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Review Article

The selection of drought-tolerant plant genotypes in Iraq

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Abstract

Water stress plays a critical role in plant growth and productivity, particularly in crops like maize. Water stress (or drought) can significantly affect plant physiology and development. Absorption vs. loss: Plants absorb water through their roots, but during water stress, the rate of water loss through transpiration exceeds the rate of absorption. This imbalance leads to reduced cell turgor and diminished cellular processes. Cellular impact: When plants are stressed, they may exhibit wilting, reduced cell expansion, and decreased metabolic activity, which affects growth and yield, especially during critical developmental stages. Initially, plants lose more water through transpiration than they can absorb, leading to slight dehydration, which the plant can partially manage through early adaptive mechanisms like closing stomata. As stress intensifies, plants reduce stomatal opening to conserve water, and leads to a decrease in photosynthesis, which affects energy production and growth. Third stage: plants may enter a state of severe dehydration. The stomata are largely closed, photosynthesis halts, and plants may enter dormancy or die. Breeding for drought tolerance. Morphological adaptations: Plant breeders focus on developing drought-resistant varieties through selection and hybridization. Key traits for drought tolerance include. Increased root size: Larger roots help plants access water stored deeper in the soil during dry periods. Reduced leaf area: Smaller leaves reduce water loss through transpiration. Water use efficiency (WUE): Breeding plants with better water use efficiency allows them to conserve water while maintaining growth. This includes focusing on traits like deep root systems: these allow the plant to access water from deeper soil layers.

Keywords: Plants, Drought, WUE, STI

1. Introduction

The critical issue of water scarcity and its profound impact on agriculture, particularly in regions like Iraq, which faces both water scarcity and significant challenges related to climate variability. As the population grows and climate change exacerbates weather patterns, ensuring a sustainable and resilient agricultural system becomes more urgent than ever [1,2].

Water scarcity and its impact on agriculture, challenges in Iraq's water resources, fluctuating river flow: Iraq depends heavily on the Tigris and Euphrates rivers for its water supply. However, the flow of these rivers fluctuates seasonally, and over the years, the water levels have been decreasing due to a variety of factors, including dam construction upstream in neighboring countries. This reduces the amount of available water for irrigation and other agricultural needs. Low Rainfall: Iraq, situated in an

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arid to semi-arid region, receives limited and erratic rainfall. Rain often falls at times when it is least beneficial for crops, which exacerbates water stress during critical growing periods. High Evaporation Rates: The region experiences high temperatures, which lead to high evaporation rates from both water bodies and soil. This means that even if there is some available water, a significant portion is lost before it can be utilized by crops [3-5]. Water management challenges: inadequate water resource management, inefficient irrigation practices, and poor soil management further exacerbate the situation. Even with available water, it may not be used effectively or distributed properly to maximize agricultural productivity. Agricultural and Socio-Economic Impacts. Reduced crop yields: Water shortage directly limits crop growth, reduces yields, and can even lead to crop failure. This is especially problematic in a country like Iraq, where agriculture is a major source of livelihood for a large portion of the population. Rising demand for food. As the population grows, the demand for food increases, but water shortages limit the ability to increase agricultural production [6,7]. This creates a food security challenge, with potential long-term effects on both the economy and society. Loss of Livelihoods: Farmers and rural communities are particularly vulnerable to water scarcity, which can lead to economic hardships, loss of livelihoods, and increased poverty. Climate Change and Future Projections. Increased Water Scarcity: The United Nations Educational, Scientific and Cultural Organization (UNESCO) highlights that by 2025, around 1.8 billion people will face water scarcity. As the climate continues to change, water availability will become even more unpredictable, with drier regions becoming more arid and more extreme weather events occurring. Impact on agriculture, which is heavily dependent on a stable water supply, will be one of the sectors most impacted by these changes. The production of key crops, such as wheat, rice, and maize, will be severely limited unless adaptive strategies are implemented [8,9].

2. Breeding for Drought Resistance and Water Use Efficiency

One of the most promising ways to mitigate the effects of water scarcity is through drought-resistant crop varieties, which can survive and produce under water-limited conditions. These efforts are essential for ensuring agricultural resilience in the face of climate change. Improving Root Systems. Root System Development: A key factor in improving drought resistance is enhancing the root system of crops. Plants with deep and extensive root systems are better able to access water stored deeper in the soil, particularly during dry spells. This adaptation allows the plants to continue growing and producing even when surface water is scarce. Root Architecture: Breeding for root traits such as increased root length, root density, and deeper penetration can enable crops to better withstand drought conditions. Water Use Efficiency (WUE). Efficient Water Use: Breeding crops with higher water use efficiency (WUE) allows them to produce more biomass or yield per unit of water consumed. This is critical in regions where water is scarce and needs to be used as efficiently as possible [10-12]. Regulation: Another important aspect of drought resistance is improving the plant's ability to regulate its stomata (pores in the leaf surface) to reduce water loss during hot, dry conditions while still allowing for necessary gas exchange for photosynthesis. Drought-Resilient Crop Varieties. Genetic Improvement: Through genetic selection and biotechnology, scientists are developing crop varieties that are better adapted to water stress. These varieties may have traits such as reduced evapotranspiration, improved drought signaling pathways, or better tolerance to high temperatures. Incorporating Drought-Tolerant Traits: For example, maize and wheat varieties with drought-tolerant genes have been developed in research settings. These crops have been shown to produce higher yields under water-limited conditions compared to conventional varieties. Agroecosystem Approaches [13,14]

Integrated Water Management: In addition to breeding drought-resistant crops, managing water resources efficiently through practices like drip irrigation, mulching, and rainwater harvesting can help conserve water and ensure its more effective use. Soil Management: Improving soil health through organic amendments, proper irrigation practices, and crop rotations can enhance soil water retention and reduce water loss through evaporation.

To address the challenges posed by water scarcity and the growing demand for food, Iraq and other countries in similar regions must take a multi-pronged approach. Investing in Water Conservation Technologies: Implementing more efficient irrigation systems (e.g., drip or sprinkler irrigation), reducing water waste, and promoting water conservation technologies will help ensure that the limited water available is used efficiently. Enhancing Breeding Programs: Continued investment in plant breeding to develop drought-resistant crops with better root systems, enhanced WUE, and improved resilience to climate extremes is crucial. Education and Awareness: Educating farmers about water-efficient agricultural practices and the importance of sustainable land and water management will be key in adapting to the changing climate and ensuring long-term agricultural productivity. Regional Cooperation: Collaboration between Iraq and neighboring countries to address the management of shared water resources, such as the Tigris and Euphrates rivers, is essential for ensuring that water resources are distributed fairly and managed sustainably [15-17]. These face both external and internal challenges. The issue is deeply tied to complex climatic, political, and socio-economic factors, and it is increasingly critical for addressing global food security. Let's break down the key points and potential solutions in more detail.

2.1 The Concept of Agricultural Drought: *Agricultural* drought is defined as the condition in which the available water in the root zone of crops is insufficient to meet the water requirements for optimal plant growth and development. It begins when the water that is readily available to the roots is depleted, typically due to a combination of climatic factors such as reduced rainfall and high evaporation rates, or poor water management. Drought is a complex phenomenon that impacts crop growth at various stages, especially during critical periods like flowering, which can lead to significant yield losses, as you mentioned for maize (45-60%). Water Scarcity and Its Impact on Iraq [18,19].

2.2 Downstream Impact of Dams and Construction of the Anatolia Project in Turkey: With its 21 dams on the Euphrates River, it has serious implications for downstream countries like Syria and Iraq. If completed, this project could reduce the flow of water to Iraq by up to 90%. Since Iraq relies heavily on the Tigris and Euphrates rivers for agriculture and industry, this could exacerbate water scarcity, which is already a pressing issue.

2.3 **International Water Agreements**: The failure to adhere to international agreements on water distribution among countries sharing river basins is another major concern. In the case of the Tigris and Euphrates, Iraq is vulnerable because the rivers originate outside its borders, and any upstream developments can directly affect Iraq's water security.

2.4 **Poor Water Management Internally:** Iraq faces challenges in water management, including inefficient irrigation systems, a lack of awareness about the importance of conserving water, and over-extraction of water for irrigation. These factors all contribute to the depletion of the available water resources. Soil and Water Interaction [20]. The distribution of water in the soil and its impact on root growth is another important aspect of agricultural drought. Improper irrigation methods or poor soil management can lead to uneven water distribution, which hinders the development of a healthy root

system and thus affects plant growth and productivity.

2.5 The Role of Water in Plant Growth: Water is a fundamental element for plant survival, playing several key roles: Solvent and Carrier Medium [21]. Water is essential for dissolving nutrients in the soil and transporting them throughout the plant. Photosynthesis: Water is necessary for the photosynthesis process, which allows plants to produce organic food and generate energy. Temperature Regulation: Through transpiration, water helps to regulate the plant's temperature, preventing overheating, especially during hot, dry conditions. Water-intensive crops and maize sensitivity to drought: Corn, a major crop in Iraq and many other parts of the world, is particularly sensitive to water stress, especially during critical growth stages like flowering and grain filling. As you noted, if drought coincides with flowering, the yield reduction can be significant, reaching up to 45-60% [22]. This makes maize particularly vulnerable to the effects of water scarcity, particularly in regions like Iraq where water availability is already a challenge. improving maize yield through drought-tolerant varieties despite advances in developing high-yielding maize hybrids, water stress continues to limit productivity. One solution to this issue is the development and use of drought-tolerant maize varieties. These varieties exhibit better resilience under water-limited conditions, showing superior performance in growth traits such as Root Growth: Drought-tolerant cultivars often have deeper, more extensive root systems, which allow them to access water from deeper soil layers. Plant Height and Biomass: These varieties may maintain larger plant size and biomass production under stress, helping to mitigate the negative effects of drought. Grain Yield: The main advantage is in maintaining or even improving grain yield under drought conditions, which can be a game-changer in regions facing water scarcity. The importance of seed quality: Seeds are the foundation of crop productivity [23,24]. The ability of seeds to germinate and establish under diverse environmental conditions directly influences the yield potential of a crop. In drought-prone areas, using high-quality seeds that are tolerant to environmental stressors is essential. Improved seed technology ensures that crops can better withstand water stress during the early stages of germination and establishment, leading to more robust plants capable of surviving through dry periods. Potential solutions to address water scarcity in Iraq: Given the projected water shortages and the current state of water resources in Iraq, the country faces a critical challenge. However, there are several strategies that can help mitigate the impact of water scarcity on agriculture. Drip irrigation: switching to more water-efficient irrigation methods, like drip irrigation, which delivers water directly to the root zone, can reduce water waste and ensure that crops receive the moisture they need. Rainwater harvesting: collecting and storing rainwater during the wet season can help supplement irrigation needs during dry periods. Water recycling: recycling water for agricultural use can significantly reduce the amount of fresh water needed for irrigation. Breeding programs aimed at developing drought-resistant maize and other key crops should be prioritized. These varieties would be specifically designed to perform well under water-limited conditions, ensuring higher yields despite reduced water availability. soil mulching: using organic or synthetic mulches can help reduce soil evaporation and improve water retention in the soil conservation tillage: reducing tillage and leaving crop residues on the soil surface can improve soil structure and water retention international water agreements Iraq should negotiate with upstream countries to ensure fair distribution of water from the rivers, emphasizing the need for sustainable water use that supports agriculture national water policy: a comprehensive water management policy that integrates agricultural, industrial, and domestic water use is essential to ensure the sustainable use of water resources farmer education: educating farmers about drought-resistant crops, efficient irrigation

practices, and water conservation techniques can help mitigate the effects of water scarcity at the local level [25,26].

2.6 Public Awareness: Broader public awareness campaigns about the importance of water conservation and sustainable agricultural practices can support nationwide efforts to tackle water shortages. Water scarcity in Iraq is a growing problem, with significant implications for agriculture, especially for crops like maize, which are highly sensitive to water stress. Addressing this issue requires a multifaceted approach, including improving water management techniques, developing drought-tolerant crop varieties, enhancing seed quality, and ensuring international cooperation on water sharing. As the global water crisis deepens, these strategies will be critical for ensuring food security and sustainable agricultural production in Iraq and similar regions. The reasons for this study on plant growth and exploring strategies to combat it are highly relevant, given the increasing challenges posed by climate change and water scarcity. As you've outlined, drought stress affects plant physiology at multiple levels, from cellular hydration to overall growth and productivity. The research focus you propose on selecting and developing drought-tolerant crops, improving soil management, and combining both approaches offers a comprehensive solution to this complex issue. Water is essential for maintaining cell turgor pressure, which is crucial for growth and the continuation of vital physiological processes. When water availability decreases, cells lose their ability to swell, which disrupts growth and leads to reduced cell division and elongation [27,28]. To conserve water, stomata close, which reduces transpiration but also limits co_2 uptake, ultimately decreasing photosynthesis. Disrupted protoplasmic activity: prolonged drought leads to a breakdown of protoplasmic processes, affecting the transport of nutrients and energy within the plant, which reduces overall productivity. This cascade of physiological responses underscores the critical need for breeding drought-resistant crops and optimizing soil management practices to mitigate water loss and support plant growth under stress.

The main objectives of the study should focus on understanding the mechanisms that allow some plants to tolerate water stress and identifying practical methods for improving drought resistance in crops, both through genetic improvements and improved soil and crop management practices.

Here are some key focus areas based on your outlined goals: developing hybrid crops or cultivars that are more resilient to drought and capable of higher productivity under water-limited conditions is essential. This can be achieved through [29].

3. Breeding for Drought Resistance:

Using conventional breeding techniques or genetic engineering to develop crops with traits such as enhanced root systems: deep, extensive roots that can access water deeper in the soil profile; water use efficiency (WUE): improved ability to use water more efficiently, reducing wastage through transpiration while maintaining productivity; regulation: crops with better regulation of opening and closing to conserve water during drought while still enabling necessary gas exchange for photosynthesis; traits of interest: traits like osmotic adjustment, drought-induced genes (such as p5cs), and the ability to maintain metabolic processes under stress are also key to developing drought-tolerant cultivars. Root systems play a critical role in drought tolerance, as they determine the plant's ability to access water from the soil. Several studies have demonstrated that root depth and architecture matter: plants with deeper or more extensively branched roots have a higher chance of surviving drought conditions because they can access water from deeper soil layers. Root-to-shoot ratio: during drought stress, a higher root-to-shoot ratio may help the plant allocate resources to survival (water uptake) over growth (shoot development).

3.1 Selection for root traits: root traits can be used as reliable indicators for selecting drought-tolerant genotypes. For example, the ability to grow roots deeper and the production of lateral roots that explore a larger soil volume are desirable traits [30]. In practice, breeding programs should focus on these root characteristics as primary selection criteria for drought tolerance. Root architecture breeding may be an effective strategy to improve drought tolerance in crops like maize, wheat, and rice. Since Iraq has unique climatic and environmental conditions, it's crucial to evaluate the drought tolerance of various crop genotypes under local conditions. Field trials: Genotypes that show promise in controlled environments may still perform differently under field conditions due to soil variability, water availability, and temperature fluctuations. Field-based trials in regions of Iraq that experience severe water stress would be critical multi-location testing to identify genotypes that perform well across different regions with varying levels of water availability. Multi-location trials should be conducted in both irrigated and rain-fed areas. These trials can reveal how genotypes respond to actual environmental stress. Additionally, drought-tolerant varieties that are developed and tested should be evaluated not only for yield but also for other agronomic characteristics such as plant height, grain quality, pest and disease resistance, and heat tolerance. Principal component analysis (PCA) can be used as a statistical method to identify key drought tolerance indicators across different crop species. by evaluating traits such as leaf water content, osmotic potential, conductance, and chlorophyll content, researchers can classify genotypes can be classified into drought-tolerant, drought-sensitive, or intermediate categories based on these traits assess water stress impact: using PCA or other multivariate techniques, researchers can assess the relative importance of various drought tolerance mechanisms (root system size, leaf traits, etc.) and correlate these with productivity under stress conditions relative water content (RWC) indicates the hydration status of a plant, which is a critical measure of drought tolerance, conductance: lower conductance during drought stress can indicate the plant's ability to conserve water. Chlorophyll fluorescence: chlorophyll fluorescence can be a good indicator of plant health and photosynthetic efficiency under drought stress [31,32].

Water scarcity, exacerbated by global warming and climate change, presents a significant challenge to agriculture, especially in water-stressed regions like Iraq. The proposed study objectives—developing drought-tolerant hybrids, focusing on root systems as selection tools, evaluating local genotypes, and refining drought indicators—are crucial for ensuring sustainable agricultural production under water-limited conditions. By combining breeding efforts with effective soil management practices, this research has the potential to make significant strides toward improving food security and agricultural resilience in Iraq and similar regions.

3.2 Methods of resistance of corn to drought: Root system in enhancing drought resistance and improving crop yield under water-limited conditions. When facing water stress, the root system is central to maintaining plant hydration, nutrient uptake, and overall health. As you mentioned, the plant's genetic structure**,** soil conditions, and environmental factors significantly influence how effectively the root system functions under drought. Let's delve deeper into the mechanisms outlined, including the role of the root system and its interaction with drought stress, and how plant breeders and agronomists can exploit this knowledge for better crop management and breeding strategies. The root system plays a pivotal role in a plant's ability to survive and produce under drought conditions. Here's how water and nutrient uptake works: the roots are responsible for absorbing water and nutrients from the soil, which are critical for sustaining cellular processes, photosynthesis, and

overall plant growth. Under drought, the plant's root system needs to become more efficient at accessing water from deeper or drier layers of the soil**.** Root phenotypic and anatomical changes in response to water stress: plants often undergo physiological and anatomical changes in their root systems to enhance water uptake. Increase in root depth: some crops may develop deeper root systems to access water stored deeper in the soil. Expansion of lateral roots: a more extensive network of lateral roots increases the surface area for water absorption, which is especially useful when surface moisture is scarce. Root hair development: Increased production of root hairs can enhance the plant's ability to absorb water and nutrients, especially in the upper layers of soil where moisture is usually most available. Water conductivity and root hydraulic conductance**:** The ability of the root system to conduct water to the rest of the plant is a key trait in drought tolerance. A higher root hydraulic conductivity allows the plant to more efficiently transport the limited water it absorbs to the leaves and other parts of the plant. Root-to-shoot ratio under drought conditions: plants often adjust their root-to-shoot ratio**,** investing more in roots to optimize water uptake, often at the expense of shoot growth [33]. This adjustment is vital for ensuring the plant survives through water scarcity, as root growth is prioritized for water absorption. In drought-prone environments, roots may also adjust their growth direction, seeking deeper or more moisture-rich areas of soil. This directional growth is critical in maintaining the plant's water supply during prolonged periods of water stress. The genetic structure of a plant plays a significant role in how it responds to drought stress, particularly with respect to root system architecture**.** Genetic selection for certain traits can enhance drought tolerance, which is why breeding programs targeting drought-resistant varieties focus heavily on root traits and root architecture genes: there are certain genes involved in the development of root structure. For example, genes that regulate lateral root initiation**,** root elongation**,** and root branching can be selected to produce plants that are better equipped to withstand drought. Water stress response genes in addition to root architecture, plants have a variety of stress-response genes that help them cope with water scarcity. These include genes involved in osmotic adjustment (which helps retain water inside cells), abscisic acid (ABA) signaling (which regulates closure during drought), and stress proteins (like heat-shock proteins, which protect cellular structures from damage during stress). Breeding for drought resistance: traditional breeding methods and modern genomic techniques (e.g., gene editing, molecular markers) can be used to select for these favorable root traits and drought stress genes. The goal is to combine both high productivity and enhanced drought tolerance in new cultivars, ensuring that crops can perform well even under fluctuating water availability. Effects of drought stress on cellular processes: as you correctly pointed out, decreased water content leads to a series of physiological disturbances. Cell swelling and growth: water is essential for maintaining cell turgor pressure, which is responsible for cell expansion. Inadequate water supply leads to a halt in cell growth or a reduction in cell size, directly affecting the plant's ability to grow and develop. In response to water stress, stomata (the pores on plant leaves) close to reduce water loss through transpiration. While this conserves water, it also limits co_2 intake, leading to reduced photosynthesis and, consequently, slower growth and lower productivity. Protoplasmic imbalance: prolonged drought stress disrupts the protoplasm (the living part of the cell), including essential biochemical processes such as protein synthesis, energy production, and cellular maintenance. This leads to a breakdown in cellular function, further reducing the plant's ability to recover from drought. to address the challenge of water stress, particularly in regions with limited water resources, the following strategies are essential breeding drought-resistant varieties with improved root systems and better water-use efficiency should be a top priority. Key focus areas

for breeding include improved root architecture: varieties with deeper, more extensive root systems, more lateral roots, or better root hair development; enhanced water use efficiency: selecting plants that can maintain high yields despite limited water availability; efficient osmotic adjustment: crops that can better maintain turgor pressure in their cells under drought conditions; and improved regulation: breeding plants with more efficient control, allowing them to conserve water while still performing necessary physiological processes. Improving the efficiency of water use through soil and crop management practices is also critical. Some strategies include conservation tillage: minimizing soil disturbance to improve water retention and root development. Mulching: Applying organic or synthetic mulches to reduce soil evaporation and maintain soil moisture.

3.3 Irrigation Management (Water Harvesting): Implementing more efficient irrigation systems such as drip irrigation to minimize water wastage. Techniques such as rainwater harvesting and water storage can supplement irrigation needs during dry spells. Using advanced tools and technologies to evaluate how different crop genotypes respond to water stress will allow breeders to identify the most resilient varieties [34].

3.4 Phenotype Platforms*:* Using controlled environments (greenhouses or growth chambers) to simulate drought stress and screen large numbers of genotypes for drought tolerance. Molecular Markers: Identifying genetic markers associated with drought tolerance traits such as root architecture and water use efficiency. Field Trials: Conducting field-based testing under natural drought conditions to identify varieties that perform well under actual stress conditions. Combining genetic improvement (through breeding for drought tolerance) with agronomic practices (like efficient irrigation, soil conservation, and crop management) will provide a more holistic solution to water stress. This integrated approach ensures that plants have the genetic traits to withstand drought, while also receiving optimal care and management to support their growth and productivity.

3.5 Plant genetic response associated with drought tolerance*:* The complex nature of drought tolerance in plants arises from the involvement of multiple biochemical and physiological processes at various stages of cell and tissue development. These processes are governed by genetic factors, and understanding them at a molecular level is crucial for improving crop resilience to water stress. Let's break down and explore the points you've highlighted, including QTL studies, biochemical processes, and the genetic basis of drought tolerance. Genetic Determinants of Drought Tolerance: Quantitative trait loci (QTL) studies are key tools in identifying genetic regions associated with drought tolerance traits. These studies have uncovered that 27 loci are associated with seven fitness traits under drought conditions; 38 loci were identified for seven root traits under drought stress, and six loci for five root traits specifically related to drought tolerance. These findings indicate that drought tolerance is a polygenic trait, meaning it is controlled by multiple genes, each contributing a small effect to the overall phenotype. The complexity of drought tolerance arises from the fact that it involves multiple traits, including root architecture, cell wall stability, regulation, and leaf water content, all of which interact in response to water availability. Cell Wall Stability: Drought-resistant plants tend to have more robust cell walls that prevent excessive water loss and structural damage under stress. ABA (Abscisic Acid) Content: ABA is a plant hormone that plays a critical role in stomatal closure and the regulation of water loss. It helps plants conserve water during drought conditions by triggering responses like closure and reduced transpiration. The ability to control aperture (openings on the leaf surface) helps minimize water loss through transpiration during drought. Root Shape and Growth: The development

of roots that can grow deeper or spread laterally enables plants to access more water during dry conditions. Leaf Water Content: Maintaining higher water content in leaves under stress is essential for sustaining metabolic activities like photosynthesis.

4. Molecular Mechanisms of Drought Tolerance

Understanding the molecular mechanisms behind drought tolerance involves looking at several key processes. Gene Expression: Identifying genes that are activated or suppressed under drought stress is essential for understanding how plants respond at the molecular level. This includes water stress-responsive genes, such as those that control ABA biosynthesis, proline accumulation, and heat-shock proteins. Gene Identification: Genomic tools can be used to identify gene expression sites and molecular markers for drought tolerance traits. With advanced tools like RNA sequencing, genomic libraries, and gene editing (e.g., CRISPR), we can pinpoint the specific genes that contribute to drought resistance. This is a key step in directing breeding programs toward developing more resilient varieties. Metabolic pathways: Under drought conditions, plants undergo significant changes in their metabolic processes, including Proline Accumulation: Proline is an amino acid that accumulates in response to water stress. It acts as a stabilizer of proteins and cellular structures during dehydration. ABA (Abscisic Acid) Synthesis: Increased ABA levels help regulate stomatal closure, reduce transpiration, and enable the plant to conserve water more efficiently. Effects of Water Stress on plant growth [35].

Water stress has direct and indirect impacts on various metabolic and physiological processes in plants, which ultimately affect growth and productivity. Cellular impact: Water is crucial for maintaining cell turgor, which is necessary for cell expansion. Under drought conditions, cells lose water, resulting in decreased cell turgor, halted cell elongation, and restricted leaf expansion. The lack of cell swelling and water loss disrupts normal metabolic processes, including protein synthesis, cell division, and growth hormone production. Drought stress limits photosynthesis due to the closure of stomata; this prevents co_2 from entering the leaves, reducing the plant's ability to produce energy through photosynthesis. Simultaneously, the plant experiences increased respiration to maintain basic functions, which further depletes energy reserves. Closure is a critical response to water stress; stomatal closure is mediated by ABA. This reduces transpiration (water loss through leaves) but also limits co_2 intake, impairing photosynthesis. Enzymatic activity and enzyme function are impaired under dehydration, leading to a reduction in essential biochemical processes like ion transport, carbohydrate metabolism, and protein synthesis. This inhibition further compromises the plant's ability to maintain growth and function under drought conditions. Reduced growth and yield: Water stress severely affects plant growth, especially during critical stages like stem elongation and leaf expansion. As you pointed out, this can result in a significant yield loss, particularly in crops like maize, where flowering is a sensitive period. Yield reductions due to drought can range from 45% to 60%, particularly if the water shortage coincides with the flowering stage. Breeding for Drought Tolerance in Maize given the importance of drought tolerance in crops like maize, breeding strategies should focus on improving key traits associated with drought resistance, root system improvement: since the root system plays a crucial role in water uptake, selecting for varieties with deeper or more extensive root systems is essential for enhancing drought tolerance, metabolic regulation: selecting for better regulation of accumulation, aba synthesis, and other can help plants survive under water-limited conditions physiological traits: traits like regulation, leaf water retention, and cell wall stability can be targeted to enhance drought tolerance genetic selection: using molecular markers linked to QTL for drought tolerance traits can accelerate the development of drought-resistant maize varieties.

Advanced breeding techniques, including marker-assisted selection (MAS) and genetic engineering, could help in rapidly developing crops suited to water-stressed environments. Understanding the genetic and biochemical mechanisms behind drought tolerance is key to improving crop resilience in water-scarce environments. The role of root architecture, regulation, and metabolic pathways like ABA signaling and proline accumulation is a critical component of drought tolerance. With the help of genomic tools and QTL mapping, breeders can identify and select for the best traits to develop varieties that can withstand water stress while maintaining high productivity. In maize, as in other crops, the goal is to combine these genetic insights with practical breeding techniques to create plants that not only survive but thrive under drought conditions. Through continuous research, we can optimize breeding programs, soil management, and crop practices to ensure food security in the face of increasing climate variability and water scarcity [36].

4.1 Role of plant breeding in reducing the effect of water stress on some growth parameters of maize.

The study of phenotypic traits related to drought tolerance has become an important area of research in genetics, plant breeding, and physiology. As you've pointed out, plants exhibit various morphological and physiological mechanisms that help them withstand water stress, and researchers are keen to identify and optimize these traits for better drought resistance. Let's explore these key points in greater detail.

5. Complexity of Drought Stress and Breeding Challenges

Drought is a complex stress factor with different types affecting crops in varying ways. Early drought: Occurs before planting, delaying the planting date and impacting crop establishment.

Medium drought: Occurs during the crop's growing season and accumulates over time, having a significant effect on crop growth and yield.

5.1 Late drought: Affects late-ripening crops, particularly those that require water during the maturation phase for grain filling. These varying types of drought pose significant challenges for plant breeders, as they must develop varieties that can handle each type, often simultaneously. The genetic diversity in response to drought within populations and the interaction between soil, water, and genetic factors make breeding for drought tolerance a complex task. This is why drought tolerance breeding often progresses slowly, as breeders must work with multiple environmental variables and genetic factors.

5.2 Phenotypic Traits of Drought-Tolerant Plants*:* Several key phenotypic traits contribute to drought tolerance, which have been identified through research. Plant Height: Dwarfism or reduced plant height has been shown to increase the harvest index (the ratio of grain yield to total biomass), as shorter plants allocate more energy to grain production than to excessive vegetative growth. Shorter plants are also less susceptible to environmental stresses because their structure requires fewer resources to maintain and is less exposed to adverse conditions like wind or heat [36].

5.3 Leaf Morphology: The shape, size, and angle of the leaf play an important role in drought tolerance. Larger leaves increase photosynthetic potential, but under drought conditions, a reduction in leaf area can actually be beneficial to reduce water loss. Leaf angle and leaf flatness also affect the plant's ability to intercept light for photosynthesis and its water use efficiency. Leaves that are more upright tend to have a smaller surface area exposed to sunlight and thus lose less water through transpiration. Leaf area reduction is one of the first indicators that a plant is experiencing drought. It represents a strategy for

conserving water by limiting transpiration, even though this reduces photosynthesis. Root Characteristics:

Root depth and root volume are directly related to a plant's ability to access water deeper in the soil, especially during periods of water deficit. Root architectural changes such as deeper or more lateral root growth allow for greater water extraction during drought conditions [37].

The rate and direction of root growth are controlled by the plant's genetic makeup and can change significantly in response to water stress. These root adjustments enable plants to survive and even thrive under drought conditions. The Role of Leaf Area and Photosynthesis in Drought: As mentioned, the leaf is crucial for photosynthesis and plant metabolism. Under drought conditions, reduced leaf area is one of the early signs of drought stress. It is often a protective response to reduce the overall water loss through transpiration. While this limits photosynthetic capacity, it helps conserve water and prevent the plant from dehydrating further. Photosynthesis is critical for plant growth, and leaf area directly affects the amount of light intercepted and the photosynthetic potential of the plant. A larger leaf area enables more efficient photosynthesis under optimal water conditions, but under drought stress, this is counterproductive as it leads to higher water loss. Thus, plants under drought conditions might adopt strategies such as leaf rolling or reducing leaf area to balance water conservation with the need for photosynthesis. Genetic and phenotypic variance in response to drought, as in studies like the one referenced, indicates that genetic diversity plays a major role in drought response. The interaction between the genetic structure of the plant and water availability creates significant phenotypic variance in populations. Some genotypes may be naturally more tolerant to drought, while others are more sensitive. This genetic variation is crucial for plant breeders because it allows them to select the most drought-resistant varieties. Genetic × soil interaction: drought tolerance may vary not only with the genotype but also with the soil properties, such as its water-holding capacity and structure. In drought-prone regions, understanding this interaction can help breeders identify crops that perform better under specific soil and water conditions sorghum case study. The example of late-green sorghum hybrids mentioned demonstrates the importance of genotype-environment interactions. Sorghum plants that remained green longer (after flowering) showed a better yield under drought conditions. This phenomenon highlights how certain genetic traits, such as late greening, can be beneficial in drought conditions by allowing plants to continue photosynthesis and produce higher yields despite reduced water availability. Such traits are important to study and incorporate into breeding programs for other crops water as a limiting factor, water is arguably the most limiting factor for plant growth and crop productivity worldwide. It not only controls the distribution of plants in various regions but also influences productivity in agricultural systems. This is why managing water resources efficiently and developing drought-tolerant crops are of utmost importance, especially in arid and semi-arid regions. Water's influence on photosynthesis: As you mentioned, water affects the growth of plants through its role in essential metabolic processes. Lack of water leads to stomatal closure, which reduces photosynthesis and growth. Without enough water, cellular processes like cell division and elongation are compromised, leading to stunted growth and reduced yield.

To overcome the challenges posed by drought and improve crop productivity in water-limited environments, breeding programs need to focus on key morphological traits such as root architecture, leaf morphology, and plant height. These traits, along with genetic selection for drought-tolerant varieties, offer practical solutions for enhancing resilience to drought. A deeper understanding of the genetic basis of drought tolerance will enable more targeted breeding strategies, helping to create crops

that can withstand water stress without sacrificing productivity. Incorporating genotype-environment interactions, root depth, and leaf traits into breeding programs, as well as developing late-green varieties, can improve crop yields in regions affected by drought. As the global demand for food increases and water resources become scarcer, such innovations will be essential for ensuring sustainable agricultural production in the face of climate change [38]. It highlights the complex relationship between water stress and maize productivity, particularly under drought conditions, and how breeding and management strategies can mitigate these impacts. Let's break down and expand upon the key points regarding drought stress, maize growth stages, and strategies to improve drought tolerance.

6. Impact of Water Stress on Maize Growth

Water stress and leaf area as mentioned, water stress leads to a decrease in leaf area, as the plant sheds leaves to conserve moisture. This decrease in leaf area significantly impacts the plant's ability to photosynthesize, leading to reduced growth and ultimately lower yields. Photosynthesis is crucial for plant growth, and less leaf area means less energy for grain production. Effect on Male and Female Flowering: Drought stress, particularly during the flowering stage, has a profound effect on the timing of male and female inflorescence development. Male flowering (pollen release) occurs after the vegetative growth phase, while female flowering (silk emergence) typically occurs shortly after pollen release. When a maize plant is exposed to water stress, female flowering is delayed by 6–9 days, which can significantly affect yield, especially because the reproductive phase is particularly sensitive to drought. Delays in Female Flowering: Delays in female flowering reduce the synchrony between pollen release and silk emergence, potentially leading to incomplete pollination. This reduces the number of grains per ear and ultimately lowers the total yield. Early maturity varieties as a strategy for drought tolerance: developing early-maturity maize varieties is a key strategy to combat drought. These varieties require less water throughout their growing season because they reach maturity more quickly. Are better suited for intercropping systems, as they require less time to grow, allowing farmers to cultivate multiple crops in a single season, which optimizes land and water use. Compete less with other crops for water, light, and nutrients, especially in regions with limited water resources.

6.1 Effects of Water Stress on Dry Matter Accumulation and Grain Yield Dry Matter Production

: The amount of dry matter produced by maize is closely linked to water availability. Plants exposed to water stress during the early stages of growth (vegetative phase) can still produce dry matter, but their rate of dry matter accumulation is often lower. If the moisture stress occurs during reproductive stages, such as silk formation and grain filling, it leads to a sharp decrease in grain yield [39]. Water Stress and Grain Filling: The grain filling stage is one of the most sensitive periods for maize plants under drought stress. Inadequate water during this stage leads to reduced mineral absorption, transport, and cellular expansion, all of which contribute to a reduction in grain weight. This can result in a 20-50% reduction in maize yields when water stress occurs during the critical stages of grain filling.

6.1.2 Grain Weight and Yield

: Water stress during grain filling not only reduces the number of grains per ear but also negatively impacts grain weight, which is a critical component of overall yield. As you mentioned, the reduced photosynthetic material causes abortion of emerging grains, resulting in lower grain set and smaller grain sizes. Consequently, grain yield decreases significantly under water-limited conditions.

6.2 Effect of Water Stress on Grain Yield Components

: Water stress during the vegetative

phase (early growth stages) has a smaller effect on grain yield compared to stress during flowering and grain filling. This is due to the fact that the plant can still undergo some degree of compensatory growth in the early stages, but during flowering and grain filling, the plant is more sensitive to drought because these stages are crucial for grain development [40].

6.2.1 Effectiveness of Water Stress on Ear Formation. As you've pointed out, water stress before silk formation leads to a significant reduction in grain yield (up to 25-50%). This is primarily because the development of ears (and the number of kernels they produce) is directly impacted by water availability.

6.2.2. The number of kernels per ear*:* Often reduced under water stress, and those that do develop are typically smaller.

6.3. Reduction in Yield Components*:* The critical yield components influenced by water stress include Number of grains per ear: Water stress during the pollination period leads to incomplete pollination, reducing the number of kernels that set on the ear and grain weight. Water stress reduces the uptake of nutrients, leading to smaller grains and lower final yield.

6.4 Strategies to Improve Drought Tolerance: To address these challenges, several strategies can be adopted. Development of Early-Maturity Varieties: As mentioned earlier, breeding maize varieties with early maturity allows crops to complete their life cycle before severe drought conditions occur.

6.5 Breeding for Drought Tolerance*:* Key traits for breeding drought-tolerant maize include efficient root systems that can access water deeper in the soil profile; leaf morphology that minimizes water loss through transpiration (e.g., smaller leaf area, leaf rolling, and regulation); reproductive timing that aligns with available water during critical stages such as pollination and grain filling; and heat tolerance in combination with drought tolerance to ensure that crops remain productive even under high temperatures. Water and Nutrient Management: Efficient irrigation systems, such as drip irrigation or deficit irrigation, can help minimize water loss while providing sufficient moisture during critical growth stages. Fertilization strategies that optimize nutrient availability can also improve crop resilience to drought stress by promoting root growth and maximizing photosynthesis.

6.6 Integrated Crop Management*:* Strategies that combine early-maturity varieties, efficient water management, and optimal crop management (e.g., timely planting, proper spacing, and nutrient application) will improve overall drought resilience and yield stability. Water stress is a major limiting factor for maize production, especially during the reproductive and grain-filling stages. The development of drought-tolerant and early-maturing varieties is one of the most promising strategies to mitigate these challenges. Through genetic selection, optimized water management, and improved breeding programs, we can enhance maize's ability to withstand drought and improve its productivity in water-limited regions. Understanding the effects of drought on the various growth stages and yield components is critical for selecting the best breeding approaches and crop management strategies to ensure food security in the face of increasing water scarcity [41].

7. Plant breeding for drought tolerance

The passage you've shared provides a comprehensive overview of the methods and strategies used to breed crops for drought tolerance, emphasizing the complex nature of drought as a multifactorial stress and the need for genetic improvements alongside crop management practices. Let's break down the key points and strategies to improve drought tolerance in crops like maize and beans. Importance of phenotypic traits in drought tolerance: root system and traits: The root system plays a crucial role in drought tolerance

because it is directly involved in water and nutrient uptake. Denser root systems are often linked with better performance under water stress, as they can access water from deeper soil layers. Additionally, fewer stomata on the leaves can reduce transpiration, thereby conserving water, which is critical under drought conditions. Selection for yield and key traits: as your passage points out, high-yield genotypes were identified through repeated selection in maize. Certain traits such as plant height, grain weight, and days to maturity were positively correlated with grain yield under drought conditions. This means that these traits directly contribute to improving yield when water is scarce, making them valuable selection criteria. Grain weight and dry weight are particularly important because they are linked with the plant's ability to store nutrients and maintain metabolic processes under limited water availability.

7.1 Breeding for Drought Tolerance: Key strategies, genetic variance and selection methods: The process of selecting for drought tolerance involves evaluating genetic variance under controlled conditions, such as irrigation experiments with water stress. Studies suggest that selection under water stress is often more effective in improving drought tolerance than selecting in non-stress conditions. This approach focuses on selecting plants that maintain higher yield performance despite the water deficit. Cross-breeding and genetic selection can enhance the genetic diversity and resilience of the crops. By selecting plants that show stronger performance in drought conditions, breeders can develop varieties that can better adapt to water stress. Molecular breeding: tools and techniques: molecular markers for drought tolerance.

7.2 The passage highlights the potential of molecular breeding to accelerate the identification of drought-tolerant traits*:* Techniques like RFLP, SNP, AFLP, and RAPD markers have been used to identify the genetic basis of drought tolerance [42]. These markers help in understanding the molecular mechanisms underlying drought resistance and provide faster, more targeted breeding solutions compared to traditional methods. QTL (Quantitative Trait Loci) Mapping: QTL mapping is particularly useful in identifying genes associated with drought tolerance. By pinpointing the loci linked to critical traits (e.g., root depth, regulation), breeders can select plants with these favorable traits more precisely, saving time and resources.

7.3 Development of Drought-Tolerant Cultivars: The development of highly variable cultivars that show high heritability for drought tolerance is essential. Such cultivars can be tested in large-scale trials, where tens of thousands of plants are exposed to water stress conditions. This allows for the evaluation of growth rates, yield performance, and the mechanisms responsible for drought tolerance.

7.4 Honeycomb Program: The honeycomb program mentioned in the passage seems to be a form of mass selection where drought-tolerant plants are selected, and their growth rates and yield under water stress are measured. This method ensures that the best-performing plants for drought tolerance are identified and used in future breeding cycles.

8. Breeding and Management Strategies for Drought Tolerance

Breeding for Early Maturity: As mentioned earlier, developing early-maturing varieties is an effective strategy for reducing water usage. Early-maturing crops can escape periods of drought stress by completing their growth cycle before severe drought conditions set in. This strategy is particularly beneficial for crops grown in regions with unpredictable or seasonal rainfall.

8.1 Water Use Efficiency (WUE): Water use efficiency is an important trait in drought-tolerant crops. It refers to the ability of plants to produce higher yields per unit of water. By selecting for crops

that use water more efficiently, breeders can help ensure that crops are more resilient to drought conditions. Techniques like reducing water loss and optimizing irrigation practices can complement.

8.2 Genetic improvements in WUE. *Management Practices:* Besides genetic improvement, crop management practices also play a crucial role in mitigating drought stress. These include: Adjusting planting depth to ensure access to deeper soil moisture; using growth regulators to help plants cope with stress; cover cropping to reduce evaporation and improve soil moisture retention; plowing and soil cultivation to improve water infiltration and reduce runoff; and cross-breeding with Drought-Tolerant Parent Plants. The cross-breeding process among drought-tolerant parent plants can help create hybrids with integrated traits for drought resistance. By focusing on both the gene action and trait superiority, breeders can maximize the drought tolerance in subsequent generations [43].

9. Drought Mechanisms and Management Insights

9.1 Drought Avoidance vs. Drought Tolerance: Plants can exhibit drought avoidance mechanisms, such as early maturity and deep root systems, which allow them to escape or avoid water stress. Alternatively, drought tolerance mechanisms help the plant survive in dry conditions by regulating water use and maintaining essential physiological processes, such as photosynthesis and respiration. It is important to select for a combination of both mechanisms, as they allow plants to not only escape drought but also tolerate it when water stress is unavoidable. Environmental Considerations: Understanding the relationship between climatic factors (e.g., temperature, rainfall) and crop growth is key to breeding drought-resistant plants. High temperatures exacerbate the effects of drought by reducing dry matter production and increasing the rate of water loss through transpiration. Radiation Use Efficiency (RUE) and Rainwater Use Efficiency (RWUE) are key indicators of how well a plant can utilize available water resources. These efficiencies are often closely related to leaf area index, canopy structure, and photosynthetic rate, all of which can be optimized through both breeding and management practices [44].

10. Conclusion: Integrating Breeding and Management

In conclusion, breeding for drought tolerance is a multifaceted approach that requires genetic improvement through selection for traits like root systems, density, and early maturity. Use of molecular tools (like QTL mapping and molecular markers) to speed up breeding for drought tolerance. Effective crop management practices such as optimizing water use, improving soil moisture retention, and utilizing growth regulators. Combining drought avoidance and tolerance mechanisms to ensure crops can survive and produce in water-limited conditions. By integrating breeding techniques with improved management strategies, it is possible to develop crops that not only withstand drought but also maintain high productivity, ensuring food security in regions affected by water scarcity [45].

10.1 Drought Tolerance Indices*:* The passage you've provided discusses important concepts related to drought tolerance and stress response mechanisms in crops, specifically focusing on genotypic stability and how certain indices can be used to assess a crop's ability to withstand drought. Let’s break down the key ideas and their implications for breeding drought-tolerant crops, genotypic stability, and yield under water stress. Genotypic stability: this refers to how consistently a genotype (or variety) can produce grain under both normal and water stress conditions. The stability of grain yield under water stress is an essential criterion in evaluating the drought tolerance of a cultivar. A genotype that maintains a relatively high yield under

water stress is considered to have better stability and stress tolerance. High stability implies that the plant can produce relatively constant yields despite fluctuations in environmental conditions, such as water availability. Genotypes with higher stability tend to have specific stress tolerance mechanisms that allow them to continue growing or maintain yield even under reduced water availability. Drought stress indices for assessing tolerance [46]. Several indices are used to quantify and assess drought tolerance in crops. These indices help in evaluating genotypes under stress conditions.

10.1.1 Sensitivity Index (SSI): The SSI measures how sensitive a genotype is to water stress. A high SSI value indicates that the genotype is very sensitive to stress and is more likely to experience a significant reduction in yield under water stress conditions. Conversely, a lower SSI suggests better resilience to drought. SSI values between 0.55-0.63 (as seen in wheat cultivars) indicate a range of susceptibility, and thus, they can be used to differentiate genotypes that are highly sensitive from those that are more tolerant.

10.1.2 Geometric Mean Productivity (GMP): The GMP is an index that combines both the yield under stress and the yield under non-stress conditions. Higher values of GMP indicate a genotype that performs well across varying environmental conditions, particularly under water stress.

10.1.3 Stress Tolerance Index (STI): The STI is another critical index used to assess drought tolerance. It compares the yield of a genotype under stressed conditions to its yield under normal conditions. A high STI value indicates that the cultivar retains a substantial proportion of its potential yield even under drought stress.

10.1.4 Mean Productivity Index: This index assesses the overall productivity of a genotype by taking into account its performance under both normal and stress conditions. It is helpful for identifying genotypes that are productive even under drought stress. These indices collectively help breeders identify genotypes that can perform well not only under optimal conditions but also when subjected to drought stress [47].

11. Genotypic Response to Stress and Water Stress

11.1 Variation in Stress Response*:* Genotypes react differently to water stress, and their performance under drought can be influenced by factors such as timing and intensity of the stress, as well as the genetic makeup of the plant. Genotypes with mechanisms that minimize the negative impact of water scarcity, like enhanced root systems or better water use efficiency (WUE), tend to perform better under stress.

11.2 Water Stress and Yield: As the passage suggests, water stress is positively correlated with grain yield in some genotypes, meaning that certain varieties can still produce high yields even when exposed to drought. The intensity and duration of water stress are key factors in determining how well a genotype will perform [48].

11.3 Classification of Genotypes Based on Yield and Stress Response: According to Fernandez, genotypes can be classified into four groups based on their yield and response to stress:

11.3.1 High Yield under Normal Conditions, Low Yield under Stress (Sensitive genotypes).

11.3.2 High Yield under Both Conditions (Tolerant genotypes).

11.3.3 Low Yield under Both Conditions (Susceptible genotypes).

11.3.4 Low Yield under Normal Conditions, High Yield under Stress (Stress-escape or drought-avoiding genotypes).

The classification helps to identify which genotypes are best suited for breeding programs focused on improving drought tolerance**.**

Table 1. ET rates, productivity, and water use efficiency WUE (kg yield / m^3 of water)

Crop ty	Evaporation - Transpiration (m	Productivity (tons/ha)	Water consu efficiency (kg/m3)
wheat	550 - 450	7 - 4	1 - 0.7
barley	450 - 350	4 - 2	1.2 – 1
Maize	850 - 750	12 – 7	1.7 – 0.7
Sorghum	550 – 450	7 - 4	1 – 0.6
Cotton	13500 - 950	6 - 4	0.5 – 0.3
Sunflower	1000 - 800	3 - 2	0.5 – 0.3
Soybean	900 - 700	5 - 3	0.6 – 0.4

12. Water Stress and Climate Impact

12.1 Deserts and Water Stress: Deserts are regions where annual rainfall is very low, and vegetation is scarce, typically consisting of small plants and shrubs. The ability of these plants to survive is highly affected by the high rates of evaporation-transpiration (ET), which is exacerbated by high temperatures. Crops exposed to similar conditions will need to adopt specific strategies to cope with both evaporation and transpiration losses.

12.2 Mechanisms for Drought Tolerance: The passage also hints at the various mechanisms that some plants possess to tolerate drought. Drought escape. Certain genotypes can avoid drought by completing their growth cycle before water availability becomes critical, for example, by maturing early.

12.3 Drought Avoidance: Other genotypes may employ mechanisms to minimize water loss, such as deeper roots or reduced opening, which reduce transpiration.

12.4 Drought Tolerance: Some genotypes can maintain metabolic functions and growth despite water stress, often by optimizing their internal water relations, increasing water use efficiency, or stabilizing their photosynthetic apparatus [49].

12.5 Implications for Breeding and Crop Management: In conclusion, understanding and utilizing drought stress indices is crucial for selecting and breeding drought-tolerant genotypes. These indices, such as the SSI, GMP, and STI, provide insights into how well different genotypes cope with water stress. By selecting plants that perform well under both stress and non-stress conditions, breeders can develop cultivars that are resilient to climatic variability, such as that experienced in semi-arid regions or desert-like conditions. Integrating genetic selection for drought tolerance with crop management practices will help ensure stable yields even under challenging environmental conditions. This integrated approach will be key in developing crops capable of withstanding the increasing frequency and severity of drought events predicted with climate change [50].

13. Conclusions

The study proposes the use of local varieties, which have adapted to the Iraqi environment, but with the addition of genetic improvements. This could involve selecting for traits like deep rooting, efficient water use, and early maturity, which are essential under water-limited conditions. The goal is to enhance the genetic base of these local varieties,

making them more resilient to drought while improving overall yield. Introducing new drought-resistant varieties the introduction of new drought-resistant varieties that are suitable for Iraqi environmental conditions is essential. These varieties would be tailored to local water availability issues, ensuring reliable food production in regions with scarce water resources. Breeding programs: The study emphasizes the importance of breeding programs to create genetic diversity and increase the chances of selection. Two main breeding approaches are highlighted: selection, identifying and selecting the most suitable genotypes based on drought tolerance, water use efficiency, and productivity; and cross-breeding: cross-breeding different species or varieties to combine beneficial traits from both, creating new, improved genetic structures that outperform local varieties under drought conditions. Key strategies for achieving these goals include screening for drought-tolerant traits; root system adaptation: breeding for plants with deep or efficient root systems that can access water from deeper soil layers. Leaf morphology: selection for plants with smaller or more efficient leaves to reduce water loss through transpiration; water use efficiency (WUE): selecting for genotypes that can optimize water use by minimizing loss and maximizing absorption and retention. Genetic diversity and evaluation genetic variations: surveying existing genetic diversity in crops, including both local varieties and exotic species, to identify drought-tolerant traits that can be incorporated into breeding programs evaluation under stress: testing these crops in water-limited environments to assess their performance under real-world drought conditions collaborative breeding approaches selection and cross-breeding: using traditional breeding techniques such as selection and cross-breeding to enhance genetic traits associated with drought tolerance. Water Efficiency and Yield Stability: Efficiency of Water Use; breeding for plants that require less water while still maintaining high yields will be key to adapting to the region's water scarcity. Stable yield under drought: selection for genotypes that can produce consistent yields even under fluctuating water availability will be important for food security in drought-prone areas study aims to achieve greater crop productivity in Iraq's dry land areas by focusing on drought tolerance, water-use efficiency, and genetic improvement. It suggests that the use of advanced breeding techniques, including genetic selection and cross-breeding, can help identify or create new crop varieties suited to the country's challenging environmental conditions. These varieties will be more resilient to water stress, ensuring sustainable crop production and enhanced food security introduction of new drought-resistant varieties and improved local varieties will help to increase productivity per unit area, reduce water consumption, and ultimately improve agricultural sustainability in Iraq.

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