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Review Article

Influence of pre harvest ethephon application on various physical, physiological and biochemical attributes of agricultural crops: A-review

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Abstract

Ethylene is a gaseous hormone which is known to promote, inhibit or modify a number of physiological processes in plants. In particular the role of ethylene in fruit ripening, abscission and senescence has been studied extensively. There are number of ethylene releasing compounds which are used in agriculture for its effect on various physiological process. Among different ethylene releasing compounds Ethephon has been primarily used commercially. Ethephon is particularly used in horticulture as a post-harvest treatment for the ripening of climacteric fruits. Beside of its use as a post-harvest treatment Ethephon can be successfully used as a pre harvest treatment for the induction of flowers, enhancement of pistillate flowers and yield and quality of different crops. Application of Ethephon under stress condition is also known to improve photosynthesis and antioxidant defense system. It has been concluded that Ethephon has been studied extensively for its post-harvest responses and its pre harvest responses has been neglected. Therefore in this review focus has been given to the responses of Ethephon as a pre harvest treatment. This review may provide useful information regarding the influence of pre harvest application of Ethephon on various attributes of plants under normal as well under different stress conditions.

Keywords: Pre harvest; Ethephon application; Physical; Physiological; Biochemical attributes; Agricultural crops

Introduction

Ethephon (2-chloroethyl phosphonic acid, CEPA) is well known PGR which is used extensively in agriculture **[1]**. Ethephon was developed for the first time by Russian scientist Kabachnik and Rossiiskaya in 1946 [2] Ethephon is the key synthetic PGR which release ethylene on chemical

biodegradation along with phosphoric acid (Fig. 1) when the pH of cytoplasm is higher than 4.1 [3]. Ethylene belongs to the hydrocarbon group of olefins and exists in the gaseous forms under normal physiological conditions. Ethylene is a colorless, odorless gas with faint and sweet smell which exist in nature and also be made in laboratories [4]. Various physiological effects of ethylene has been documented on different aspects of plant growth and development [5] in both stressed and normal conditions. Most commonly ethylene is used as a post-harvest treatment for uniform ripening of different climacteric fruits [4]. Ethylene is usually known as growth inhibitor, for the first time it was demonstrated in *Psium sativum*. In *Arabidopsis* ethylene inhibited hypocotyl growth and root elongation however there are number of reports which stated that ethylene plays important role in different plants processes like stimulation of growth, germination, flowering, vegetative growth, seed dormancy, fruit ripening maturation and senescence and response to pathogens [6,7] Ethylene is well known for influencing sex expression in different plants especially cucurbits where it promotes femaleness and influence number of pistillate and staminate flowers. Number of research articles are present on effect of Ethephon on sex expression and fruit production [8, 9, 10]. Ethylene is also well known to effect ripening related processes like fruit softening, cell wall breakdown, and chlorophyll degradation and fruit senescence. Among different plant growth regulators Ethephon is one of the important synthetic growth regulator which advance maturity [11] and accelerate fruit ripening and improve fruit quality parameters [12]. Ethylene is a multifunctional hormone which regulates both growth and senescence. It promote or inhibit growth and senescence depending upon plant species, concentration and timing [13]. Ethephon application on mustard plant increase leaf area with low concentration while with high concentration leaf area was significantly reduced [14, 15]. Under stress conditions Ethephon has been known to regulate various physiological processes such as photosynthesis, stomatal opening and closing and plant defense system. Despite of importance of ethylene in various physiological processes it use was very difficult due to its gaseous nature which cannot be directly applied to the soil. With the discovery of compounds like Ethephon and calcium carbide this problem was solved because these compounds release ethylene once absorbed by the plant tissues [16].

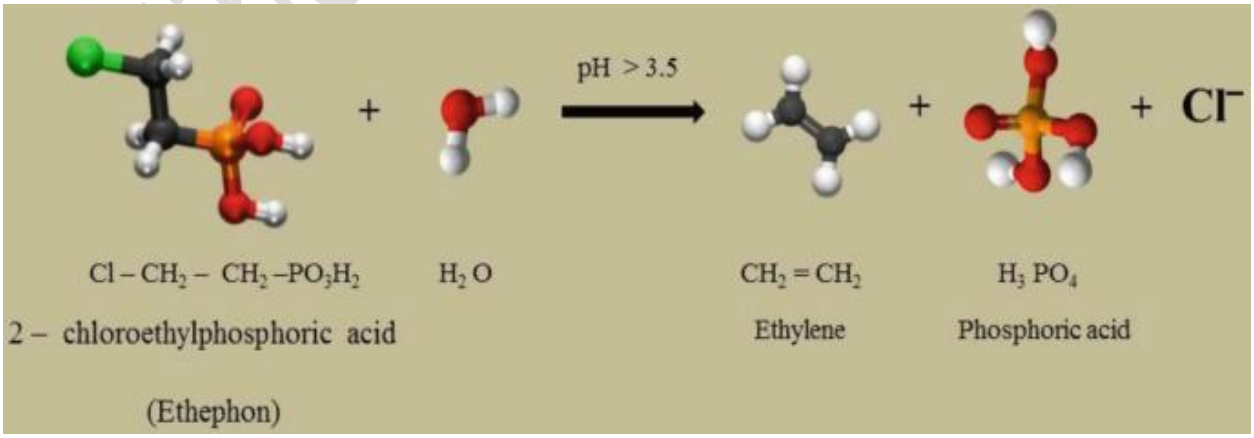

Figure 1: **Chemical biodegradation of ethephon [17]**

Effect of ethephon on photosynthesis and photosynthetic pigments

Photosynthesis is the most crucial processes in the life of plants which greatly affects growth and yield potential of a particular plant. Ethephon has been shown to influence both photosynthetic pigments and photosynthetic rate under normal as well as under stress conditions (Table 1). Exogenous application of Ethephon on sugar cane plants resulted in improved photosynthesis with low concentration while with higher concentrations reduction was noted **[18]**. The improvement in net photosynthesis is due to the role of Ethephon in the activation of enzymes like PEP carboxylase **[19]**, pyruvate phosphate dikinase **[20]** etc. and improvement in the photosynthetic pigments **[20]**. The findings of **[21]** suggests that photosynthesis was improved with Ethephon application by improving carbohydrate metabolism and antioxidant system. Pigments such as chlorophylls are important because it absorbs photons from the light during photosynthesis. Level of chlorophyll during leaf development is increased to provide enough energy in photosynthesis and aid in various physiological process of the plant **[3]**. Various authors reported increase in photosynthetic pigments with the application of Ethephon. Ethephon application delayed the phenological cycle and increased chlorophyll content in soybean **[22]**. Increase in chlorophyll content with Ethephon application were also noted by **[23, 24]** in *Brassica nappus* and pigeon pea respectively.

Table 1: Influence of pre-harvest Ethephon application on photosynthesis and photosynthetic pigments

Plant species	Ethephon treatment	Photosynthesis or photosynthetic pigments	Reference
Soybean	600 mg L^{-1}	Increased chlorophyll content	**[22]**
Mustard	200 ul L^{-1}	Increased photosynthesis	**[25]**
Mustard	200 ul L^{-1}	Increased photosynthetic efficiency and chlorophyll content	**[26]**
Cucumis melo L.	100 mg L^{-1}	Reduced *Chl a+b* content	**[27]**
Rice	1.6 mM	Increased net photosynthesis	**[21]**

Effect of ethephon on vegetative growth

Balanced vegetative growth is necessary to perform photosynthesis and to provide enough carbohydrates for plant to aid in various physiological processes of plant. Ethephon has been known to influence various vegetative parameters in different crops (Table 2). It has been the own observation of the author that pre harvest Ethephon application positively improved vegetative parameters of sweet lime such as shoot length, leaf area and number of new summer shoots. In leaf growth and development the role of ethylene has been confirmed physiologically through inhibitors of ethylene and genetically using ethylene insensitive mutants or transgenic plants that do not contain the essential enzymes necessary for biosynthesis of ethylene **[28, 29]**. Maximum leaf area is required to absorb maximum light through photosynthesis and to provide enough carbohydrates to plants. **[30]** reported that with Ethephon application leaf area was significantly increased. Pre flowering application of Ethephon has a vital role in

cell division which leads to maximum leaf area [31]. Reactive oxygen species ROS and nitric oxide NO are also involved in leaf expansion which has been up regulated by ethylene [32]. [33] noted that Ethephon at lower concentration produced increased leaf area, while with higher concentration leaf area was reduced. According to [34] leaf elongation of maize plants has no relation with ethylene evolution rate. Ethylene induce reduction in leaf area is also noted in pea by [35]. The influence of ethylene on leaf may be independent or it may be dependent with the interaction with other hormones [13]. It has also been reported that Ethephon application on different vegetables significantly reduced plant height and increased lateral branches. The reduction in plant is due to the anti-gibberellin property of ethylene. Ethylene actually reduce cell elongation which in turn reduce plant height. Similar findings has been reported by [36] who stated that stunted plant height with Ethephon is actually due to the poor cell elongation. By reducing plant height Ethephon generally increase branching capacity of the plant. Due to reduced plant height more photoassimilate is diverted to the lateral buds and hence plant produce more branches. [22]. The increase in branches with Ethephon is related with the inhibition of apical dominance and breaking the dormancy of lateral buds.

Table 2: Influence of pre-harvest Ethephon application on vegetative parameters

Plant species	Ethephon treatment	Vegetative parameters	Reference
Cucumber	200-400	Reduced plant height and increased number of nodes and branches plant^{-1}	[37]
Sugarcane	100 ppm	Increased leaf area and shoots number	[38]
Soybean	600 mg L^{-1}	Increased number of branches plant^{-1}	[22]
Maize	180 ml ha^{-1}	Decrease plant height and increase stem girth	[39]
Camellia sinensis	3000 mg L^{-1}	Increased shoot length	[40]

Effect of ethephon on flowering

Ethylene releasing compounds regulates flower induction and development and is critical for female fertility. It has now well established that Flower bud formation has been regulated by Ethephon [41]. With the application of ethrel ethylene is released within plant tissues where it stimulate the mechanism of flowering and bring the vegetative shoots into flowering [42]. Flower bud formation in young apple trees has been reported with the application of Ethephon [43, 44]. Ethephon application in peach resulted in delay flowering [45], this could be beneficial for areas with late spring frost. Ethephon has been used commercially for induction of flowering in bromeliads particularly pineapple [46]. The AVG is an ethylene biosynthesis inhibitor can delay flowering in pineapple [47]. Ethephon has been used for induction of flowers in mango in different countries [48]. A significant increase in flowering laterals in cashew nut with ethrel application was also reported which could be related with increased activity of α-amylase and peroxidase enzymes which release more sugars for flower induction [49]. Ethylene has been

involved in the flower development. The expression of ethylene biosynthesis genes are linked with the development of particular organ of a flower [13]. During early developing stigma, style, and ovary in tobacco ACC oxidase (ACO) gene was expressed [50]. In tomato, LeACO1, 2, 3, and 4 and LeACS1A transcripts were detected in pistils [51]. Plant growth regulators are well known for its influence on sex expression (Fig 2). Ethylene or compounds that release ethylene has been known to effect sex expression and promote femaleness in cucurbits and other andomonoecious species (Table 3). The influence of photoperiod and temperature on sex expression could be overcome with the spray application of PGRs [52], for example pistillate flowers production was increased in cucumber with the application of Ethephon [53]. In cashew nut tree application of ethrel increased hermaphrodite along with flowering laterals [54]. Similar findings were published by [55] who reported that Ethephon at 50 ppm significantly increased perfect flowers and flowers per panicle in cashew nut.

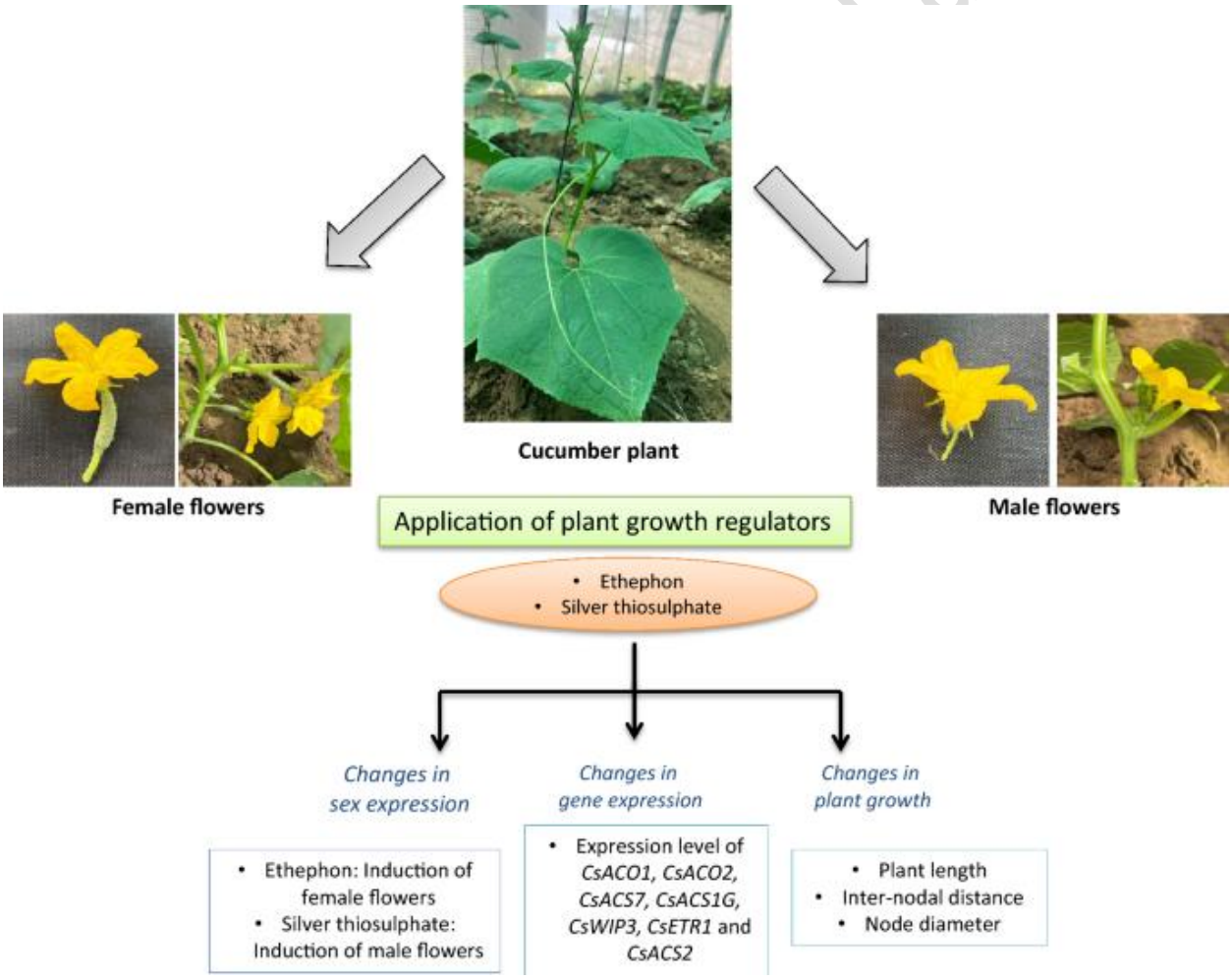

Figure 2: **Changes in sex expression by Ethephon and Silver thiosulphate [56]**

Table 3: Influence of pre-harvest Ethephon application on sex expression

Plant species	Ethephon treatment (ppm)	Sex expression	Reference
Pomegranate	20	Increased hermaphrodite flowers and reduced staminate flowers	[57]
Cashew	100	As above	[58]
Litchi	400	Increased female flowers and reduced staminate flowers	[59]
Melon	100	As above	[60]
Pumpkin	250	Increased female to male sex ratio and reduced number of days to pistillate flowers	[61]

Effect of Ethephon on fruit yield attributes

Plant growth regulators are well known to effect sex expression of a plant and increase pistillate or perfect flowers. Benefits of increasing perfect flowers with ethylene releasing compounds will be achieved only when it also increase the production of the particular crop [62]. Plant growth regulators also helps in fruit setting, reduce fruit drop and increase fruit weight and volume which in turn improve overall yield. Plant growth regulators like GA_3, Ethylene and Auxin are used for the improvement of both vegetative and reproductive growth and regulate hormonal balance which in turn improve crop productivity [63, 64] Ethylene releasing compounds like Ethephon and calcium carbide are commonly used in modern agriculture to alter the sex expression and improve production by improving fruit weight and fruits plant^{-1} (Table 4). Final yield of crops plants largely depends on optimum photosynthesis rate, ethylene synthesis from Ethephon has been known to improve photosynthesis by enhancement of leaf area and photosynthetic pigments. Better yield mainly depends on accumulation and partitioning of photo assimilates to growing sink. [21] stated Ethephon plays critical role in photosynthesis, carbohydrate metabolism and antioxidant defense system. Similarly according to [65] Growth retardant like Ethephon increase endogenous ethylene which trigger different physiological processes related to C:N which then stimulate fruit set, sex ratio and ultimately yield. Ethephon when applied after conventional GA_3 application fruit size was significantly increased as well as it improved source sink strength and cell expansion in pear [66]. Pre harvest application of Ethephon on cucumber increased fruits per plant and total yield [67]. In mango ethrel positively improved fruit weight, fruits per tree and yield [68]. According to [58] ethrel positively improved fruit set, number of hermaphrodite flowers, nuts per tree and yield of cashew. Similarly according to [69] among different plant growth regulators Ethephon significantly increased fruit yield through production of maximum pistillate flowers, fruit number and fruit weight.

Table 4: Influence of pre-harvest Ethephon application on yield attributes

Plant species	Ethephon treatment (ppm)	Yield attributes	Reference
Pomegranate	20	Increased number of fruit tree^{-1} and fruit yield tree^{-1}	[57]
Cashew	100	Increased nut weight and nuts tree^{-1}	[58]
Litchi	400	Increased fruit weight and yield tree^{-1}	[59]
Cucumber	200-400	Increased number of fruits and fruit yield plant^{-1}	[37]
Jatropha	2000	Increased number of fruits plant^{-1}	[70]

Effect of ethephon on fruit quality

Ethylene is mainly utilized in post-harvest industry for ripening of non-climacteric fruits. Ethylene is generally known for ripening purposes as it influence fruit ripening parameters such as fruit color, sugars content, TSS and acidity [16, 71]. Fruit softening during fruit ripening and maintenance of shelf life in many fruits is also regulated by ethylene, fruit softening is characterized by dissolution of cell wall [72, 73]. Nowadays ethylene releasing compounds has been used as a pre harvest treatment for improving quality of various vegetables and fruits (Table 5). Pre-harvest application of Ethephon has the ability to hastens ripening processes and improve fruit quality parameters [12]. Ethephon is commonly used as pre-harvest treatment for improvement for fruit skin color. Anthocyanin biosynthesis in apple has been influenced by endogenous ethylene. During apple maturation red blush is closely associated with rise in endogenous ethylene concentration [74], hence ethylene releasing compounds like Ethephon can be successfully used for anthocyanin biosynthesis. Pre-harvest spraying of Ethephon on date palm trees significantly reduced maturation period and increased ascorbic acid, sucrose, glucose, fructose, total phenol, flavonoids, antioxidants TSS and sugars content [75]. Similarly in dates Ethephon application increased TSS and total sugars which could be due to the crucial role of ethylene in ripening [76]. According to [77] improvement in TSS is due to increase translocation of sugars from leaves to sink by ethrel. Similar findings were published by [67] who stated that reducing and total sugars in cucumber were increased with the pre-harvest application of ethrel. Opposite results were reported by [27] who stated that Ethephon significantly reduced TSS, total sugars, vitamin C content and increase in titratable acidity in cucumber. For quality improvement of grapes Ethephon was applied which significantly increased TSS, TSS: Acid ratio, anthocyanin content and minimum acidity [78]. It is cleared that pre-harvest application of ethylene releasing compounds can plays important role in quality improvement of both fruits and vegetables.

Table 5: Influence of pre-harvest Ethephon application on fruit quality attributes

Plant species	Ethephon treatment	Fruit quality	Reference
Papaya	150 ppm	Increased TSS, total sugars, Ascorbic acid, TSS acid ratio and reduced acidity	[79]
Date palm	1500 ppm	Increased TSS, total sugars and reduced acidity	[76]
Phalsa	1000 ppm	Increased TSS, total sugars, ascorbic acid and reduced acidity	[77]
Apple	280 g ha^{-1}	Improved fruit color and increased anthocyanin formation	[80]
Grapes	500 ppm	Improved anthocyanin formation, TSS, TSS acid ratio, palatability and reduced acidity	[78]

Pre-harvest ethephon application under stress conditions

In natural environment plants deal with different stresses like drought stress, salinity stress, pathogen stress etc., which greatly affect plant growth and development [81]. Ethylene is stress related gaseous hormone which contribute greatly in the growth and development of plants under stress conditions [82]. Ethephon application in stress conditions affects different vital process of agricultural crops (Table 6). It has been reported that exogenously applied Ethylene enhanced photosynthetic capacity [83] by improving stomatal conductance and Rubisco [84] under abiotic stress condition. Seed priming with ethephon improved drought tolerance in winter wheat (Fig 3). Ethephon alone or in combination with split doses of N and S greatly reduced salt stress and improved plant growth and development by up regulation the antioxidant enzymes, accumulation of osmolytes and improving photosynthetic rate [26]. Similarly heat stress enhanced the content of H_2O_2 and TBARS (thiobarbituric acid reactive substances) and declined sucrose, starch and carbohydrates metabolism enzymes activities and photosynthesis in rice plants. With Ethephon application H_2O_2 and TBARS were significantly reduced by improving enzymatic antioxidant defense system. Carbohydrate metabolism, photosynthesis and growth were also improved with Ethephon application in rice plants under heat stress condition [21].

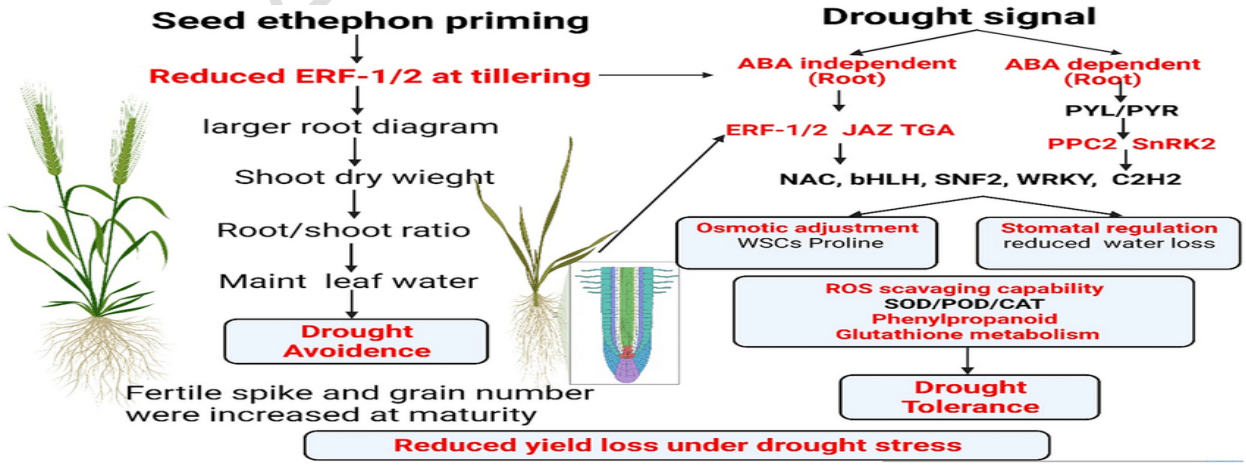

Figure 3: **Process associated with seed primed Ethephon in inducing drought tolerance and avoidance in dry land winter wheat [85]**

Table 6: Influence of pre-harvest Ethephon application on various plant attributes under stress conditions

Plant species	Type of Stress	Ethephon treatment	Various plant attributes	Reference
Wheat	Drought	200 ppm	Maintained leaf water by improving root volume and dry weight	[85]
Rice	Heat	1.6 Mm	Increased photosynthesis, carbohydrate metabolism and antioxidant enzyme system	[21]
Indian Mustard	Nickel	200 ul L^{-1}	Increased growth rate, photosynthesis, nutrients content, and elevated the formation of antioxidant enzymes, glyoxalase system and proline	[86]
Buck Wheat	Salt stress	0.4-0.6 Mm	Increased seed germination, Malondialdehyde (MDA) and chlorophyll content	[87]
Barley	waterlogging	37.5 uM	Enhanced arenchyma formation and induced the development of shorter and shallow roots	[88]

Conclusion

It has been concluded that pre-harvest application of Ethephon is a very useful practice to improve photosynthesis, antioxidant defense system, growth, yield and quality of different crops under normal as well as under stress conditions. The role of Ethephon particularly in sex expression is of prime importance especially in those species which produce small number of pistillate flowers. The pre-harvest application of Ethephon under stress condition is another useful practice to enhance the defense mechanism of different plants under various stress conditions. However further research is required to study the basic mechanism of Ethephon involved in the regulation of these vital processes.

Authors' contributions

Conceived and designed the Manuscript: MN Khan & N Gul, Wrote the Manuscript: MN Khan, K Aslam, M Irshad, Anjum, Dawood, Mehwish, S Siddique, Fazalullah & Salman Khan.

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