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Breeding methods and their importance in improving the productivity of field crop varieties to withstand various stresses(Article Review)

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Abstract

In light of the environmental challenges and stresses facing the agricultural sector, it has become imperative to seek effective solutions to enhance the productivity of field crop varieties. This includes selecting varieties that possess genetic stability and a high tolerance to salt and water stress. Environmental challenges such as drought, salinity, high temperatures, and the accumulation of heavy metals in the soil place significant pressure on agricultural productivity, especially in light of accelerating climate change.

Field crop varieties are the cornerstone of achieving food security and agricultural sustainability in the face of growing global challenges such as climate change and population growth. These varieties play a pivotal role in meeting human needs for food, feed, and industrial raw materials, while also enhancing the ability to adapt to challenging environmental conditions.

The mechanism of plant tolerance to stress (stress) is a complex molecular genetic mechanism, with interconnected actions, which varies according to the type and intensity of stress and is linked to the type of plant and its growth stage, in addition to the type of soil and other factors. These mechanisms also include the physiological, chemical and anatomical effects, reaching the phenotypic effect, in addition to the molecular effect, which overlap with each other in general to be reflected in the performance and production of the plant, so its growth rate, number, number of flowers, fertilization rate, leaf area and other characteristics of vegetative and fruit growth are affected until the yield deteriorates or may disappear under severe stress for a long period.

I. Introduction:

The agricultural sector faces numerous challenges, particularly in plant communities growing in environments subject to environmental stresses. Among these challenges are biotic stress and abiotic stress, which cause physiological disturbances in plants, negatively impacting their growth. Biotic stresses are defined as stresses that occur as a result of damage to plants by other living organisms represented by biological factors (such as insects, weeds, diseases caused by bacteria, viruses, fungi, and parasites), while abiotic stresses are defined as the negative impact of non-living factors on living organisms

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represented by environmental factors, including salinity, drought, waterlogging, strong winds, high and low temperatures. Hence, the role of plant breeders in breeding and improving crops to resist stresses, and deriving varieties that can withstand environmental stress using traditional and modern breeding and improvement methods, molecular breeding, and genetic engineering (Al-Burki, 2020).

Breeding Field Crops to Tolerate Salt and Water Stress:

Exposing a plant throughout its life cycle to harsh environmental conditions, such as water scarcity or high salinity, causes stress that affects all physiological and metabolic processes. Physically, stress is a set of conditions that cause marked changes in physiological processes, gradually leading to damage. Physiologically, it is a reflection of a set of environmental pressures that induce changes in plant physiology. Stress damage can be divided into direct damage, indirect damage, and secondary damage.

More than 60% of agricultural land is subject to moderate or severe degradation due to drought and desertification, with approximately 12 million hectares of land potentially usable for production being lost each year. More than 7% of the world's land area and more than 15% of the world's arable land are suffering from salinization. Over the next 25 years, land degradation could reduce global food production by as much as 15%. Therefore, it is necessary to understand and study the damage caused by these stresses and to understand the mechanisms by which plants tolerate them in order to improve and produce tolerant varieties and compositions. Abiotic stresses (salinity first) and (drought second) are among the most important of these stresses, causing real problems in the process of agricultural expansion in the world and the most harmful to plants and crop production. The concept of acclimatization or adaptation to stress (of any type) is the ability of a plant to produce acceptable output under stressful conditions. An acclimatized plant is one that resists a certain stress and can produce at an acceptable level compared to another plant that is not acclimatized to that stress

Studies on the effects of salt and water stress (drought) on the tolerance of field crop varieties:

Water deficits significantly reduce growth and productivity. This is attributed to the disruption of gas exchange and its clear impact on photosynthesis. Drought stress also inhibits dry matter production through its inhibitory effects on leaf expansion and development, thus reducing light capture. Drought also leads to a lack of fruit set or flower sterility and may lead to reduced assimilation and obstruction of mass movement to the plant's fruit, i.e., obstructing the movement of mass to levels that achieve optimal grain growth. When maize plants are exposed to water stress during the teaseling stage, this leads to a significant decrease in yield and its components, such as ear, grain yield per plant, biological yield, and harvest index (Demirevsk et al., 2009).Samarah et al. (2009) indicated that drought reduces plant growth and development, impedes flower production and kernel thickness, and consequently, produces small kernels in the maize crop. The reduced kernel size is due to decreased metabolism and activity of sugar-producing sources and starch-reducing enzymes (Al-Rubaye, 2021).

In a study on salinity tolerance, Thomson et al. (2010) focused on a QTL called Saltol in rice. The results showed a strong association between it and reduced sodium uptake, which enhances salinity tolerance. A set of rice cultivars were used and exposed to salinity. The QTLs and associated traits were analyzed. It was found that QTLs control sodium and potassium uptake and growth under salinity. Therefore, it was recommended that incorporating QTLs into rice crop improvement programs could enhance performance under high salinity conditions. Wahid et al. (2007) reported in his study on the tolerance of maize cultivars to heat stress. The study addressed physiological mechanisms such as the activity of defensive enzymes,

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and showed that heat-tolerant cultivars exhibited higher levels of cytoprotection. This study aimed to understand how maize responds to heat stress from a physiological and molecular perspective.

This is a comparative study between varieties with varying degrees of tolerance to heat stress. Indicators such as antioxidant enzymes and gene expression were measured. The results of the study showed that tolerant varieties exhibited higher activity of defense enzymes and increased levels of heat-protective proteins. These indicators can be used to select more tolerant varieties in breeding programs. In their study on the role of genetic mutations in cultivars' tolerance to frost stress, (Shu et al. ,2012) used inducible mutations such as radiation to identify genetic loci responsible for frost tolerance in wheat. Field experiments and growth chambers were used to measure frost tolerance and correlate them with QTL analysis. Loci associated with the production of protective proteins and germination rate under frost were identified. These loci can be integrated into conventional and molecular breeding to improve wheat in cold regions. Almeida et al. (2013) also reported in a study on maize's drought tolerance, using QTL analysis to identify gene loci associated with drought tolerance in maize using QTL techniques. Inbred inbred lines (RILs) grown under drought conditions were used. Phenotypic data were collected and linked to genomes via QTL analysis. Multiple genetic loci associated with drought tolerance at different growth stages were identified, and these loci can be used in molecular breeding programs to improve maize cultivars. (AL-Hasany,2014) showed in his study on irrigation with saline water for the Turkish variety LUZ DE OTONO broad bean crop using five levels of irrigation water salinity 1.8 (river water), 4, 6, 8 and 10) dS m. The results showed that high levels of salinity caused an increase in the period from planting to 50% flowering. The results also showed a decrease in plant height, number of branches and pod length using river water, while the number of pods per plant, number of seeds per pod and weight of 100 seeds decreased from 8.31, 4.43 and 112.02 g using river water to 2.68, 3.24 and 91.06 g when using water with a salinity of 10 dS m. The total seed yield decreased from 2986.67 kg ha-1 using river water to 1009.17 kg ha-1 when irrigated with water of 10 dS m-salinity, a decrease of 66%. A one-unit increase (dS m-1) in the salinity level of irrigation water leads to a decrease in the total seed yield by 227.7 kg ha-1 (or 7.6% of the yield irrigated with river water). The protein yield decreased by 77% (Wani and Hossain ,2015) reviewed the methods used to improve salinity tolerance in crops, including hybridization, selection, and mutation, and highlighted their effectiveness in improving salinity tolerance, especially in wheat and barley. It also emphasized the importance of combining traditional methods with molecular techniques to develop highly tolerant and productive varieties.

Kalhoro et al. (2016) showed that increased salt stress led to an increase in Ca+, Na+, and Mg+ ions and a decrease in potassium ions in the plant. It also led to a significant decrease in plant height, leaf area, spike number, number of grains per spike, 1000-grain weight, grain yield, and biological yield. In a study conducted by Khalid and Amjad (2018) to analyze the role of genetic mutations in crop breeding to withstand climate change, rice and barley varieties were developed to be resistant to drought and salinity using radiation and chemical mutations. Said (2018) concluded that irrigating maize plants with water with different salinity levels caused a significant decrease in the dry weight of the shoot and a decrease in the absorbed amount of nutrients, namely nitrogen, phosphorus, and potassium (N.PK), respectively. Kreet and Al Nasson (2020) showed that wheat crops were exposed to salt and water stress, leading to significant decreases in plant height, number of branches, number of spikes, number of grains per spike, 1000-grain weight, grain yield, and biological yield. Mayes et al. (2022) discussed how natural genetic diversity can be used to improve crop climate resilience. They found that genetic diversity is key to developing resilient varieties, particularly through extensive genetic selection programs, investment in genebanks, and selection programs for the use of native and modified genetic resources. Zheng et al. (2025) examined progress in wheat breeding for heat stress tolerance, reviewing techniques such as marker-assisted selection (MAS), genomic selection (GS),

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and gene editing, as well as field variety analysis. The results showed that improved varieties possess better water retention capacity and photosynthetic efficiency under high temperature conditions, contributing to improved productivity under climate change.

Physiological and Genetic Tolerance Mechanisms:

Plants respond to stress using mechanisms that vary depending on the species. These mechanisms cannot be separated from each other because they are almost complementary. These responses are usually morpho-physiological in nature and related to the plant's life cycle. Generally, a plant under stress employs one or both of two methods to resist stress:

1- Avoidance: The plant avoids the stressful factor, such as by undertaking several chemical transformations within the cells to ward off the stressor and its effects.

2- Endurance: The ability of the plant cell's protoplasm to resist the stressful factor. Therefore, we find that a plant's ability to survive in a stressful environment depends on its ability to escape or tolerate stress, or to recover after the stress has subsided.

Drought avoidance mechanisms that maintain plant cell turgor are among the most desirable traits during short-term droughts. However, they fail to maintain water balance in plant cells when droughts become prolonged or severe. For cells to survive, they must develop true tolerance mechanisms when exposed to adverse environmental conditions. These mechanisms allow for the maintenance of growth during periods of water stress and also ensure the ability to recover growth when the drought ends. Among the mechanisms that plants use to reduce the severity of drought (water stress), for example, and which are linked to the plant's life cycle, is to end their life cycle during the period when water is available. Rapid growth and early flowering help avoid periods of drought. Plants have developed adaptation mechanisms linked to their life cycle (earliness). Typically, early-maturing varieties can avoid the period of water deficit that typically occurs at the end of the plant's life cycle and are highly productive.

There are several morpho-physiological mechanisms that plants use to cope with drought, including continued absorption. The ability to absorb water during water deficits in cereals, for example, is linked to the development of the root system, or to reducing water loss, such as leaf curling and stomatal regulation. The terminal leaf contributes significantly to yield in most cereal crops during the flowering and ripening stages. Delaying leaf senescence can improve grain filling. The stem also contributes to acclimatization, as it is the primary site for the concentration of dry matter such as sucrose, glucose, and fructose, which subsequently move toward the grain to contribute to its filling. The dry matter formed in the stem before flowering contributes 3–30% to grain filling. The stem's contribution to grain filling increases in cases of water deficit, exceeding 40% of the grain's dry matter. It has been found that varieties with short stems are unable to store sufficient quantities of nutrients, making them generally less tolerant to stresses. A study observed the extent of overlap and complexity of physiological phenomena involved in adapting to water deficit, for example, in durum wheat. Proline accumulation was recorded in plants exposed to water stress, leading to desiccation of older leaves and a reduction in the ability of roots to absorb water, thus reducing yield. What helps barley plants withstand both drought and salinity is its content of certain compounds such as betaines, osmolytes, and glycinebetaines. These compounds reduce sodium absorption or trap it in the

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vacuoles or apoplast of plant cells, and absorb calcium and potassium ions. In addition, plants produce antioxidants, and antioxidants are molecules that have the ability to reduce or prevent oxidation by inhibiting or preventing the oxidative chain reaction in the cell and relieving it from oxidative stress by acting as a chelating substance for free radicals, leading to their conversion into an inactive substance, or by inhibiting the work of oxidation enzymes, or by oxidizing themselves, meaning they donate an electron (Al-Rubaye, 2021).

From a genetic perspective, salinity and drought tolerance are quantitative traits controlled by a large group of genes that express themselves as tolerance traits. There are several biochemical, functional (physiological), anatomical, and morphological features associated with a large group of gene combinations that make plants tolerant to salinity or drought. In the case of water stress, the genes controlling it are classified into several groups, including plasma membrane protection genes and proteins, signaling genes, transcription factors, antioxidant genes, ion transport genes, and solutes such as proline, among other genes whose action and expression vary depending on the genus, species, and variety of the plant. With regard to tolerance to saline stress, plants are divided into two types**:**

1- Glycophytes: Salt-sensitive plants that cannot tolerate medium to high salt concentrations.

2- Halophytes: Salt-tolerant plants that grow in salinized soil or salty water. They employ several mechanisms to withstand the severity of this stress and reduce its cumulative harmful effects. Among these mechanisms is the salt tolerance mechanism, which involves accumulating sodium chloride in plant tissues, especially in the gaps and old leaves. These plants tolerate sodium by storing it in their various tissues, called includers. The second mechanism is the salt avoidance mechanism, meaning they are salt-excluder plants. The plant reduces the concentration of sodium chloride within its tissues by excreting excess sodium through the leaves or roots. Salt-tolerant plants that rely on a mechanism for excreting excess salts have special glands that excrete excess salts, while succulent plants rely on the principle of increasing the water content in their tissues to reduce the toxicity of those salts.

Agricultural methods for protecting crops from stress:

Among the most important methods for protecting field crops are agricultural methods that include crop rotations, eliminating residues from the previous crop, early control of diseases or insects before they spread, pre-planting seed dusting against fungal and insect diseases, and using seeds from genetic sources resistant to diseases and insects. It must be emphasized that the genetic makeup of varieties and strains varies in terms of resistance to diseases and insects. Therefore, it is recommended not to rely on planting a single genetic makeup or variety in a specific region. Each variety must have a broad genetic base that enables it to resist diseases better than varieties or hybrids with a limited genetic base. Furthermore, attention should be paid to genetic makeups adapted to the conditions of the region, as they are better able to tolerate and resist diseases.

The use and application of the above-mentioned agricultural methods for prevention, no matter how advanced their methods of use, are not an alternative to genetic methods in breeding and improving crops to resist diseases and insects. Genetic methods, both traditional and modern, remain the basis for protecting crops from diseases and insects by developing resistant varieties using various breeding methods, the most important of which are selection to improve the resistant variety, improving adapted varieties, using genetic mutations, selecting plants that show resistance to stresses or plants from

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introduced sources, hybridization, transferring the resistance trait from local or introduced varieties, using genetic engineering technology to transfer genetic factors characterized by resistance to varieties of economic importance in terms of production, using plant tissue culture technology, and selecting varieties that tolerate environmental stresses at the cell level.

Screening experiments for tolerance and resistance Plant breeders have taken it upon themselves to find and develop plant varieties that are resistant or tolerant to these stresses. Indeed, plant breeders have succeeded for decades in breeding stress-resistant plants by developing varieties and strains based on screening experiments, which have contributed to reducing production costs, environmental pollution risks, and health damage to humans and animals. Breeders have relied on several sources of resistance in screening experiments, most notably related wild species, resistant commercial varieties, and newly developed artificial mutations. Important experiments used in screening commercial and other varieties to resist or tolerate all stresses are:

:First, screening experiments for disease and insect resistance

Field crops are often exposed to various types of insects and pathogens (fungi, viruses, bacteria), which may infect roots, seedlings, stems, leaves, or fruits. Infection or disease infection of plants often occurs through the soil, with the pathogen entering the roots or underground stems of the host plant, as in the case of root rot diseases of wheat, barley, and maize. Infection also occurs through seeds, as in the case of covered diseases in wheat and barley, which carry the pathogen on the surface of the seeds. Infection also occurs through the aerial parts of the plant, with the pathogen entering the stomata, lenticels, and wounds, as in the case of rust diseases in most cereal crops, smut diseases in maize and rice, bacterial spot diseases in tobacco and cotton, and downy mildew in wheat and barley, among others. In addition, diseases transmitted by insect bodies, such as various viral diseases that infect crops, are also exposed to attacks by many types of insects, which cause significant damage. As an insect of barley, wheat, oats, yellow corn, etc., and a leaf-boring insect of cotton and other insects.

Plant breeders must distinguish between resistance states to successfully implement a breeding program. Specifically, they must understand the nature of resistance in the genetic makeup of the cultivars. They must also distinguish between diseases and insects, given the potential for crops to be in several states of resistance to disease and insect infestations:

1- **Susceptible plants (Sensitive plants):** It is preferable to exclude these types of genotypes due to the difficulty of genetically improving them.

2- **Moderately tolerant:** This condition occurs because the genes responsible for resistance in such a cultivar are incomplete or complementary, and the plants are not identical in their resistance genes, resulting in complete resistance to disease or insect infestations.

3- **Tolerant plants:** The variety is relatively resistant to infection, and the genetic effect of resistance is governed by more than one pair of genes, with a complementary or combined effect of the resistance trait.

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4- **Completely resistant plants (immune genotype):** In this case, a small number of genes (one or two pairs) are controlled by the immune genotype. This enables the breeder to implement a breeding program using cross-breeding and selecting plant-line offspring to test resistance and produce resistant line seeds while maintaining the productive performance of these selected lines. This is achieved by conducting crop comparison experiments with the original variety whose resistance trait is to be improved.

Screening experiments are conducted to develop varieties and strains that are tolerant or resistant to disease and insect infection under field conditions or in protected cultivation (after providing natural infection conditions) by following the following steps

A. Infection is carried out by planting plants in a field infested with the pathogen or insect to test them, and then selecting the uninfected plants as resistant

B. Crossbreeding the selected resistant plants with a local variety lacking the resistance trait

C. Continuing crossbreeding, using backcrossing (the most common method) or pedigree registration, ensures the transfer of the genes responsible for expressing the resistance or tolerance trait (usually a single gene, rarely more). Artificial infection is carried out in the absence of a significant infestation in the field for testing, using several methods, including**:**

1- Collect a sample of soil infested with the pathogen and spread it in the test field or greenhouse

2- Inoculate the soil with a culture of artificially bred pathogens

3- Mix the seeds with the pathogens before planting or dust them with dry pathogens

4- Spray the plants with an aqueous solution containing the dry pathogens

5- Injecting plants with an aqueous solution containing the pathogen

6- Planting test plants in areas where the insect is prevalent or during a season with a high incidence of the insect

7- Artificially rearing insects and then transferring them to a greenhouse or field where

There are numerous experiments through which plant breeders have succeeded in developing disease- and insect-resistant varieties for many crops. In barley, for example, the National Institute of Agricultural Research in Morocco was able to screen germplasm and evaluate approximately 5,000 barley lines under artificial infestation conditions in greenhouses and at two field sites. A total of 99 lines were selected for their tolerance to this pest, with 55% of them yielding very good results under drought conditions in the 2001 season. In 1990, researchers began an intensive field screening of more than 44,000 introduced barley germplasm lines for resistance to yellow rust, which had spread widely in fields in South American countries. Joint research between ICARDA and CIMMYT resulted in the development and adoption of germplasm resistant

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to the most widespread pathogens in the Americas. Researchers have also succeeded in transferring a gene for resistance to the cotton borer into the Bt. Cotton variety, which is now grown in several countries around the world.

Second: Screening experiments for drought tolerance

The process of breeding plants and improving their varieties for drought tolerance or resistance is called drought hardening. Due to the worsening drought phenomenon resulting from the worsening water scarcity problem worldwide, plant breeders have become increasingly interested in developing drought-resistant varieties and genetic lines for the soils of arid and semi-arid regions. They have used two different treatment methods

There are two methods for hardening seeds or plants in the seedling stage under moisture stress conditions:

The first method: This is done by immersing the seeds of the variety or strain under test in water for 24 hours and then drying them in the sun. These seeds are then planted in the field to test plants that have responded to the hardening treatment and have undergone physiological tolerance transformations. With continued selection of plants that have demonstrated tolerance, strains or varieties with stability to withstand field drought conditions can be obtained.

The second method: This is done by exposing young seedlings to water stress to increase their tolerance to water shortage conditions in subsequent droughts. As the growth stages progress, physiological developments in terms of tolerance can be monitored and plants can be selected. In general, the process of developing saline agriculture techniques and producing plant species that are resistant or tolerant to salt has taken many scientific methods, including adopting the application of genetic engineering technology with the aim of genetically and physiologically modifying traditional plants and transforming them from being salt-sensitive plants to salt-tolerant ones by transferring tolerance genes to one of the gene families responsible for salt stress tolerance.

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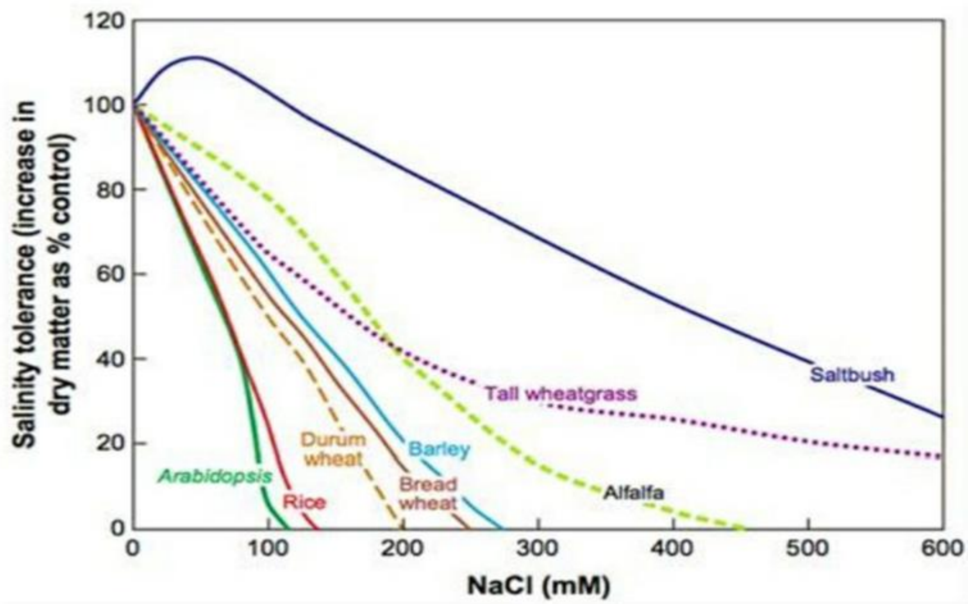

The figure(1) shows the variation in some crops' tolerance to salt stress,(Munns,Tester,2008).

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