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Effect of low temperature stress on crop plants: A review

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Abstract
Plants are exposed to a variety of abiotic stresses in the field, all of which are detrimental to plant growth and output. Plants' morphological, physiological, and molecular responses can be altered by the freezing conditions as a result of extreme and rapid global climate change. Despite the major advances, there is still a lot of space for development in terms of freezing tolerance. As a result, future research should focus on biotechnological and molecular approaches to generate genetically altered plants with improved tolerance.

Keywords: Chilling temperature stress, photosynthesis, reactive oxygen species, antioxidant enzymes

Introduction
During the life cycle of crops grown in open fields, they frequently experience abiotic stress. Such stresses frequently coincide, causing crop growth and output to suffer as a result. In order to reduce the effects of abiotic stresses, plants goes through a variety of morphological, physiological, biochemical, and molecular modifications. A lot of research has been done on the adaptive capacities of crops plants to various abiotic stresses, with a focus on specific stress components (Chinnusamy *et al*., 2007) [5]. Crops in various parts of the world are subjected to periods of extremely low temperatures (Ruelland *et al*., 2009) [26]. Plant growth is hampered when plants are exposed to freezing, which is undesirable for productivity (Tommasini *et al*., 2008) [35]. The impact of freezing stresses on plants is poorly understood. In general, freezing stress slows the speed of several physiological and metabolic processes in plants (Ruelland *et al*., 2009) [26]. It decreases germination rate and uniformity, diminishes seedling vigour, and delays ontogenic plant growth (Oliver *et al*., 2007) [20], leading in significant crop yield losses (Ruelland *et al*., 2009) [26].

Plant's Responses to Low temperature stress:
Chilling is very damaging to several field crops, especially during germination and the early stages of seedling growth. For germination, each seed requires the ideal temperature. Chilling stress produces severe production losses by impairing germination and often lowering seedling vigor (Kang and Saltveit, 2002) [15]. It also affects plant development (Oliver *et al*., 2007) [20]. Energetically, chilling stress is known to limit the kinetics of numerous physiological and metabolic processes in plants (Ruelland *et al*., 2009) [26]. Due to its thermophilic tendency, low temperature stress causes a water deficit in the shoots and decreased root water absorption (Stewart *et al*., 1990) [32]. Plant growth and development are known to be severely hampered by low temperature stress. Low temperature stress has been shown to inhibit cotton (Zhao *et al*., 2012) [39], tomato (Starck *et al*., 2000) [31], and sugarcane development in a number of studies (Anjum *et al*., 2011) [2]. Low temperature stress can produce necrotic lesions on leaves, impede leaf growth, extend the cell cycle with reduced cell formation, cause wilting, and make plants more susceptible to infections and illnesses (Rymen *et al*., 2007) [27].
Smaller leaf area results from a slower rate of cell division and elongation, whereas a slower rate of leaf initiation results in a lower number of leaves during periods of freezing stress (Lukatkin *et al*., 2012) [17]. Chilling stress inhibits root development by reducing root length, biomass, and shape and also reducing the volume of the root system available for nutrition and water exploration (Richner *et al*., 1996) [22].

Chilling stress substantially reduced barley yield, according to Rizza *et al*. (1994) [23]. Chickpea flower abortion and poor pod setting were caused by chilling stress throughout the reproductive cycle (Nayyar *et al*., 2005) [19].

Low temperature stress resulted in spikelet degeneration, panicle distortion and poor spikelet fertility in temperate growing regions, resulting in a 30-40 percent drop in rice yields (Andaya and Mackill, 2003) [1]. Low temperature stress during reproductive development in grain crops can result in floral abscission, ovule abortion, pollen sterility, pollen tube deformation, poor fruit set, and hence decreased ultimate yields (Thakur *et al*., 2010) [33]. Low temperature stress during stem elongation decreased internode extension, induced spikelet mortality, and reduced biomass accumulation and grain production in wheat, according to Whaley *et al*. (2004) [36]. Finally, low temperature has a negative impact on crop production and yield. Reductions in these characteristics might be the result of stress-induced changes in metabolic and physiological processes, which would have a detrimental impact on plant reproductive organ productivity. Although the freezing is harmful to plants in general, the reproductive stage of the plant is likely the most vulnerable to these stress factors than the pre- and post-reproductive stages.

The rates of photosynthesis and other gas exchange characteristics in agricultural plants are altered by chilling conditions. Sales *et al*., (2013) [28] discovered that chilling stress had a significant impact on leaf gas exchange, photochemical activity, CO_2 assimilation, production of energetic pressure at the PSII level, electron transport rate, and transpiration when working on sugarcane. Low photosynthetic rates in agricultural plants under cold stress have been ascribed to inadequate CO_2 stomatal and mesophyll conductance, limited metabolite transport and quantum yield for CO_2 assimilation (Sowiski *et al*., 2005) [21]. Due to excessive stimulation of thylakoid membranes and consequent degradation of photosynthetic activity, cold stress decreases photosynthetic efficiency and increases photo-inhibition (Jung and Steffen, 1997) [14]. Furthermore, cooling reduces the amount of $NADP^+$ supplement available to receive electrons from the electron transport chain, slowing CO_2 fixation (Wise, 1995) [37].

The main parameters characterizing plant water relations include relative water content, leaf water potential, transpiration rate and stomatal conductance (Farooq *et al*., 2009) [8]. Cold stress resulted in substantial decreases in sugarcane leaf water potential, according to Sales *et al*. (2013) [28]. McWilliam *et al*. (1982) [18] also found that chilling-induced wilting in plants was caused by a decrease in root hydraulic conductivity and a loss of stomatal control. Low temperature-induced reductions in the vapour pressure difference between the leaf surface and the atmosphere, which significantly reduced transpiration rate and root water absorption (Aroca *et al*., 2003) [25]. Chilling stress induced shoot water deficits in maize plants by significantly reducing root water absorption (Janowiak and Markowski, 1994) [13]. Plant nutrient absorption behavior is also affected by chilling stress, in addition to decreased plant growth and production (Hu *et al*., 2007) [11, 12]. Plants with a poor root system that are subjected to cold stress have lower nutrient absorption (Domisch *et al*., 2002) [7]. The direct effect of low temperature on shoot meristems and the limited availability of nutrients via roots both slowed maize seedling shoot development under low temperature stress (Hund *et al*., 2007) [11, 12]. Decreased root length, limited hydraulic conductivity, poor root branching, and a thicker root axis under cold stress, according to Farooq *et al*. (2009) [9], contribute to reduced mineral nutrient absorption in plants. Variations in these effects may occur depending on plant species, stress period and physiological plant growth stage.

The metabolic condition of oxidative stress is defined as an imbalance between the production and detoxification of reactive oxygen species (Baier *et al*., 2005) [4]. Protein oxidation, membrane lipid peroxidation, DNA and RNA damage, and even cell death can all be caused by too much ROS (Apel and Hirt, 2004) [3]. The reactive oxygen species generated in plants under adverse environmental circumstances are hydrogen peroxide, singlet oxygen, superoxide radicals, and hydroxyl radicals (Apel and Hirt, 2004) [3]. The generation of reactive oxygen species is often proportional to the intensity of stress situations.

Overproduction of reactive oxygen species in plant cells causes oxidative stress (Shu *et al*., 2011) [10]. Chinnusamy *et al*. (2007) [6] found that cold stress causes tissue necrosis by affecting membrane and enzyme activity. Bundle sheath proteins in maize leaves were more susceptible to oxidative degradation at low temperatures than mesophyll (Kingston-Smith and Foyer, 2000) [16]. By quickly interacting with key cellular structures, ROS overproduction under chilling stress causes significant cellular damage (Sattler *et al*., 2000) [30]. According to Zhang *et al*. (1995) [38], the balance between the production and detoxification of reactive oxygen species is critical for cell survival under chilling stress.

The enhanced O_2 photo reduction rate in chloroplasts resulted in a significantly greater buildup of reactive oxygen species under drought stress, according to Robinson and Bunce (2000) [24]. For adverse situations such as cold stress, plants have evolved strong antioxidative defence mechanisms to deal with oxidative damage. Plants have been shown to have increased the levels of numerous enzymatic and non-enzymatic antioxidants in order to maintain cellular homeostasis and reduce oxidative damage (Gill and Tuteja, 2010). Abscisic acid-induced increased antioxidant enzyme activity enhanced chilling stress tolerance in several crops (Zhou *et al*., 2005) [40]. Low temperature stress, according to Thomashow (1994) [34], triggered the antioxidant defense response by damaging membrane components and generating ROS-induced protein denaturation.

Conclusions and future perspectives

Climate change is a complicated phenomenon with long-term consequences in the form of many abiotic stresses. Abiotic stresses such as low temperature stress are among the abiotic factors that harm agricultural plants. Plants exhibit a wide range of reactions to this stress, which might result in severe agricultural production decreases or, in extreme cases, crop collapse. Chilling conditions pose a significant threat to crop yield in the field. Plants' capacity to survive cold temperatures varies depending on the species. The morphology of the roots can be altered by freezing stress. Chilling stresses, on the other hand, result in decreased crop yields due to poor dry matter buildup, reduced flower and pod development, increased flower and pod abortion and small seed size. Reduced nutrient absorption behavior, CO_2 diffusion into chloroplasts, and the photosynthetic system in plants are further apparent consequences. Chilling stress produces osmotic and oxidative stress. Plants counteract these stresses by accumulating solutes detoxifying proteins, as well as regulating antioxidant enzyme activity.

Gene expression changes in response to chilling stress; certain genes are only regulated by low temperature stress. Various innovative ways to reducing the harmful impacts of cold stress have been tried so far. Despite the major advances, there is still a lot of opportunity for development in terms of cold tolerance. Furthermore, future research should focus on producing genetically modified plants that can produce a specific response to cold stress utilizing molecular and biotechnological techniques.

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