tropical environments includes poor rainfall distribution, poor water holding capacity of soil, shallow effective root depths, high surface runoff and evapotranspiration (Lal *et al.,* 1982). Drought stress can affect the performance of maize plants at all growth stages of the crop. Maize plants will be severely affected and complete yield loss can be expected, if drought stress occurs just before tassel emergence to the onset of grain filling (Grant *et al*., 1989).The reduction in grain yield due to drought stress during the vegetative, silking and ear stages are 25%, 50%, and 21%, respectively (Denmead and Shaw, 1960).

Mechanism of Adaptation to Drought Stress in Maize:

The ability of a crop species or variety to grow and yield satisfactorily in areas subjected to periodic water deficits has been termed as drought resistance (Ashley, 1993). No distinction is usually made between drought resistance and tolerance as the two terms are used interchangeably. Several morphological, anatomical, physiological and biochemical attributes of a plant confer drought resistance. These adaptations can be heritable or non-heritable, constitutive or facultative (Turner, 1986a). Turner (1979) suggested that the mechanisms of adaptation to water deficits can be divided into three categories:

Drought Escape: The ability of a plant to complete its life cycle before serious soil and plant water deficits develop. By using early maturing cultivars may allow the crop to complete its lifecycle (or at least the critical growth stage) before the onset of drought later in the season. In nature, drought escapers are characterized by rapid phenological development after the incidence of rain and extension of the reproductive phase of development while good soil moisture conditions prevail (Turner, 1986b).

Drought Avoidance: The ability of the plant to endure periods without significant rainfall with maintaining a high plant water status i.e., dehydration postponement. Some plants avoid drought stress by decreasing water loss, for example by having cuticular wax or by having the capacity to extract soil moisture efficiently. Drought Avoidance permits the plants to reduce water loss from leaves by regulating stomatal function or to increase water absorption by adapting root architecture (Moreno *et al*., 2005). Mechanisms for reducing water loss include decreased stomatal conductance, leaf rolling and decrease in leaf area. However, all these processes decrease productivity (Turner, 1979). They increase water use efficiency by reducing water loss at critical times of the day when water vapour pressure deficits are large but allow photosynthesis to continue in the early morning or late afternoon when vapour pressure deficits are less severe.

Drought Tolerance: The ability of a plant to endure periods without significant rainfall and endure low tissue water status i.e., dehydration tolerance; In species such as cereals, in which grain filling depends on both the actual photosynthesis during grain filling stage as well as on dry matter distribution from carbohydrates stored in pre-anthesis stage, terminal drought significantly reduces photosynthesis. This shifts the burden of grain filling to stored carbohydrate as the source of dry matter for the purpose. Consequently, such species may be more tolerant of post-anthesis drought, being able to produce appreciable yield under the stress. Drought tolerance allows the plants to sustain osmotic stress through the re-establishment of cellular homeostasis, the structural and functional protection of proteins and membranes (Moreno *et al*., 2005). Tolerance to dehydration is considered to arise at the molecular level and depends on membrane structure and enzyme activity. It depends on the ability of the cells to withstand mechanical injury, the ability of the membranes to withstand degradation and the ability of the membrane and cytoplasm to withstand denaturing of proteins (Gaff, 1980).

Breeding for Drought stress in Maize:

Breeding for maize cultivars with high and stable grain yields under drought is an important priority. Moreover, the use of drought tolerant cultivars may be the only affordable option for many small-scale farmers (Bolaños and Edmeades, 1993a). There are many reasons for this. The most obvious is that selecting for drought resistance is difficult, as the response is complex and it interacts with other factors such as high temperature and nutrient uptake. In breeding for drought tolerance, one needs to identify the type of drought that the crop is likely to encounter. Breeding maize for drought-prone environments has two major goals, to develop cultivars that can escape drought or those that are drought tolerant (Bänziger *et al*., 2000). Cultivars that escape drought mature early enough so as to complete their life cycle within a given season length. However, earliness is often subject to a penalty in yield when the rainfall amount and duration are higher than average. Drought tolerant cultivars, on the other hand, are characterized by increased production under drought (Bänziger *et al.,* 2000). This makes the use of recurrent selection methods appropriate for improving maize for drought tolerance.

Selection strategy for Drought stress

The efficiency in selection of germplasm for drought tolerance can be improved through use of managed drought environments. This can be done during the off-season (winter) with the use of controlled irrigation whereby the occurrence, extent and amount of drought stress on the crop are controlled (Banziger *et al*., 2000). As a result of significant G x E interaction, it is important that genotypes screened for drought tolerance are evaluated in the target locations before they are incorporated as parents in the breeding programmes. The choice of a selection strategy is critical to breeding for stress tolerance. Byrne *et al*. (1995) summarized three selection strategies that breeders use in selecting maize for drought tolerance: selecting only under well-watered conditions, selecting only under stress conditions, and selecting in a combination of stressed and unstressed environments.

Johnson and Gealdelmann (1989) found that gains from selection under well-watered conditions were equal to those from selection under drought stress when evaluated in stress conditions and that such gains were superior when evaluated in favourable conditions. However, Martinez-Barajas *et al.* (1992) found that progress from selection for high yield under well-watered conditions was greatly reduced under crop water deficits. This method, therefore, may not be effective in breeding for drought tolerance. Selection can also be undertaken using a combination of stressed and unstressed environments. Generally**,** three strategies have been used to develop tolerant /resistant cultivars for drought stress, viz., the use of earliness as a drought escape mechanism, testing of material in drought-prone areas, use of anthesis-silking interval as a trait for drought tolerance selection and collaboration with well established drought breeding programs such as those at CIMMYT to obtain drought-tolerant material**.**

Low N stress:

Since maize is highly responsive to N fertilizer, nitrogen fertilizer is a vital plant nutrient and a major yield-determining factor required for maize production. According to Demissew *et al*., (2002) nitrogen is the nutrient element required in high dose from emergence to grain filling stage of maize. Its availability in sufficient quantity throughout growing season is essential for optimum maize growth. Consequently, nitrogen deficiency results in decreased crop leaf-area, photosynthetic assimilation and seed growth. N deficiency has also been reported to negatively affect leaf expansion, emergence rate, radiation interception, radiation use efficiency and assimilate distribution amongst vegetative and reproductive organs (Sun et *al*., 2001).

Effect of low N stress on crop photosynthesis

N stress reduces crop photosynthesis by reducing leaf area development and leaf photosynthesis rate and by accelerating leaf senescence. About 50% of all leaf N is directly involved in photosynthesis either as enzymes or as chlorophyll. Photosynthesis rate is decreased at low-N as compared to the higher N levels (Fondo, 2006). On the other hand, Photosynthesis rate increase as N level increases (Worku, 2005). He also found that prolonged leaf greenness had an influence on photosynthesis rate. Cultivars with high N use efficiency also had high photosynthesis rate (Worku, 2005). When N becomes scarce, plants reallocate N from older tissue (leaves, stalk) to younger tissue (leaves, grains), leading to early senescence of the older, lower leaf tissue.

Effect of low N stress on root growth

The roots are central to the acquisition of water and mineral nutrients including N. The morphology of the root system may be influenced by a locally restricted nitrate supply. Wang *et al*. (2004) stated that nitrate has a pronounced influence on the total length of primary roots. He also reported that the N-efficient maize line showed higher values of total root-length at low N compared to an N-inefficient genotype. The higher total root length by N-efficient genotypes than the N-inefficient genotypes also reported by (Ermany, 2008). Plants favor root growth over shoot growth under N stress and the root/shoot ratio increases. The absolute amount of roots, however, is usually less for plants grown under N stress than under normal N fertilization (Wang *et al*., 2004)

Effect of low N stress on reproductive development

Relatively little is known about the effects of N stress on reproductive development. Initiation and development of reproductive structures occur in distinct phases, each of which can be affected by N stress. The number of potential kernel ovules is established early in plant development. The kernel row number is set by the time, most tropical maize plants have12-14 visible leaves and the number of kernels per row by the time 16-18 leaves are visible (Below 1997). The number of ovules that ultimately develop into mature kernels is affected by the extent of kernel abortion in the two weeks bracketing flowering (Below 1997). Severe N stress delays both pollen shed and silking, but the delay in silking is relatively more so that the ASI becomes greater under N stress at flowering. As with drought, silking delay is correlated with kernel and ear abortion.

Breeding strategies for N stressed environments

The use of large quantity of N fertilizer to meet the optimum yields of maize leads to environmental pollution and ecological imbalance. In order to minimize these problems the development of N efficient maize verities are the critical issues. It is simpler to breed for low N than for drought conditions mainly because unavailability of N affects plant growth in a more even manner unlike drought periods that occur randomly (Banziger *et al*., 2000). It has been found that screening germplasm under severe low N conditions should be adequate to infer low N stress tolerance for different levels of N deficiency. Breeding for high NUE and low-N stress tolerance requires the availability of adequate genetic variability for the target traits. Breeding for tolerance to low N may be related to tolerance to other stress factors and vice versa. Bänziger *et al* (2002) report that tropical maize selected for drought tolerance is also tolerant to low N. Selection under low N field conditions will greatly increase the breeding efficiency (Bänziger *et al.* 1997). Anthesis silking interval, leaf senescence and ears per plant have been suggested as ideal secondary traits to select when improving maize genotypes for low N conditions (Banziger *et al*., 2000).

CONCLUSION

Maize (*Zea mays* L.) is one of the most important cereal crops in world agricultural economy and ranks third next to wheat and rice in production. It is the world's most widely grown cereal crops. It is one of the most important food crops worldwide, serving as staple food, livestock feed, and industrial raw material. Maize grows in most parts of the world over a wide range of environmental conditions, with altitudinal ranges of 0 to 3000 meters above sea level.

Drought and low N are the most important a biotic factor that affects maize production. Both factors are ranks among the most important constraints to maize production and productivity in all maize growing areas of the country. Drought affects maize at different stages of development starting from crop establishment up to grain filling. Maize grain yield is affected to some degree at almost all growth stages; however, the crop is more susceptible during flowering. The use of genetics to improve drought tolerance and low N tolerance and to provide yield stability is an important part of the solution to stabilizing global maize production. That is why the development of maize varieties with enhanced tolerance to low N and drought stress and higher water use efficiency (WUE) has become a high priority goal for major breeding programs. Even if there is no completely drought resistance variety, there are three mechanisms of adaptation to water deficits or drought. Those are:- drought escape, drought avoidance and drought tolerance**.** In breeding maize for drought, three selection strategies (selecting only under well-watered conditions, selecting only under stress conditions and selecting in a combination of stressed and unstressed environments) were used by plant breeders while selecting maize for drought tolerance. There are few breeding programs that have deliberately tried to increase the low N tolerance of maize, and most selection for N stressed environments has been conducted under well-fertilized conditions. However, selections under N stressed environments are the most common for breeding maize for low N tolerance.

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