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Drought Stress and Response Mechanisms of Plants

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Abstract – With the global climate anomalies and the deterioration of the ecological balance, water scarcity has become a serious ecological problem facing all humanity, and drought has become an important factor restricting the development of agricultural production. In this review, based on previous studies, the effects of drought stress on plant morphology and physiology and defense mechanisms of plants against drought stress were examined.

Keywords – Biotic Stress, Abiotic Stress, Defense Mechanisms, Water Deficiency

I. Introduction

The changes that occur in plants under the influence of biotic and abiotic stress factors are expressed as stress. While stress negatively affects the growth and development of plants by causing important physiological and metabolic changes, it can also cause a loss of quality and quantity in the product and even the loss of vitality of the plant and plant organs. Stress factors are divided into biotic and abiotic categories (Levitt, 1972). Biotic factors are microorganisms (fungi, bacteria, and viruses), insects, wild plants, and stress factors resulting from diseases. Abiotic factors are environmental factors such as drought, temperature, radiation, flooding, mechanical effects (wind, snow, ice effect), air pollution, plant nutrients, pesticides, toxins, salts, and pH (Lichtenhaler, 1996).

Plants are not stressed when environmental conditions do not cause damage to plants and there is no negative effect on growth and development as well as on the quality and quantity of the product. Conditions that do not cause stress are expressed as optimum environmental conditions. Under these conditions, the adaptation of plants to the environment is complete.

II. Drought Stress

Drought is a meteorological phenomenon in general, and it is a period without precipitation that lasts long enough to cause a noticeable decrease in the water content of the soil and plant growth. The drought in the dry period depends on the water holding capacity of the soil and the evapotranspiration rate performed by the plants (Kutlu, 2010).

Water stress is the most important environmental factor affecting the growth and development of plants. Water stress occurs in two forms: excess or lack of water. The stress caused by a lack of water is commonly referred to as drought stress. It occurs when the amount of water lost by transpiration in plants over a certain period of time exceeds the amount of water taken from the environment. A competition for water intake begins between plant tissues whose amount of water decreases. In other words, the water balance between plant tissues is disturbed. Drought can be broadly divided into two types: water deficiency and desiccation (Smirnoff, 1993).

Water deficiency: It is moderate water loss that causes closure of stomata and restriction in gas exchange. In plants exposed to mild water deficiency, where the proportional water content remains at approximately 70%, carbon dioxide uptake is restricted due to the closure of stomata (Smirnoff, 1993).

Desiccation: It can be defined as excessive loss of water, which has the potential to cause complete disruption of metabolism and cell structure, and eventual cessation of enzyme-catalyzed reactions. As a general rule, vegetative tissue in most vascular plants susceptible to desiccation cannot recover at a relative water content of less than 30% (Smirnoff, 1993).

Plants are divided into three groups: hydrophytes, mesophytes, and xerophytes, depending on their water requirements or, especially, the available water in the environment they live in. Hydrophytes are plants that live partially or completely in water, Mesophytes are plants that grow in areas with suitable soil moisture; and Xerophytes are plants that grow in arid areas (Öztürk and Seçmen, 1992). While the vitality of hydrophyte plants depends entirely on the presence of abundant water in the environment, some xerophyte plants can survive even in deserts where no precipitation falls for several years in a row (Çırak and Esendal, 2006).

III. EFFECTS OF DROUGHT ON PLANT DEVELOPMENT

A. *Mechanical Effects*

The mechanical effect is the primary stress manifested by the loss of turgor in the plant when significant water loss occurs from plant cells. With the loss of water from the cell, the membrane structure changes, the hydrophilic heads of the phospholipids converge, and the membranes take on a compact appearance. In this new structure, membrane lipids have lateral and rotational movement with less kinetic energy than in the liquid-solid phase. Due to the loss of water, the volume of the cell also decreases, and the plasma membrane separates from the cell wall and maintains its relationship only through plasmodesms. The plasma membrane under tension can rupture, resulting in the release of hydrolytic enzymes located on the membranes and thus autolysis of the cytoplasm. This damage often permanently disrupts normal cellular metabolism (Kalefetoğlu and Ekmekçi, 2005).

The morphological changes that occur in the leaves under arid conditions are generally aimed at reducing the amount of water lost by transpiration and absorbing it with a force that occurs in the roots. First, root growth accelerates under drought stress, and the ratio of root to trunk increases. In arid conditions, photosynthesis slows down, and as a result, sprout development is weakened. Most of the photosynthesis products are transported to the roots for root development. Thus, root development accelerates, and the ratio of root to trunk increases (Kutlu, 2010).

Another change that occurs in the roots under drought stress is that they are covered with a thick layer of tissue similar to a fungus. This layer protects the living cells below from the effects of dry and hot soil. In cases of drought, soluble carbohydrates are carried from above-ground organs to roots. Thus, the osmotic pressure of the roots increases, and their water absorption power increases. As the leaf surface width in plants increases, water loss also increases. Plants try to reduce their total leaf area by shedding their leaves in order to reduce water loss. This is especially common in desert plants. Leaf growth is highly sensitive to drought stress. Even short dry periods slow down leaf growth. This is associated with a decrease in photosynthesis. As a response to drought stress, the leaves of the plant are covered with dense hairs. These hairs lower the temperature of the underlying cells by 1-2 °C, reducing the rate of transpiration. In addition, as wax (cuticle) production on the leaf increases, the cuticle layer reflects the sun's rays, reducing the effect of temperature, and thus the rate of transpiration is interrupted (Göksoy and Turan, 1991). During the dry period, some herbaceous plants curl their leaves into ribbons. Thus, the transcribing surface is reduced. Cells shrink, cell walls thicken, and intercellular spaces decrease.

In cases of drought stress, leaves fall, the growth and development of leaves and shoots slows down, leaf blades become smaller, and leaves curl or roll. Stomata are buried deeper. In order to protect the stomatal surfaces, the leaves and stems are covered with dense hairs, and the thickness of the cuticle and wax layers on the epidermis increases. Root development accelerates, the ratio of root to trunk increases, and root systems go deeper. Cells shrink, cell walls thicken, and intercellular spaces decrease.

IV. Response Mechanisms of Plants Against Drought Stress

Drought stress induces many physiological, biochemical, and molecular responses in plants that will enable them to adapt to limited environmental conditions. The two main defense mechanisms developed against drought stress in vegetative tissues are stress avoidance and stress tolerance (Levitt, 1972). Stress-avoidant plants survive only under moderate drought stress, while stress-tolerant plant groups can survive much more severe drought stress by activating their protective mechanisms (Çetinkaya, 2013).

The first of the stress avoidance mechanisms is the escape seen in ephemeral plants. Desert ephemeral plants are annual plants that escape drought by existing only as dormant seeds during the dry season. Their protoplasm is never exposed to severe negative water potentials. Another avoidance mechanism is seen in succulent plants. These plants resist drought by storing water in their tissues and can survive for long periods without taking in moisture because of their extremely low water loss rates. In resurrection plants, which are among the plant groups that are tolerant of desiccation, a quite different strategy is followed, in which up to 5% of the relative water content in the vegetative tissues can be lost during periods of water shortage, and rehydration can occur if the water can be reabsorbed. The vegetative tissues of these plants have the ability to cope with the stresses associated with extreme drought in the presence of light. Desert evergreen plants avoid drought by synthesizing osmotic preservatives to maintain turgor in their tissues during water shortages (Kalefetoğlu and Ekmekçi, 2005).

V. Conclusion

Plants have evolved to respond and adapt appropriately to drought stress conditions through spacetime and gradual signals in tissues throughout the entire plant in order to achieve drought stress resistance. As mentioned above, changes in plant external morphology and internal biochemical properties under drought stress have been described in detail in past studies. Plants react to water scarcity in different ways, and this is a complex process that we still need to try to solve. Critical information about drought stress resistance mechanisms deserves further research for future crop innovation. This review provides valuable background information and a theoretical basis for the selective breeding, cross-breeding, and molecular breeding of agricultural and forest crops in the future by systematically analyzing and summarizing the mechanisms of plants' responses to drought.

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