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Review Article

Maize in Pakistan: Major Abiotic Stresses and their Management

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Abstract

To achieve the projected increase in demand of food for the rapidly increasing population of the world, global production of food crops need to be increased on a sustainable rate. This can be accomplished by eliminating all the production constraints to food crops which appear from time to time with changing climate. Maize, being one of the most widely distributed crop of the world has its unique importance in agriculture sector due to its multiple uses as food, feed and in industry. In Pakistan it is the third most important crop after wheat and rice and grown widely. It has been grown as a multipurpose crop for fodder, grain flour and feed. Also, its consumption as raw material for different industries is increasing. Like all other crops, maize production is also threatened by several biotic and abiotic stresses which reduce quantity and quality of the produce. The present review will provide necessary information about status of maize crop in Pakistan. It will also cover several abiotic production constraints and breeding strategies to overcome these constraints for a sustainable agriculture produce.

Keywords: Abiotic stress; Agriculture; Breeding; Maize; Tolerance.

Introduction

Maize (*Zea mays* L.) commonly known as corn is the most widely distributed crop and cultivated in different regions of the world for fodder, feed and food purpose (Kaul *et al.*, 2011). It is a multipurpose cereal crop contributing to food, livestock feed, and industrial applications due to its adaptability to diverse climatic conditions and its high nutritional value (Erenstein *et al.*, 2022; Wallington *et al.*, 2012).

It belongs to the family Poaceae (grass family) and tribe Maydaea. The origin of maize is southern Mexico where it was first cultivated more than 9,000 years ago (Awika, 2011; Kennett *et al.*, 2020) but Being the highly cross pollinated crop it does not survive in its wild form (Bothast and Schlicher, 2005; Ram and Singh, 2003). The inheritance studies showed that it was evolved from a wild grass known as Teosinte (Kellogg, 1997).

Genetically, maize is a C4 plant with high photosynthetic efficiency and is able to perform well in diverse environments, including the tropics, subtropics and temperate

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zones (Erenstein *et al.*, 2022). In Maize, per hectare yield in terms of energy is quite high as compared to wheat and rice (Shiferaw *et al.*, 2011). The major producer of maize is United States producing 37% of the total maize production of the world, followed by China, Brazil, Argentina, Ukraine, India, and Mexico.

Maize as food, plays a dynamic role in global food systems and food security (Grote *et al.*, 2021; Poole *et al.*, 2021). Maize provides food to 9.4 million human populations of the world and is a staple crop of many countries. World consumption of maize by humans is about 116 million tons which is less than 30% of total production. While the rest of the total produce is being used as livestock feed and industrial purpose (Ranum *et al.*, 2014).

Maize is the most important grain used as livestock feed throughout the world. According to an estimate over half of the global maize (dry grain) production is used as feed for livestock (Loy and Lundy, 2019). Nutritionally maize kernel is rich in starch (72–79%) which makes it perfect for livestock feed. Maize also contains various vitamins, minerals, proteins, fiber and fat (Ahmad *et al.*, 2017; Anjum *et al.*, 2018). The major protein present in maize is zein protein that is deficient in two major amino acids i. e. tryptophan and lysine (Erenstein *et al.*, 2022). Although maize is lower in protein than other feeds, maize is an important source of protein in animal feed due to the volume fed (Loy and Lundy, 2019).

It is the primary feedstuff used to produce ethanol. Among industrial applications a major part of maize is being used to generate ethanol fuel (ethyl alcohol). It is also used as a motor fuel, mainly as a biofuel additive for gasoline (Ranum *et al.*, 2014). The diverse industrial uses of maize are generation of by-products that provide important additional feed resources and nutrients for the livestock industries (Loy and Lundy, 2019). Internationally the global demand for maize continues to grow because of the increasing need for feed and industrial raw materials (Zhu *et al.*, 2021).

Maize in Pakistan

In Pakistan maize is the third most important cereal crop after wheat and rice and holds significant importance in agricultural sector. It contributes 3.4 percent to the value added in agriculture and 0.6 percent to GDP (Hussain *et al.*, 2022). It is cultivated in different regions of the country for fodder, feed and food purpose with an average production of 6.4 tons per hectare (FAO, 2023). Being a versatile and highly adapted crop the average productivity of maize is highest among all cereals grown in the country (Tariq and Iqbal, 2010). During the year 2022-23 the production of maize in Pakistan was 10.5 million tons and it was cultivated on approximately 1.6 million hectares (FAO, 2023). Table 1 shows the area and production of maize in Pakistan for last eight year. It is clear that production of Maize in Pakistan has been increased over last five years with the increase in area (Figure 1).

The role of maize is significant in agriculture sector of Pakistan due to its multiple uses and economic importance. It serves as a staple food for humans and feed for animals, making its contribution to food security and livestock production. However, its consumption is also increasing in industries as raw material (Khaliq *et al.*, 2004). Being a versatile crop, it has been utilized in the form of whole grain, flour, cornmeal, and corn oil (Akhtar *et al.*, 2021). It also serves as a valuable source of raw material for industries such as poultry, dairy, and feed manufacturing (Juroszek and Tiedemann, 2013).

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Table 1. Area and production of Maize in Pakistan.

Year	Area '000' Hectares	Production '000' Tonnes
2016	1,210	5,337
2017	1,348	6,134
2018	1,251	5,902
2019	1,374	6,826
2020	1,404	7,883
2021	1,418	8,465
2022	1600	9331
2023	1650	10,500

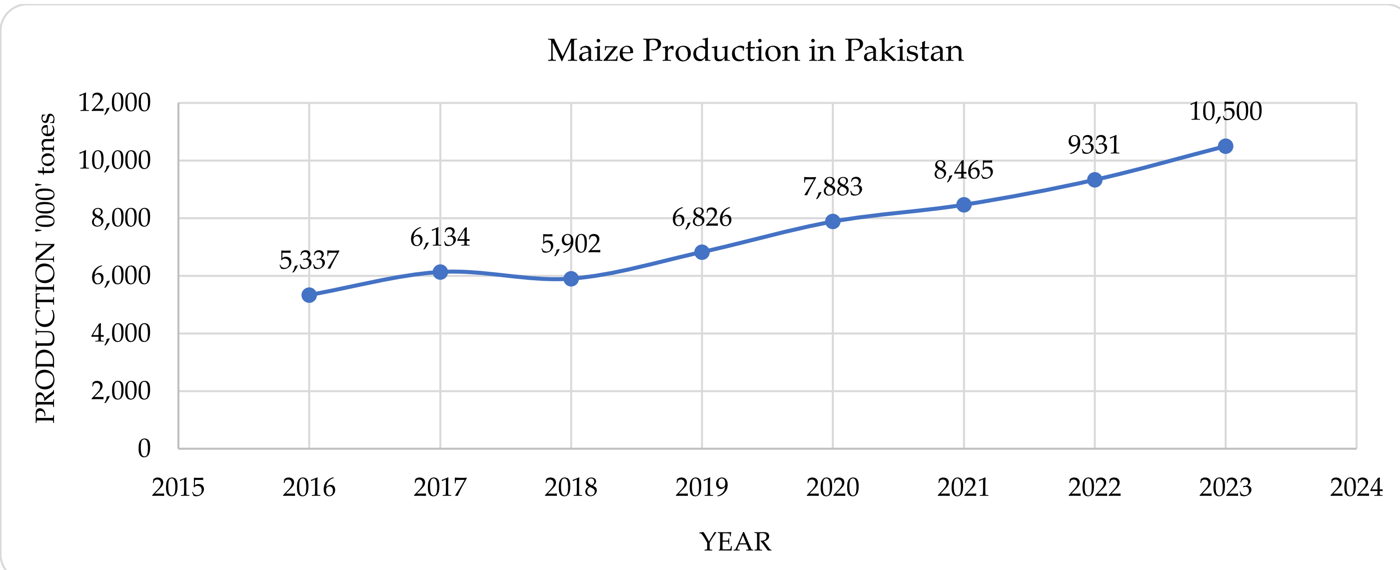

Figure 1. Maize production in Pakistan.

The maize grown in Pakistan is ample for domestic needs (Tariq and Iqbal, 2010) and its productivity is increasing at a very fast rate (FAO, 2021). During the year 2022-23 its production is 7.4% increased (FAO, 2023). The increase in production is due to increase in area, availability of improved variety of seed, and better economic returns (Akhtar *et al.*, 2021). However, like any other crop, maize crop is also vulnerable to several diseases and environmental stresses that can significantly impact its productivity and quality.

Maize in grown in all four provinces, however major growing areas in Pakistan include parts of Punjab and KPK. According to an estimate about 99% of total maize production comes from Punjab and KPK and only 1% comes from other two provinces (FAO, 2023). Punjab contributes 48% of the cultivated area of maize with 69% of total production while KPK accounts for 51% of total area and 31% of production (Rehman *et al.*, 2016).

Maize is a Kharif crop grown during March to August but in some areas it is also growing as spring crop which has been increased since the involvement of multinationals in Pakistan. Spring maize covers around 0.10 million ha and produces about 0.71 million tons of maize grain (Tariq and Iqbal, 2010). Approximately 66% of the maize in Pakistan is grown in irrigated area while rest is farmed under strictly rain-fed conditions (Mubeen *et al.*, 2017). Due to its adaptability to different agro-ecological

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zones and being cultivated in both irrigated and rainfed areas, maize cultivation provides livelihood opportunities for a substantial number of farmers in maize-growing regions of Pakistan. Moreover, being a short duration crop it is a good option for crop diversification and rotation strategies (Gerpacio and Pingali, 2007).

Major production constraints of maize

Like all other crops Maize production is also affected by a number environmental stresses and biological diseases which reduce quality and quantity of produce resulting in fluctuation in prices and financial risks to Maize growers (Akhtar *et al*., 2021). These stresses become more acute because of climate change, resulting in potential losses in maize production in the maize growing areas (Jiang and Zhang, 2002; Mehla *et al*., 2017).

Abiotic stresses

Maize crop seems to be more vulnerable to climate change and abiotic stresses. Abiotic stress in general is particularly harmful to maize yields, regardless of the germplasm and stress faced during a developmental stage of the plant (Bänzinger, 2000). Drought, salinity, temperature fluctuations and nutrient deficiency are the major environmental factors that affect maize productivity (Tebaldi and Lobell, 2018). The growth and final produce of the crop is highly affected by extreme droughts, waterlogging and low or high temperatures (Ahuja *et al*., 2010; Yang *et al*., 2014). High temperatures caused by climatic changes play an important role in overall effects of abiotic stresses (Challinor *et al*., 2010; Lobell and Field, 2007). It directly effects on the metabolism by reducing the moisture contents of plant resulting in reduced pollination and grain set (Iqbal and Arif, 2010). It also shortens the maturity time which affects the quality of the produce (Ali *et al*., 2022). Studies showed that due to severe climate change the global production of Maize is decreased by 8.3% with every degree increase in temperature, due to which despite of giving all necessary inputs, yields are expected to fall by 10 to 20% in the coming years (Xu *et al*., 2016).

Drought stress

Most of maize is cultivated in the rainfed area and is highly vulnerable to drought from flowering through to grain filling stage (Edmeades *et al*., 2000). Drought is considered as a significant threat to crop growth and development depending on its severity and duration (Ganie and Ahammed, 2021; Wang *et al*., 2016; Qaisrani *et al*., 2022). In a study drought has been compared to cancer in mammalian biology due to its complexity and extent of destructiveness in plant biology (Pennisi, 2008).

Maize is grown in a wide range of climatic conditions from semi-arid to temperate regions, and is a highly drought-sensitive crop, especially in critical stages of its growth (Xie *et al*., 2017). Drought stress during vegetative growth, reduces the relative water contents of plant, effects the growth and reproductive development (Aslam *et al*., 2015). The low water contents of plant results in reduced photosynthetic activity (Meng *et al*., 2016).

Plants adopt several strategies to avoid water loss due to drought conditions. This involves a number morphological and physiological changes which lead to drought tolerance (Osmolovskaya *et al*., 2018) which makes the plants able to maintain favorable water balance and turgidity under water stress conditions. To minimize the effects of drought, scientific research has been conducted time to time to identify drought-tolerant genotypes. Now a days, due to advancements in technology, the research focus has been changed from morphological characterization to identifying genes responsible for drought tolerance using molecular tools (Ali *et al*., 2022).

Salinity stress

Salinity is a serious environmental stress caused by high concentration of salts in soil that constrains the production of agricultural crops in the irrigated and non-irrigated area (Flowers and Yeo, 1995; Munns, 2002). According to a global estimation, 20% of cultivated land and 50% of irrigated land is under salinity stress (Wang *et al.*, 2017). More

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than 800 million hectares of land worldwide is affected by either salinity or sodicity (Munns, 2005).

Salt stress has become one of the main limiting factors hindering maize production (Hu *et al.*, 2022). Salinity stress retards plant growth and productivity, mainly due to ion toxicity and osmotic stress (Munns and Tester, 2008). Salinity causes accumulation of toxic compounds in plant cells which inhibits photosynthetic activity of plants by producing Reactive oxygen species (Lobell *et al.*, 2014). It also effects on transpiration, ion balance and senescence reducing the growth rate of plant (Iqbal *et al.*, 2021).

Maize is moderately sensitive to salinity (Ali *et al.*, 2022). However germination and early seedling growth are more sensitive to salinity than later developmental stages (Goldsworthy, 1994; Ahmad *et al.*, 2012; Farooq *et al.*, 2015). The most critical stage of plant growth affected by saline soils is seed germination and salt stress during this delays or sometimes inhibit germination (Farsiani and Ghobadi, 2009).

After germination, shoot growth in maize is strongly inhibited by salt stress (Wakeel *et al.*, 2011). Shoot growth is stunted with dark green leaves in the first phase of salt stress (De Costa *et al.*, 2007) Shoots are more sensitive to salt stress as compared to roots as it rapidly reduces leaf growth rate and leaf elongation which ultimately leads to low photosynthetic activity.

Temperature stress

Maize crop is sensitive to high temperature. Fluctuations in temperature is effecting maize growth and development leading to low productivity. A sudden increase in temperature above 38°C causes a drop in photosynthetic activity (Magar *et al.*, 2019). An increase in temperature greater than 32.5°C decreased the activation state of photosynthetic compounds which is followed by complete inactivation at 45°C (Foyer *et al.*, 2002). Maize is also sensitive to low temperatures and shows less growth rate in temperatures below 15°C leading to chilling injury. The exposure of Maize leaves to temperature less than 10°C leads to inhibition of photosynthesis (Miedema, 1982). Maize is less adapted to low temperatures and appears to take more time adjusting to low temperatures. The tolerant genotypes needed to have ability to germinate, grow, and mature at low temperatures and resist to frost and soil fungi during germination.

Management of abiotic stresses

The ability of plants to produce harvestable yields under stress conditions is called tolerance. Plants exhibit a number of adaptations at cellular, subcellular, and organ levels to express their level of tolerance under particular stress (Jafar *et al.*, 2012; Kaya *et al.*, 2010; Sadiq *et al.*, 2023). Plants reduce their growth activity under severe stress conditions and develop various internal defense mechanisms to cope with the abiotic stresses (Atif *et al.*, 2019). These mechanisms can be manifested phenotypically as stress adaptations such as reduced leaf angles, increased leaf wax, compacted tassels, and reduced evaporation rate in anthers to prevent anther dehiscence (Shah *et al.*, 2011). These phenotypic indicators serve as a tool for selecting tolerant genotypes for their use in breeding programs.

The primary way to manage abiotic stress affected areas is utilization of tolerant genotypes. However in stress affected areas exogenous use of growth regulators and nutrient management is also helpful for successful cultivation of maize (Kaya *et al.*, 2010; Gunes *et al.*, 2007). Tolerant genotypes which are the ultimate solution to bring uncultivable soils under cultivation can be evolved through selection among already existing lines or hybridization to incorporate desired tolerant genes to an already existing well adapted genotype (Pixley *et al.*, 2006). In maize, inbred lines are more useful for resistance breeding because they have been entirely genotyped, easily maintained and cost effective (Atwell *et al.*, 2010).

Conventional breeding for stress tolerance

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The improvement of tolerance through conventional breeding is difficult, time consuming, costly and labor-intensive because it requires repetitive number of selection and breeding cycles. It also requires ample genetic diversity and availability of desirable genes in the same plant species (Sheoran *et al.*, 2022). Moreover, tolerance is always been a polygenic trait and it has strong interactions with other traits especially yield traits which makes the application of conventional breeding methods limited. However, a number of stress tolerant cultivars have been developed using conventional breeding methods such as selection, inbreeding, backcrossing, and hybridization (Cairns *et al.*, 2013).

Molecular Breeding for Stress Tolerance

Molecular breeding plays an important role in developing tolerant crop varieties by enhancing the understanding of genetic basis of variety of traits. It involves a number of advanced molecular techniques including identification of molecular markers, selection and incorporation of desired genes from wide range of sources to breed crop plants tolerant to biotic and abiotic stresses (Ali and Yan, 2012). Scientists have been using techniques of modern molecular biology to incorporate desired genes of different traits in crop plants from wider resources which have helped in significant improvement in the genetic makeup of crop plants.

The application of molecular breeding techniques has improved the efficiency of breeding tolerant crops. Unlike conventional breeding, molecular breeding provide wider chances for incorporating quantitative traits into specific cultivars without disturbing rest of genome through genetic engineering.

Marker-Assisted Selection (MAS): Marker assisted selection considers identification and utilization of DNA markers for specific genes or genomic regions. This involves screening of large populations of plants along with extensive molecular assessment to identify specific genes for specific traits which serve as a marker. These markers then serve as a tool for selecting tolerant genotypes through molecular methods (Wakchaure *et al.*, 2015).

Gene Discovery and Cloning: Molecular breeding techniques also facilitate the identification and isolation of specific genes involved in tolerance. First a desired gene is identified and then it is cloned and directly incorporated in the genotype of already existing variety either through breeding or genetic engineering (Peterson *et al.*, 2002). In this way specific traits can be easily incorporated in the elite maize varieties. Genetic Diversity and Association Mapping: Genetic diversity already available in the existing populations can be assessed by utilization of different molecular markers. This helps scientists to identify potential sources of tolerance. This information can help scientists in selection of parental lines with desirable traits for breeding programs (Yan *et al.*, 2011).

Genomic Selection and Breeding: Breeding of tolerant maize varieties can be enhanced by integrating genomic information and selection of tolerant genotypes and marker data. This would be accelerating the development of tolerant varieties (Crossa *et al.*, 2017).

Molecular breeding techniques provide valuable tools for scientists to speed up the development of tolerant genotypes to cope with abiotic stresses. Incorporation of advance molecular breeding techniques such as molecular markers and genetic engineering along with the conventional methods has helped scientists to produce more resilient genotypes in less time (Ali and Yan, 2012). In future, research will be focusing more on utilization of molecular techniques for development of high yielding tolerant germplasm along with high protein quality and early maturing maize. However a combined approach using conventional breeding along with marker-assisted selection and biotechnology may be needed for successful development of tolerant genotypes for stress affected areas (Li *et al.*, 2010).

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Conclusion

Maize plays and important role in Pakistan's Economy. Therefore, it is necessary to enhance its production by addressing the major production constraint to it. The high yielding varieties have been produced through breeding strategies to enhance its production under stressed conditions. Development of hybrids and inputs management has remarkably increased the production of Maize in last decade, however involvement of molecular breeding techniques have become important to cope with the upcoming challenges to Maize production due to changing climate.

Conflict of Interest

The authors have not declared any conflict of interest.

Authors Contributions

All the authors contributed equally to the manuscript.

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