Journal of Crop Nutrition Science
ISSN: 2423-7353 (Print) 2538-2470 (Online)
Vol. 9, No. 2, 2023
https://jcns.ahvaz.iau.ir/ OPEN ACCESS

Review Paper

Effects of Paclobutrazol Application on Plants as a Chilling Stress Ameliorator

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RESEARCH ARTICLE

ARTICLE INFO.
Received Date: *8 Apr. 2023*
Received in revised form: *19 May. 2023*
Accepted Date: *25 Jun. 2023*
Available online: *30 Jun. 2023*

To Cite This Article:
Mahroo Mojtabaie Zaman. Effects of Paclobutrazol Application on Plants as a Chilling Stress Ameliorator. ***J. Crop. Nutr. Sci.,*** 9(2): 88-100, 2023.

ABSTRACT

Paclobutrazol ((2RS, 3RS)-1-4(-chlorophenyl)-4,4-dimethyl-2-1,2,4-triazol-1-yl-penten-3-ol) is a member of the triazole family, that protects plants against various stresses. Probably paclobutrazol affects the morphology and biochemical and physiological reactions of plant by regulating the level of endogenous hormones (inhibition of gibberellin biosynthesis, increase of abscisic acid, decrease of ethylene, change of cytokinin content and modulation of their transporter genes). Morphological effects of paclobutrazol are include reduction of stem length and lower internode length, increase in stem physical strength, thicker stems, increase in leaf thickness, thicker epicuticular wax layer on leaf, reduction of leaf area, larger chloroplasts, and increase in root growth. Biochemical effects of paclobutrazol include the increase of proline, chlorophyll and carotenoids, polyamines, protein, and soluble carbohydrates and the detoxification of reactive oxygen species through the increase of antioxidant activities. These changes increase the tolerance of plants to environmental stress. One of the environmental stresses that disrupts the natural activity of plants, and the use of paclobutrazol helps to moderate its negative effects, is chilling stress. Chilling stress, especially in tropical and sub-tropical species, through changes in biochemical and physiological processes, causes negative effects on plants. Paclobutrazol protects plants against chilling stress and ameliorates chilling damage by strengthening the antioxidant defense system, regulating hormone levels, and improving photosynthesis system. In this article, the role of paclobutrazol to alleviate the adverse effects of cold stress in plants is examined. Moreover, various morphological, biochemical and physiological processes leading to improved crop production under the effect of paclobutrazol are discoursed in detail.

KEYWORDS: *Antioxidants, Environmental Stresses, Photosynthetic Pigments, Protection, Triazoles*

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1. BACKGROUND

Plants are subjected to a wide range of abiotic (includes radiation, salinity, drought, flooding, waterlogging, heavy metals, heat and cold stress) and biotic (includes bacteria, fungi, nematodes, insects, arachnids and weeds) stresses which reduces and limits the productivity of agricultural crops (Chandra and Roychoudhury, 2020, Gull *et al*., 2019, Pandey *et al*., 2017). The use of environmental stress modifiers is one of the strategies that researchers are interested in to reduce the adverse effects of environmental stress (Shaki *et al*., 2022, Abdalla *et al*., 2021). One of the most important physiological effects of the use of plant growth regulators is increasing the tolerance of many monocots and dicots species to environmental stresses (Desta and Amare, 2021). Plant growth regulators are substances that naturally present (phytohormones) in plants or synthetically developed, and alter or regulate various physiological processes considerably in a plant when used in small concentrations (Zahid *et al*., 2023). These substances change the biological processes or the appearance of the plant and its growth process and improve the quality and quantity of the product (Desta and Amare, 2021). Paclobutrazol ((2RS, 3RS)-1-4(-chlorophenyl)-4,4-dimethyl-2-1,2,4-triazol-1-yl-penten-3-ol) is a member of the triazole family (Lin *et al*., 2006), that inhibits gibberellin biosynthesis by blocking the oxidation of ent-kaurene to ent-kaurenoic acid through deactivating ent-kaurene oxidase (Chandra and Roychoudhury, 2020). Triazoles are the active ingredient of fungicides and plant growth regulators (Shaki *et al*., 2022). In addition, due to their inherent ability to induce environmental stress tolerance by regulating hormones level, increasing antioxidant activities, and osmolytes in plants under stress, they can protect plants against various stresses (Desta and Amer, 2021). They induce stress resistance by regulating physiological and morphological processes through signal transduction pathways. The use of these compounds can change the metabolic balance and lead to stress-like symptoms to protect plants against environmental stresses (Shaki *et al*., 2022). Paclobutrazol has morphological and anatomical, biochemical and physiological effects in plants (Fig.1). Morphological and anatomical effects are include reduction of stem length and lower internode length (Hütsch and Schubert, 2021, Kamran *et al*., 2018a), increase in stem physical strength (Kamran *et al*., 2018a), thicker stems (Tekalign *et al*., 2005), increase in leaf thickness (Sankar *et al*., 2013, Tekalign and Hammes, 2005), thicker epicuticular wax layer on leaf (Jenks *et al*., 2001), reduction of leaf area (Roseli *et al*., 2012), larger chloroplasts (Sopher *et al*., 1999), and increase in root growth (Urfan *et al*., 2022, Kamran *et al*., 2018b). In paclobutrazol treatment, the increase in leaf thickness is attributed to an increase in epidermal cell diameter, palisade cell length and spongy mesophyll depth, and thicker stem is attributed to an increase in cortex thickness, size of the vascular bundles, and pith diameter (Tekalign and Hammes, 2005, Tekalign *et al*., 2005).

Biochemical effects of paclobutrazol include the increase of proline (Yang *et al*., 2019), chlorophyll and carotenoids (Nivedithadev *et al*., 2012), polyamines (Bindu *et al*., 2017), protein (Saleh, 2007), and soluble carbohydrates (Ghasemi *et al*., 2014) and the detoxification of reactive oxygen species (ROS) through the increase of antioxidant activities (Attarzadeh *et al*., 2018, Hu *et al*., 2017, Lin *et al*., 2006).

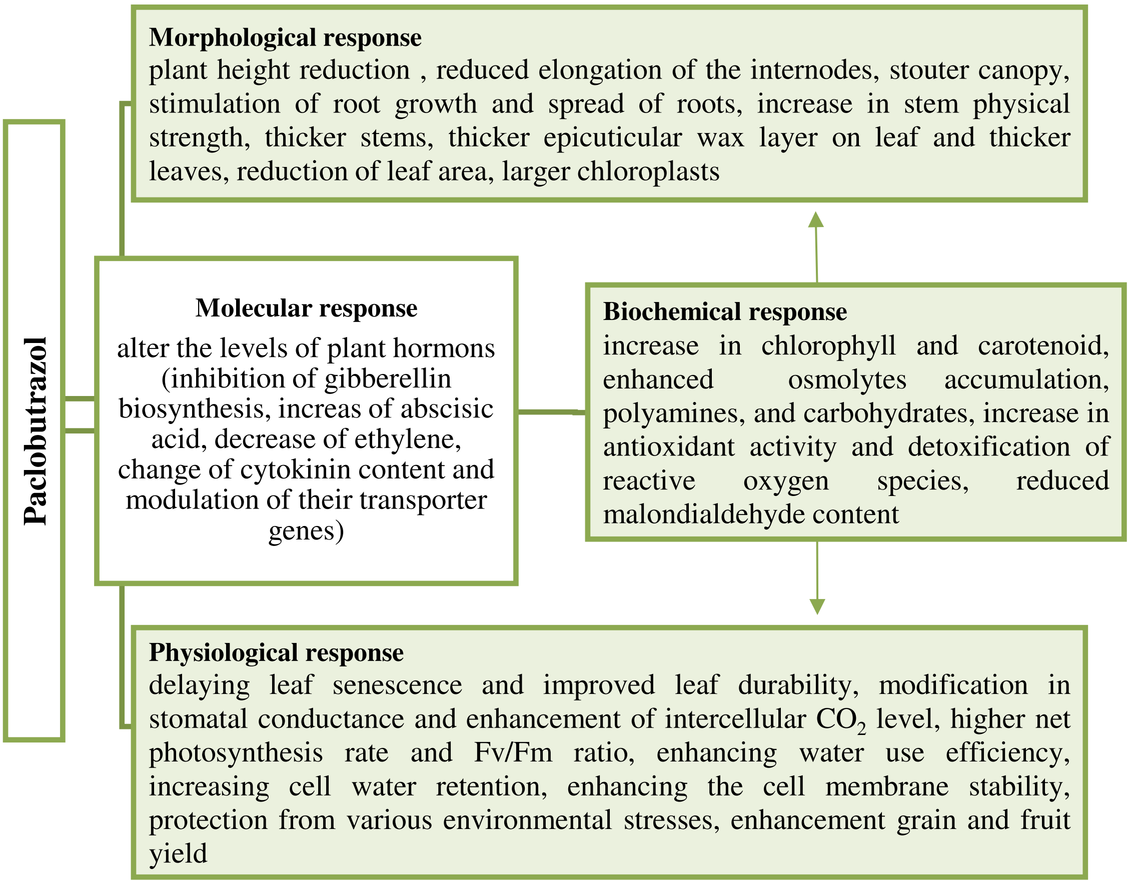

Fig. 1. Morphological, biochemical and physiological responses of the plant to paclobutrazol

Many of the biochemical effects of paclobutrazol are caused by changes in the levels of gibberellin, abscisic acid (ABA), cytokinin and ethylene in the plant or the effect of these hormones on changing physiological responses in the plant (Desta and Amare, 2021). Paclobutrazol has a significant effect on the growth and development of the plant by changing the hormonal level in the plant and changing the rate of photosynthesis (Tesfahun, 2018). The effect of paclobutrazol on expanding the root system to absorb water, and on reducing the stomatal pores, reducing the shoot growth, creating less surface area for transpiration, and anatomical changes in the leaves that prevent water loss is due to the inhibition of gibberellin biosynthesisthe, and the increase in ABA concentration (Desta and Amare, 2021). The increase in total chlorophyll, chlorophyll a, chlorophyll b and carotenoid content as a result of paclobutrazol application is due to stimulation of cytokinin synthesis by triazoles. With the increase of cytokinin, chloroplast differentiation and chlorophyll biosynthesis increase (Nivedithadev *et al.*, 2012). Paclobutrazol-induced physiological responses are related to alter the the levels of plant hormones (Desta and Amare, 2021). By increasing the endogenous levels of cytokinins and promoting the formation of chlorophyll and increasing the activity of certain antioxidant enzymes, paclobutrazol significantly delays the onset of senescence and prolongs the period of staying green. With the prolongation of the 'staygreen' in plants treated with paclobutrazol, photosynthesis continues for a longer period (Kumar *et al*., 2012). The greater amount of carbohydrates under triazole application can be the result of stimulation of chlorophyll biosynthesis, and enhancement of photosynthesis rate in plants (Shaki *et al*., 2022). Roseli *et al*. (2012) reported that applications of paclobutrazol in *Syzygium myrtifolium* significantly reduced plant height and leaf area but increased the leaf area index. moreover, photosynthetic rates reduced in the treated plants as compared to the control plants. They considered the reason for reduction of photosynthetic rate to be the decrease in the leaf area and, as a result, the level of light absorption decreased. On the contrary, paclobutrazol increased the rate of net photosynthesis in chickpea (Soumya and Kumar, 2017) and basil (Santos Filho *et al*., 2022), that could be attributed to the higher chlorophyll content and enhancement of intercellular CO_2 level in response to the paclobutrazol treatment (Santos Filho *et al*., 2022, Soumya and Kumar, 2017). On the other hand, although paclobutrazol reduced leaf area, it improved leaf durability. Therefore, the reduction of the leaf area was compensated by the absence of leaf falling and by the leaf durability, and the net assimiltion rate increased (Tekalign and Hammes, 2005). Paclobutrazol increases grain/fruit yield due to relatively stouter canopy, enhancement plant photosynthetic pigments, delaying leaf senescence, regulating photosynthetic capacity and improving rooting system (Abdalla *et al*., 2021). Tesfahun (2018) stated that positive effect of paclobutrazol on yield and yield components of crop plants is due to the change in canopy coverage (plant developed broader canopy this in turn facilitated improved light interception for better photosynthesis in leaves and stems), (ii) the dark green leaves with slow senescence, and (iii) the spread of roots and improved rooting system (increased the uptake of nutrients and water). Kamran *et al*. (2018b) showed that paclobutrazol could efficiently be used to enhance root-physiological and morphological characteristics, resulting in higher grain yield. In paclobutrazol-treated maize improved root length density, root-surface area density, root-weight density, root-activity, root dry weight, diameter and root/shoot ratio, and thus increased the grain yield. One of the other effects of using paclobutrazol, especially in cereals, is to create lodging resistance through mediation of plant height, stem physical strength, and lignin biosynthesis (Kamran *et al*., 2018a). In wheat, application of paclobutrazol decreased the internode length, plant height, and gravity center height, and improved the stem morphological characteristics and the lignin accumulation, thus increasing the lodging resistance (Kamran *et al*., 2018a). Reducing damage caused by environmental stress in plants is considered another feature of paclobutzazole. This combination mitigates the adverse effects of environmental stresses on plant growth and development, through regulating endogenous hormones level, maintaining relative water content, cell membrane stability, photosynthetic activity, and photosynthetic pigments and protects the photosynthetic apparatus by enhancing the level of osmolytes, and antioxidants activities (Liu *et al*., 2022, Maheshwari *et al*., 2022, Abdalla et al., 2021). So far, increased tolerance to several abiotic stresses such as drought (Babarashi *et al*., 2021, Hütsch and Schubert, 2021, Mehmood *et al*., 2021, Soumya and Kumar, 2017), salinity (Sofy *et al*., 2020, Khunpon *et al*., 2018, Hu *et al*., 2017), heat (Nagar *et* *al*., 2021, Zhao *et al*., 2018, Tekalign and Hammes, 2005), chilling (Attarzadeh *et al*., 2018, Alizadeh Frutan *et al*., 2017, Saleh, 2007), freezing (Yang *et al.*, 2019, Moradi *et al*., 2016, Ghasemi *et al*., 2014), heavy metal (Neamah and Hamad, 2020) and flooding stress (Yadav and Hemantaranjan, 2017), as a result of paclobutrazol application has been reported. One of the environmental stresses that disrupts the natural activity of plants, and the use of paclobutrazol helps to moderate its negative effects, is chilling stress. Low temperatures, also called chilling, refer to low, but not freezing, temperatures (0–15°C) (Liu *et al*., 2018). Chilling stress, especially in tropical and sub-tropical species, through changes in biochemical and physiological processes, causes negative effects in plants (Lin *et al*., 2006). Symptoms of chilling injury include wilting, the reduction of growth and photosynthesis rate, the reduction in root architectural growth, chlorosis, necrosis, discoloration, changes in respiration, abnormal ripening, increased disease susceptibility, the increase in levels of ROS, and leakage of ions from cell membranes (Wu *et al*., 2022, Attarzadeh *et al*., 2018, Liu *et al*., 2018, Lin *et al*., 2006). The decrease in growth and yield caused by chilling stress shows the importance of investigating treatments that can reduce the effects of this stress.

2. OBJECTIVES

The aim of this review is to summarize the evidence regarding the biochemical and physiological responses of paclobutrazol as a cold stress modulator.

3. EVIDENCE ACQUISITION

This research was conducted based on the published findings of valid scientific research.

4. RESULTS AND DISCUSSION

The positive effect of paclobutrazol application in cold stress conditions on the growth of crops such as wheat (Anwar *et al*., 2017, Berova *et al*., 2002), maize (Sopher *et al*., 1999), bean (Alizadeh Frutan e*t al*., 2017, Amooaghaie and Shariat, 2014), soybean (Attarzadeh *et al*., 2018), mung bean (Saleh, 2007), watermelon (Baninasab, 2009), cucumber (Ramin, 2009), tomato (Jafari *et al*., 2006), medicinal plants (Peng *et al*., 2021), and trees (Roostaei *et al*., 2019, Zhou *et al*., 2012) has been reported in various articles (Table 1). Paclobutrazol protects plants against chilling stress and ameliorates chilling damage by increasing antioxidant defense system, regulating hormone levels, and improving photosynthesis system (Yang *et al*., 2019, Attarzadeh *et al*., 2018, Zhou *et al*., 2012). Based on results of triazoles studies, paclobutrazol can enhance activity of the ROS scavenging systems (Lin *et al*., 2006, Berova *et al*., 2002). ROS include free radicals like superoxide anion ($O_2^{\bullet -}$), hydroxyl radical ($^{\bullet}OH$), and non-radicals like singlet oxygen ($^1O_2$) and hydrogen peroxide (H_2O_2). The damage caused by ROS is extensive and damages the integrity of cell by destroying biological molecules such as lipids, proteins and DNA, and ultimately leads to cell death (Das and Roychoudhury, 2014). The over-accumulation of ROS during chilling stress can cause lipid peroxidation, which increases membrane leakage and decreases membrane fluidity. So, ROS is considered reason for damaged membrane-localized proteins associated with ion-channels, receptors, and enzyme architecture (Wu *et al*., 2022). As stress conditions help to produce ROS, their detoxification can be reasons for ability of paclobutrazol to moderate adverse effects of stress (Attarzadeh *et al*., 2018, Hu *et al*., 2017, Lin *et al*., 2006).

Table 1. Effects of Paclobutrazol on modulating chilling stress in some plants

plant	Key findings	Reference
Grape (*Vitis vinifera*)	Treatment with 500 mg L^{-1} of paclobutrazol caused a significant increase in the amount of proline and antioxidant enzymes (peroxidase, polyphenol oxidase and ascorbate peroxidase) and a relative increase in the amount of soluble sugar and a significant decrease in the amount of malondialdehyde. The concentration of 500 mg L^{-1} was determined as the best concentration to improve the adaptability of buds grape for late cold spring tolerance.	Roostaei *et al.* (2019)
Soybean (*Glycine max* L.)	By examining two factors of cold stress (by 5°C in four intervals times: 0, 8, 16 and 24 h) and paclobutrazol pretreatment (0, 100, 500 and 1000 µM), it was observed that an increase in cold stress led to electrolyte leakage of the soybean's leaves, but pretreatment of paclobutrazol (100 and 500 µM) increased catalase and peroxidase antioxidant enzymes and soluble proteins in the leaves of soybean, and led to an increase in cell membeane stability and a decrease in ion leakage.	Attarzadeh *et al.* (2018)
Green bean (*Phaseolus vulgaris* L.)	Paclobutrazol spraying (40 and 80 mg L^{-1}) had a positive effect on chilling (by 5°C for 3 and 6 days) tolerance in green beans. Application of paclobutrazol at the rate of 40 mg L^{-1} increased chlorophyll a, carotenoid and SPAD value. Moreover, paclobutrazol spraying reduced electrolyte leakage in which the maximum reduction (up to 20% lower than non-application) was obtained with 80 mg L^{-1} of paclobutrazol.	Alizadeh Frutan *et al.* (2017)
Bean (*Phaseolus vulgaris* L.)	paclobutrazol treatment (25 or 50 mg L^{-1}) improved ability of plant responses to the cold stress (at 5±1 °C for 1 day) through increasing root development, increasing chlorophyll content, and reducing electrolyte leakage, and these effects were more remarkable in cold sensitive cultivars.	Amooaghaie and Shariat, (2014)
watermelon (*Citrullus lanatus*)	Paclobutrazol applied either through seed soaking or through foliar spray (50 or 75 mg L^{-1}) improved growth rate of seedling subjected to chilling stress (5 h/day at 4 °C for 5 days) and increased relative leaf chlorophyll content and chlorophyll fluorescence ratio (Fv/Fm) compared with the control.	Baninasab, (2009)
Cucumber (*Cucumis sativus* L.)	Paclobutrazol applied (presoaked seeds in 20 mg·L^{-1} of paclobutrazol) ameliorated the response to chilling injury in 14 days old seedlings following 4 days of 5°C. Seedlings treated with paclobutrazol had higher chlorophyll concentrations, and chlorophyll fluorescence ratio, and lower ion leakage following chilling stress. The highest root diameter, root number and root length were obtained in plants treated with 10-20 mg/L of paclobutrazol, but hypocotyl length was reduced.	Ramin, (2009)
Mung Bean (*Vigna radiata* L.)	Paclobutrazol applied (25 or 50 mg·L^{-1}) ameliorated the injuries of chilling (5 °C for 5 or 10 h) by lowering lipid peroxidation, membrane leakage and H_2O_2 level, and increasing in total chlorophyll, carbohydrates, protein content, proline level and antioxidant enzymes activities (Catalase, Peroxidase, Ascorbate peroxidase).	Saleh, (2007)
Tomato (*lycopersicum esculentum* L.)	Paclobutrazol (30 or 60 mg·L^{-1}) were sprayed on 5-week-old seedlings. After 3 days, seedlings were exposed to chilling stress (6 h/day at 1±0.2 ºC for 5 days). Chilling stress induced membrane lipid peroxidation, and increased proline content. Application of paclobutrazol led to an increase in chlorophyll and carotenoid contents, and reduction in lipid peroxidation and proline content.	Jafari *et al.* (2006)

The antioxidant enzymes and the non-enzymatic antioxidant metabolites, work in conjunction to alleviate the damaging effects of ROS and develop tolerance against various environmental stress conditions (Das and Roychoudhury, 2014). In a research, sweet potato sprayed by paclobutrazol 24 h prior to exposure to chilling conditions (7°C /7°C (day/night) for periods of 1, 3 and 5 days). The results showed that antioxidative system level of sweet potato under chilling conditions was regulated by paclobutrazol pre-treatment. As a result, Paclobutrazol protected sweet potato from chilling stress through scavenging free radicals (Lin *et al*., 2006). Berova *et al*. (2002) showed, in paclobutrazol-treated seedlings of wheat, Malondialdehyde content decreased by 77-79% compared to the control. The higher activity of peroxidase in seedlings treated with paclobutrazol immediately after stress treatment showed that paclobutrazol protects the cell from the harmful effects of stress by increasing antioxidant activity and maintaining membrane stability (Berova *et al*., 2002). Paclobutrazol increased survival rate of maize seedlings following chilling (2°C for 8 h) and alleviated damage symptoms owing to chilling in seedlings, the degree of protection being greater in cultivar sensitive to stress. Following chilling, leaves of control seedlings were flaccid and necrotic indicating a loss of membrane integrity and this damage was reduced by paclobutrazol (Sopher *et al*., 1999). The stress-resistance mediated by paclobutrazol might be due to changes in hormones, including gibberellin, cytokinin, ABA and ethylene (Desta and Amare, 2021). Paclobutrazol alters and regulates the level of endogenous hormones (Opio *et al*., 2022, Liu *et al*., 2022, Bindu *et al*., 2017). Opio *et al*. (2020) showed, paclobutrazol increased the ABA concentration and the biosynthesis-related gene. Moreover, the ABA transporter gene was upregulated by paclobutrazol. The concentrations of the gibberellins decreased in the paclobutrazol-treated apple rootstocks. The gibberellin transporter gene and the signaling gene were strongly down regulated. Paclobutrazol treatment significantly reduced trans-zeatin levels and down regulated the cytokinin biosynthesis gene. Additionally, paclobutrazol upregulated the cytokinin-related transporter genes (Opio *et al*., 2020). In the study of Liu *et al*. (2022), paclobutrazol up-regulated the ABA-receptor genes and ABA synthesis gene, thereby increasing the endogenous ABA concentration under stress conditions (Liu *et al*., 2022). In the buds and leaves of mango that treated with paclobutrazol, the total free polyamines, spermidine and spermine contents increased and ethylene production, 1-aminocyclopropane carboxylic acid (ACC) content and ACC oxidase activity decreased as compared to untreated trees. The decrease in ethylene is probably related to the decrease in the activity of ACC oxidase. Since the precursor of ethylene and polyamine is S-adenosine methionine (SAM), inhibiting ethylene biosynthesis increases polyamines (Bindu *et al*., 2017). Polyamines as protective molecules, are involved in several physiological and metabolic processes, including photosynthetic pigment defense, antioxidant systems, hormonal interplay, and ionic homeostasis, which ultimately ameliorate the negative effects of environmental stresses on plants (Shao *et al*., 2022). Changes in the level of hormones in plants are associated with changes in physiological responses. An increased ABA concentration enhances the photosynthetic performance and antioxidant capacity to remove excess ROS (Liu *et al*., 2022). Additionally, by increasing the endogenous levels of cytokinins, chloroplast differentiation and chlorophyll biosynthesis increase (Nivedithadev *et al*., 2012). Leaves from paclobutrazol-treated maize had larger chloroplasts and grana stacks, and more stroma lamellae (Sopher *et al*., 1999). In paclobutrazol-treated seedlings of wheat was observed significant reduction in length (44–49%) and fresh weight of shoots (15–23%), and an increase in root growth, leading to an increased root to shoot ratio (21–32%). The leaves of control plants after low temperature stress were chlorotic and the rate of chlorophyll and carotenoid markedly decreased, but paclobutrazol application significantly reduced the severity of this damage. After exposure to stress, the chlorophyll fluorescence ratio (Fv/Fm) decreased in both control and paclobutrazol-treated wheat plants. But, the decrease in the treated seedlings was from 4 to 6% while in the control was 17%. Paclobutrazol-treated seedlings were more efficient photosynthetically (11-13%). (Berova *et al*., 2002). Proline plays a highly beneficial role in plants exposed to various stress conditions. Besides acting as an excellent osmolyte, proline is as a metal chelator, an antioxidative defense molecule and a signaling molecule during stress (Hayat *et al*., 2012). Proline is an important osmoprotectant and signaling molecule to avoid chilling injury induced by chilling stress (Wu *et al*., 2022). Moreover, exogenous application of proline or modification of its responsive genes is known to be an effective strategy to improve cold tolerance (Hayat *et al*., 2012). Wu *et al*. (2022) attributed the increase in proline accumulation under cold stress conditions to the increase in osmotic potential to prevent chilling-induced dehydration, and in addition, they stated that proline is involved in scavenging of ROS, stabilizing membranes and proteins, and regulating protein synthesis. There are conflicting reports about the effect of paclobutrazol on proline content under chilling stress conditions. In all reports, the content of proline has increased under chilling stress conditions. But, in some of these studies paclobutrazol increased the proline content (Yang *et al*., 2019, Roostaei *et al*., 2019, Saleh, 2007) and in others it decreased the proline content (Baninasab, 2009, Jafari *et al*., 2006). However, proline is not the only effective osmolyte in increasing chilling stress tolerance, and other amino acids, polyamines, soluble proteins and carbohydrates are also effective in regulating cell osmotic and protecting it (Yang *et al*., 2019, Zhou *et al*., 2012, Saleh, 2007). In *Ligustrum lucidum*, by using paclobutrazol to improve cold tolerance (500 mg L^{-1}), a series of processes were initiated to create the cold acclimation and finally improve cold resistance. Cold acclimation in *Ligustrum lucidum* under the application of paclobutrazol was associated with the increase of chlorophyll, proline, soluble protein, and soluble sugar and the regulation of gibberellic acid and ABA content (Yang *et al*., 2019). Foliar spray paclobutrazol at 50 and 100 mg L^{-1} by increasing the photosynthetic pigments, accumulation of osmotic adjustment compounds, increasing antioxidant (superoxide dismutase and peroxidase) activities, and decreasing membrane lipid peroxidation, alleviated the damage caused by low temperature stress on teak seedlings (Zhou *et al*., 2012). Similarly, paclobutrazol has an effective role in protecting the plant under conditions of freezing stress. Paclobutrazol applied (50 or 75 mg L^{-1}) ameliorated the injury caused by freezing stress (−3°C for 7 hours) on pomegranate by inhibiting leaf electrolyte leakage. paclobutrazol improved the growth rate of seedlings subjected to freezing stress and increased relative leaf chlorophyll content, chlorophyll fluorescence ratio, relative water content, soluble carbohydrate content, and enzyme activity of ascorbate peroxidase and guaiacol peroxidase compared with the control (Moradi *et al*., 2016). In study of Ghasemi *et al*. (2014), also foliar spray of paclobutrazol (125 or 250 mg L^{-1}) reduced freezing injury with evidence of less electrolyte leakage through increasing soluble carbohydrates and proline contents.

5. CONCLUSION

The findings of various researches have shown the positive and strong effect of paclobutrazol in moderating the adverse effects of various environmental stresses, especially chilling stress. Paclobutrazol protects plants against chilling stress and ameliorates chilling damage by regulating the level of hormones (inhibition of gibberellin biosynthesis, increase of abscisic acid, decrease of ethylene, change of cytokinin content and modulation of their transporter genes) and strengthening the antioxidant defense systems. Increasing cell membrane stability, increasing photosynthetic pigments, improving leaf durability, maintaining chlorophyll fluorescence ratio and increasing photosynthesis efficiency, increasing accumulation of osmolytes, polyamines, carbohydrates and increasing cell water retention are other consequences of paclobutrazol consumption in cold stress conditions. In general, considering the role of paclobutrazol in creating physiological, biochemical and morphological adaptations in plants and improving performance in stressful environmental conditions, it is important to investigate its use as a management strategy to achieve yield stability in agriculture.

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