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REVIEW ARTICLE

THE ROLE OF ETHREL IN PLANT GROWTH AND DEVELOPMENT UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

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ABSTRACT

A phytohormone may be defined as an organic substance other than a nutrient, active in very minute amounts which is formed in certain parts of the plant and which is usually translocated to other sites, where it evokes specific biochemical, physiological and morphological responses. Hormones are effective at internal concentration of about 1 μM, where as other metabolites necessary for growth and development are usually present at concentration 1 to 50 μM. The most commonly used and best understood group of plant growth hormones consists of those which regulate the production of ethylene. Ethylene is the simplest olfin, which exists in the gaseous state under normal physiological conditions. It is colourless with ether like smell and is lighter than air. It is also highly flammable and more soluble in water than air O_2 or N_2. Ethylene is known to exert its effects by altering gene expression both at transcriptional and post transcriptional phases. Ethrel is versatile ethylene releasing agent have remarkable marketed value and registered for several crops. It is involved in a diverse array of cellular, developmental and stress-released processes in plants. Ethrel reduces the problem of pod shattering by restricting the flower and pod abortions. It also improves the crop by manipulating source/sink relationship at pod development stage. In this study a number of examples of the role played by ethrel in the growth and development of plants are described; plant height, leaf number, leaf area, leaf area index, dry weight, chlorophyll, photosynthesis, photosynthetic active radiation, nutrient uptake, seed yield, biological yield, harvest index, oil yield, amino acid content, protein content and fatty acid. So the present study indicates that the process of growth and development in addition to the yield of plants is significantly affected by the ethrel in both irrigated and non -irrigated conditions.

INTRODUCTION

Ethrel or ethephon (2-chloroethyl phosphonic acid) is ethylene generating commercial chemical (Warner and Leopold, 1969). Ethrel is most important and versatile ethylene –releasing agent marketed and registered for more than 20 crops. Ethephon is a synthetic plant growth regulator that undergoes chemical biodegradation at pH greater than 4.1 in cell cytoplasm to release ethylene (Urwiler and Stutte, 1986; Kasele *et al*., 1995). The use of ethephon as a growth retardant has been shown for controlling lodging of cereal and grain crops (Davis and Curry, 1991). Ethephon has also been found to impart tolerance against water stress and increasing the productivity of oil seed crop (Khan *et al.,* 2000).

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The other ethylene releasing compounds are etacelasil, holoethylsulfunic acids, 2-hydroethyle lydrazine (Palmer *et al*., 1967; Dowlet and Kumamoto, 1972; Lursen, 1982: Artera, 1997).

Ethylene is a gaseous plant growth regulator involved in a diverse array of cellular, development and stress related processes in plants. Prevention of ethylene accumulation in atmosphere and inhibition of its effects by lowering the temperature and increasing the CO_2 concentration are widespread produce storage practices. Silver ion also inhibits the ethylene action, acting at the receptor level (Veen, 1986), is a useful laboratory to (Yang, 1987; Smalle *et al*., 1987). Cobalt (CO^{2+}) has also been found to inhibit ethylene production and reversed the effects of ethylene (Samimy, 1978). Mohan Ram and Rina (1982)

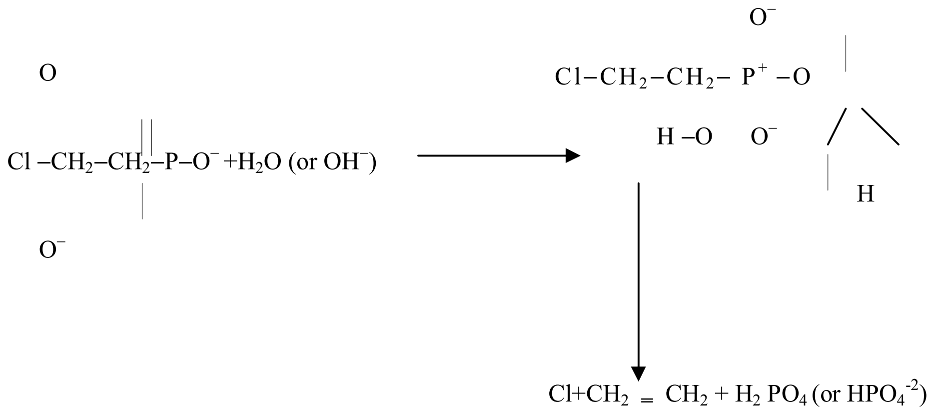

Fig. 2- Chloroethyl phosphonic acid decomposes spontaneously in plant tissues to yield ethylene and phosphonic acid.

found to inhibit ethylene production and reversed the effects of ethylene (Samimy, 1978). Mohan Ram and Rina (1982) reported the antagonistic properties of Ag NO_3 and $COCl_2$ on ethylene and application of these compounds reverse the effects of ethylene in plants of *canabis sativa.* Similar results for cobalt chloride and silver nitrate have been reported by Mhatre *et al*. (1988). Silver thiosulphate, an inhibitor of ethylene action completely reversed the inhibitory effect of ethephon on stem elongation (Sainewske and Ludhika, 1989). Kortisas (1988); Child *et al*. (1988) and Kushad and Pooviah (1984) showed that aminoethoxy vinylglycine inhibits the biosynthesis of ethylene. Cyclopropenes and 2,5-norbormadiene have also been found to be effective antagonists of the ethylene response (Sisler and Yang, 1984; Sisler *et al*., 1996a b).

Ethylene is a growth regulator that do not inhibit gibberellin biosynthesis. Ethylene is the simplest olefin with molecular formula $H_2C{=}CH_2$ exists in the gaseous state under normal physiological conditions .Its effect on various physiological processes at different stages of plant growth and development have been well documented (Yang and Hoffman, 1984; Reid,1987; Abeles *et al*., 1992; Pua and Chi, 1993; Reid and Howell, 1995; Fluhr and Mattoo, 1996; Khan, 1996, Dolan, 1997; Khan *et al*., 2000). Ethylene is known to exert its effects by altering gene expression both transcriptional and post transcriptional processes (Lincolin and Fischer, 1988). Dependent on the plant material and state of development, promoting or inhibiting effects of ethylene on internode growth has been observed (Raskin and Kande ,1984; Sisler and yang, 1984). Physiological conditions like water stress on drought also promote the ethylene synthesis in plants (Tudela and Primomillo, 1992; Bergner and Teichmann, 1993; Michelozi *et al*., 1995). Ethylene is important both in normal development, and for plant response to stress. During normal development, ethylene is thought to co -ordinate events such as growth and development, senescence, abscission and fruit ripening (Yang and Hoffman 1984; Reid, 1987; Abeles *et al*., 1992; Pua and Chi, 1993).

Germination, flowering, vegetative development, maturation senescence and response to pathogen are same of the process for which regulation involves ethylene (Essahi, 1991; Mattoo and Suttle, 1991; Kepczymski and Kepczymka, 1997; Morgan and Drew, 1997; Smalle and Van Der Straeten, 1997; Matilla, 2000). Ethylene biosynthesis has been found to increase in response to wounding, pathogen attack, mechanical stimulation and drought (Abeles *et al*., 1992).

Crop Response to Ethrel

Ethrel and growth parameters

1. Plant height

Growth regulators have been found to affect plant height (Sauerbreg *et al*., 1987; Guruprassad and Guruprasad, 1988, Dijikstra and Kuiper, 1989; Krisnamorthy, 1993). Depending on the plant material and the state of development, promoting or inhibiting effects of ethylene on internode growth has been observed (Sisler and Yang, 1984; Krishnamoorthy, 1993). Ethephon appreciably reduced the shoot length of sunflower plants and the internode elongation (Sauerbrey *et al*., 1987). Slife and Earely (1970) applied ethrel to flowering soyabean plants at 0.56 to 2.24 Kg/ha rates and all the treatments caused a decrease in plant height.

Foliar application of ethrel at the rate of 500,1000 and 1500ppm reduced plant height in barely (Bulman and Smith, 1993; Sanvicente *et al*., 1999), sunflower (Sauerbrey *et al*., 1988), Winter rape (Wareing and Paulips 1981), soybean (Urwiller and Charles, 1986) rice (Nafziger *et al* .,1986) winter wheat (Van Sanford *et al*., 1989), lupin (Ortuno *et al*., 1993), Linseed (Leitch and Kaut, 1999), radish (Vreugdenhil and Harrow, 1989), arabidiopsis seedlings (Smalle *et al*., 1997). Contrarily Jana and Kabir (1991) reported that the application of ethrel to cauliflower cv. Dania significantly increased plant height at 300ppm. However, growth was adversely affected at higher concentration.

2. Leaf number

Ramos *et al*. (1989) observed ethephon application at tillering increased both number of ears/plant and per pot in spring barely (Hordeum Vulgare). Ethrel was found to be beneficial for increasing the number of leaves per plant of muatrd Lone (2001). Researchers have observed controlling effects of ethrel on leaf expansion and production of plants with darker green forliage (Shanahan and Nielsen, 1987; Davis *et al*., 1988; Butler *et al.,* 1989; Sairam *et al*., 1989; Reddy *et al*., 1996 Zheu and Xi, 1993; Kulkarni *et al*., 1995; Zhou and Ye, 1996; Lee and Reid, 1997; Hussain *et al*., 1999).

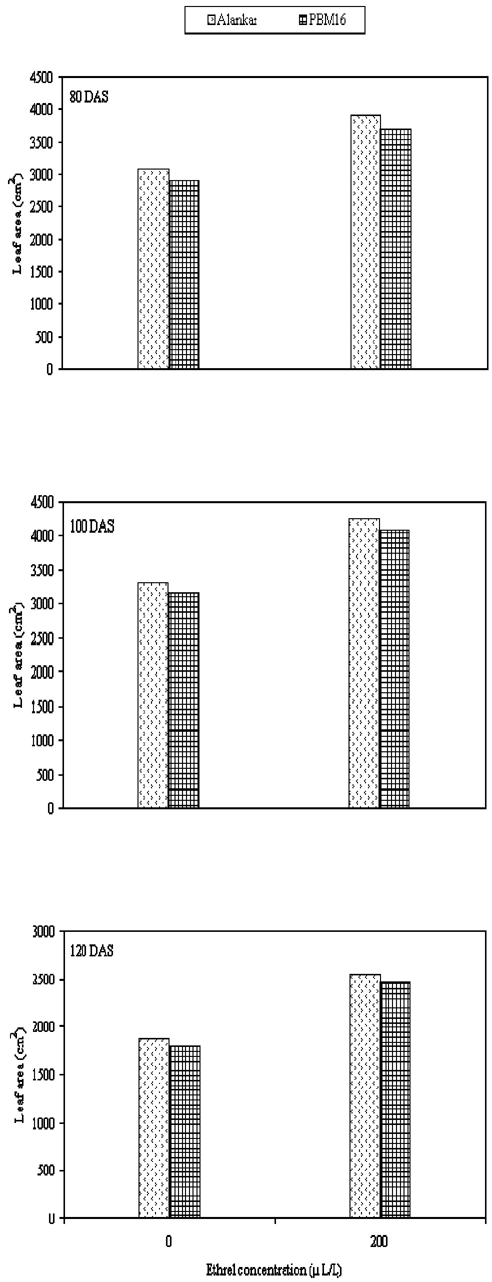

Fig. 1. Effect of ethrel spray at 60d after sowing (DAS, flowering stage) on leaf area (cm^2 plant^{-1}) of mustard (Brassica juncea L.) cultivar Alankar and PBM16 at 80, 100 and 120 DAS.

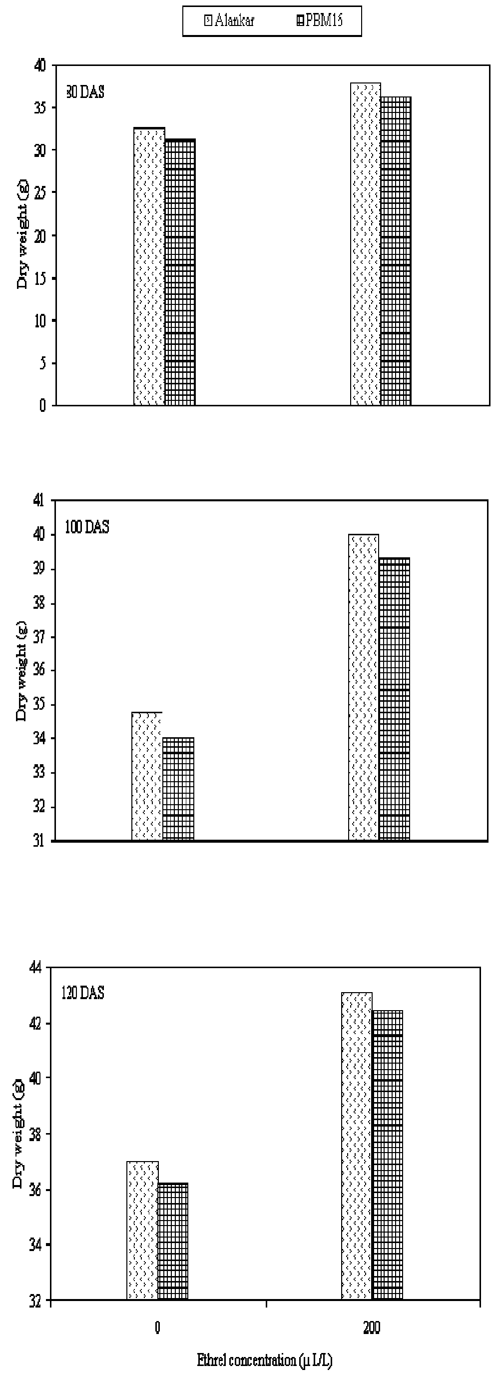

Fig.2. Effect of ethrel spray at 60d after sowing (DAS, flowering stage) on plant dry weight weight (g plant^{-1}) of mustard (Brassica juncea L.) cultivar Alankar and PBM16 at 80, 100 and 120 DAS.

3. Leaf area

Ehtylene has been shown in influence leaf exapnsion by suppressing cell enlargement rather than division (Kieber *et al*., 1993; Rodriguez pousida *et al*., 1993). Ethephon treatment reduced leaf area as compared to Control plants in *Zea mays* (Kasele *et al.,* 1995). However, ethephon application promoted expansion of primary leaves, while at higher concentration of ethephon showed a reduction in the area the primary leaves of *Helianthus annus* (Lee and Reid, 1997), and in mustard (Lone 2001; Mir 2002 and Mir *et al*., 2009a). The application of ethrel (200 µL/L) enhancing the leaf area (Fig. 1) has been reported from author's laboratory.

4. Leaf area index

Singh *et al*. (1987) working on soybean and Grewal and Kolar (1990) on mustard reported an increase in leaf area index in soybean by the application of the ethrel. Flag leaf area was greater in wheat treated with ethephon over control but plant leaf area index was not effected by ethephon (Van Sanford *et al*., 1989). Khan (1996); Khan *et al*. (2000); Lone (2001); Mir (2002); Mir *et al*. (2008) and Mir *et al*. (2009b,c) also reported an increase in leaf area index in response to ethrel spray in *Brassica juncea* L. under irrigated and non -irrigated conditions.

5. Dry weight

The plant growth regulator ethephon influenced the dry matter significantly in mustard (Khan 1996; Khan *et al*., 2000; Lone 2001; Mir 2002, Mir *et al*., 2008; Mir *et al*., 2009a,b), winter wheat (Nafziger *et al*., 1986; Van Sanford *et al.,* 1989) and barley (Simmons *et al*., 1988). Dry weight was found improved with ethrel (200 µL/L) application (Fig. 2) reported from author's laboratory. The dry weight of a main stem and root of ethrel treated mungbean plants was significantly higher (Panwar *et al*., 1988). Contrarily to these reports, Urwiler and Stute (1986) noted decrease in dry weight of soybean plants due to ethephon treatment.

Ethrel and photosynthetic parameters

1. Chlorophyll

Ethrel at 500ppm significantly increased the chlorophyll content in leaves of *Brassica napus*, however, higher doses of Ethrel (1000 and 1500 ppm) showed determinent effect (Grewal *et al*., 1993). The exogenous application of ethylene in mustard (Sinapis alba L.). Seedlings enhanced chlorophyll synthesis considerably (Buechler *et al*., 1978, Similar results were reported by Lone (2001).

2. Photosynthesis

Growth regulators may be employed to improve the physiological efficiency of plants by modifying the balance between photosynthesis and respiration (Arteca and Dong, 1981; Zerbe and Wild, 1981; Makeev *et al*., 1992). Increased rates of photosynthesis per unit leaf area have been observed after the application of growth regulators on different plant species (Liu *et al*., 1993; Yang *et al*., 1994). Plant growth regulators can effect photosynthetic CO_2 uptake either by affecting stomatal aperture or by affecting the activity of photosynthetic enzymes (Foroulam –pour *et al*., 1997). Foliar application of ethephon to spring barely caused an increase in penultimate leaf photosynthetic rate (Pua and Chi, 1993). Some reports also indicate that ethrel application either do not effect photosynthetic rate or had adverse effect on the parameter. In one of the study of Subrahmanyam and Rathore (1992a) they found that ethrel

C.D at 5%

80 DAS	100 DAS	120 DAS
0.31	0.32	0.33

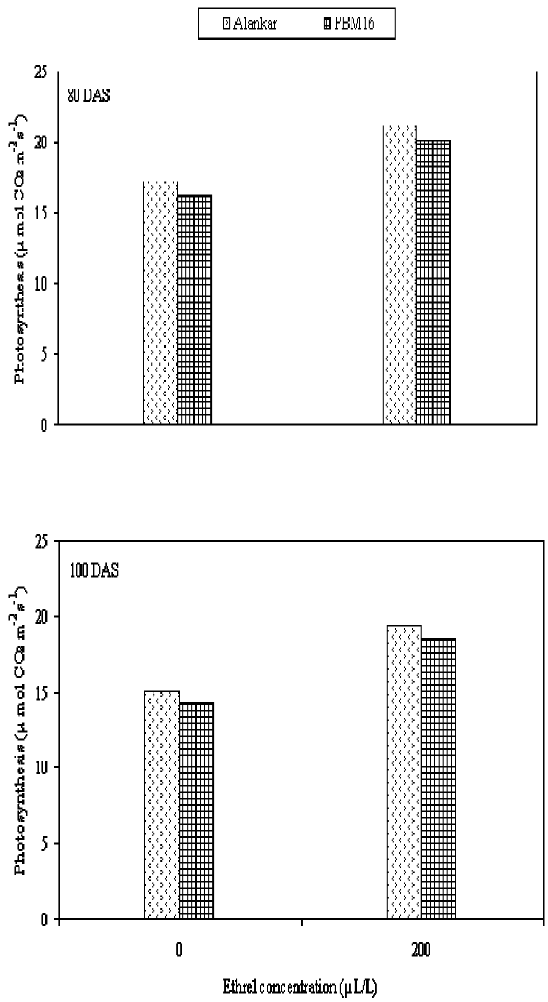

Fig.3. Effect of ethrel spray at 60d after sowing (DAS, flowering stage) on rate of photosynthesis (µ mol CO_2 $m^{-2}s^{-1}$) of mustard (Brassica juncea L.) cultivar Alankar and PBM16 at 80 and 100 DAS.

application had no significant effect on photosynthesis Indian mustard. However, photosynthesis in upper leaves and to a lesser extent in lower leaves was lowered by ethrel application. Exogenous application of ethrel has also been found to cause 12-18% reduction in photosynthesis (Subrahmanyam and Rathore1992 a, b; Pua and Chi, 1993). Studies conducted in the author's laboratory have shown that exogenous application of ethrel enhanced photosynthesis of mustard in irrigated and unirrigated conditions (Khan, 1996; Khan, 1998; Khan *et al*., 2000; Lone 2001; Mir, 2002 and Mir *et al*., 2009b). The beneficial effect of ethrel (200 µL/L) in enhancing photosynthesis (Fig. 3) has been reported from author's laboratory.

3. Photsynthetically active radiation

Photsynthetically active radiation (PAR) is a measure of radiation available for photosynthesis. It is well known for that plants vary in response to radiations of different wavelengths within the canopy. Mean sunlight irradiance or the proportion of sunlight leaf surface diminishes as an exponential function of leaf area index. Changes in radiation quantity also occur largely due to the spectral properties of leaf pigments, leading to a reduction in the red/far red ratio as light penetrates the canopy (Holmes, 1981; Ballare *et al*., 1989; Guiamet *et al*., 1989). In this respect there are several evidences that potentiate the climate of canopy change under the influence of growth regulators, which bring about a desirable modification in PAR (Mathias *et al*., 1989). Grewal and Kolar (1990) in their experiment on *Brassica juncea* reported that application of ethrel (500, 1000 and 1500ppm) had negative impact on PAR interception. While ethrel application increased the PAR in mustard in non -irrigated conditions (Lone 2001).

Ethrel and nutrient uptake

Plant growth regulators are known to influence ion transports, have special effects on membrane properties and functions .Growth regulators have affiliated with reinforcement of assimilate translocation in established sink –source systems (Thomas, 1986; Patrick and Steains, 1987). Desirable increase in the produce of field crops was due to alteration in the trends of assimilate distribution (Addo-Quaye *et al*., 1986). The allocation of newly fixed carbon in to different metabolic products influenced the partitioning of carbon growth activity of the whole plant (Champigny, 1985). Foliar application of ethrel at the rate of 200ppm at the flower initiation stage increased the uptake of N, P and P in soyabean plants (Sing *et al*., 1987). Ethephon had a strong effect on cultivatar N use efficiency and in particular on the role of N uptake efficiency in winter wheat (Van Sanford *et al*., 1989). Use of ethephon result in an increased uptake in barley (Bulman & Smith, 1993) and Indian mustard (Suberhmanyam and Rathore, 1992a,b; Khan, 1998; Khan *et al*., 2000). Contrarily Dhakal and Erdi (1986) found that ethylenehad no influence on K^+ and Na^+ levels neither at lower nor at higher concentrations in wheat. In a filed trail on mustard under irrigated conditions (Khan, 1998) and under non -irrigated conditions (Khan *et al*., 2000; Lone, 2001 and Mir, 2002) reported that ethrel sprayed plants accumulated higher plant N and seed N content and enhanced nitrogen harvest index and nitrogen yield merit (Khan, 1998). Under non irrigated conditions ethrel sprayed plants utilized N from the soil more effectively and showed increased nitrogen harvest index and nitrogen yield merit (Khan *et al*., 2000; Lone, 2001; Mir, 2002 and Mir *et al*., 2009c).

Ethrel and yield parameters

Yield components like pod number, seed number per pod and seed weight do not only depend on nutritional factor but also on hormonal status (Morgan, 1980; Crosby *et al*., 1981; Carlson *et al*., 1987; De -Bouille *et al*., 1989; Paulpandi *et al*., 1998).

1. Pod number

Foliar application of ethrel at the rate of 200 ppm at the flower initiation stage improved the number of pods per plant in soyabean (Singh *et al*. 1987). Foliar spray of ethrel increased the number of mature pods per plant of peanut (*Arachis hypogea*) positively with sequential spray treatment over no spray in all the varieties (Saini *et al.,* 1984). Urwiller and stutte (1986) reported increased the number of one seeded pods in the ethepon treated soyabean plants. Results reported from the author's laboratory have confirmed the beneficial effects of the ethrel in pod number of mustard (*Braasica juncea* L.). Under irrigated (Khan, 1996; 1998 and Mir 2002) and non -irrigated (Khan *et al*., 2000; Lone, 2001; Mir 2002 and Mir *et al*. 2009b,c) conditions. However, exogenous application of ethrel resulted in detrimental effect on pods per plant in *Braasica napus* reported by Grewal *et al*. (1993).

2. Seed number

Pod number and seed number per pod are determined early after flowering (Pechan and Morgan, 1983) and have been found to be influenced by growth regulators (Zhou and Xi, 1993; Foroutan -Pour *et al*., 1997). Foliar application of ethrel at flowering and pegging stages increased number of seeds and size of seeds in groundnut (Mishra *et al*., 1984).

3. 1000 Seed weight

Foliar application of ethrel at 200ppm concentration increased 1000 grain weight in soybean (Singh *et al*., 1987). Spray at flowering stage on Indian mustard also increased seed weight (Sing and Kumar, 1991). Ethephon increased 1000-seed weight in onion (*Allium cepa* L.) comapred to control (Sing *et al*., 1995). However, Grewal *et al*. (1993) observed that ethrel treatment resulted in detrimental effect on 1000- seed weight in *Brassiac napus*, while Ramos *et al.* (1989) in barley (Hordeum vulgare L.), Khan *et al*. (2000); Mir *et al*., (2008) and Mir *et al*., (2009 b,c) in mustard (*Brassica juncea* L.), Coffelt and Howell (1986) in pea nut (*Arachis hypogei*) failed to observe any increase in 1000 seed weight in response to the foliar spray of ethephon.

4. **Seed yield**

Improkement in seed yield of different crops in response to growth substances was observed by Gopalkrishnan and Srinivasan (1975); Ries *et al*. (1977) and Menon and Srivastva (1984). The growth regulators have been found to engage in assimilate translocation towards reproductive parts of plants (Pando and Srivastava, 1985; Khan *et al*., 2000). Differential response of ethephon were observed and several investigators reported about the beneficial effect on grain yields of winter wheat (Dahnous *et al.,* 1982; Leary and Oplinger, 1983; Wiersma *et al*; 1986), while others claimed reduction with the use of ethephon (Nafziger *et al*., 1986; Simmons *et al*., 1988; Taylor, 1991).

Increase in the seed yield of mustard in response to ethrel has been reported by Grewal *et al.* (1993); Khan (1996; 1998) and sing and Kumar (1991). Joshi *et al*. (1987) also reported increase in seed yield in ground nut (*Arachis hypogea* L.) when treated with ethrel. Foliar application of ethrel cauliflower increased the seed yield per plant at 300ppm while it was adversely affected at higher concentration (Jana and Kabir, 1991). Ethephon treatment increased significantly grain yield in corn (Kasele *et al*., 1995) and barley (Bulman and Smith, 1993). Contrarily, Slife and Earley (1970) found that applied ethrel to flowering soybean plants at 0.56 to 2.24 kg/ha rates decreased yield of seed per hectare. Grewal *et al*. (1993) at the rate of 1000 and 1500 ppm ethrel also observed substantial decrease in seed yield in *Brassica napus*. Under non -irrigated conditions application of 200ppm ethrel to foliage enhanced seed yield in *Brassica juncea* was reported by Khan *et al*. (2000); Lone (2001); Mir (2002); Mir *et al*. (2008) and Mir *et al*. (2009b,c). The effect of ethrel (200 µL/L) was found beneficial in enhancing seed yield (Fig. 4), a repot from author's laboratory. Early application of ethrel resulted in significant reduction in seed yield of linseed (Leitch and Kuat, 1999).

C.D at 5%
120 DAS
0.20

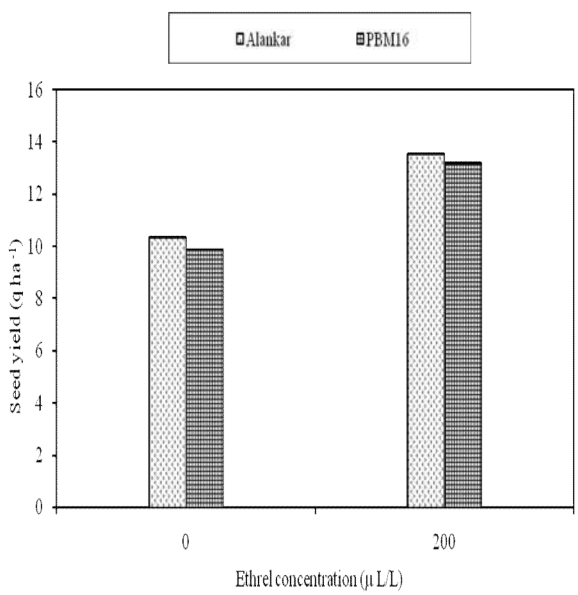

Fig.4. Effect of ethrel spray at 60d after sowing (DAS, flowering stage) on seed yield (q ha^{-1}) of mustard (*Brassica juncea* L.) cultivar Alankar and PBM16 at 120 DAS.

5. Biological yield

Biological yield and merit of genotype were enhanced in ethylene treated mustard plants under non -irrigated conditions (Khan *et al*., 2000; Lone, 2001; Khan, 1996; 1998; Mir, 2002 and Mir *et al*. (2009b,c) in another study with availability of water, found enhancing effect of ethrel on biological yield of mustard .

6. Harvest Index

Dormant seeds of groundnut (*Arachis hypogea* L.) when treated with ethrel gave higher harvest index than the water soaked dormant seeds (Joshi *et al*., 1987), While Van Sanford *et al.* (1989) observed equivalent harvest index in both ethephon treated and control plants in winter wheat. Khan (1996; 1998); Khan *et al*. (2000) and Mir (2002) also found that harvest index was not influenced significantly in ethylene treated plants of mustard.

7. Oil Yield

Khan (1996); Lone (2001) and Mir (2002) reported impressive increase in the oil yield of mustard in response to ethrel application.

Ethrel and quality parameters

1. Oil content

Exogenous application of ethephon at the rate of 250 ppm reudced essentail oil content of peppermint and slight increse in essential oil content of Sage (El -Keltawi and Rodney, 1986) was reported. Farooqi and Sharma (1988) also reported an increase in oil content of *Rosa damascena* Mill by the application of 0.02 ad 0.06% concentrations of ethrel. However, Khan (1996); Lone (2001) and Mir (2002) showed an increase in oil content in seeds of mustard. Grewal *et al*. (1993) in *B. napus*, Grewal and Kolar (1990) in *Brassica juncea*, Leitch and Kaut (1999) in linseed reported that ethrel application had no influence on the seed oil content of the plants .

2. Amino Acid Content

Sharma *et al*. (1982) reported that free amino acids increased during the pod development stages on application of ethrel on groundnut (*Arachis hypogea*). Ethrel treatments increased protein content as well as depletion of amino acids and efficient in corporation of amino acids into the protein in wheat (Sekhon and Singh, 1994).

3. Protein content

Plant growth regulators have been found to influence significantly the protein content in crop plants (Liu *et al*., 1993; Lurie *et al*., Yang *et al*., 1994; Kulkarni *et al.,* 1995). They have also been implicated in the control of protein allocation among plant organs and accumulation in developing cereal grains (Oritant and Yoshida; 1971). Grain protein concentration increased (Morris *et al*., 1989; Van sanford *et al*., 1989) or remain unaffected (Pearson *et al*. 1989) by ethephon treatment .Soluble proteins increased with the application of ethrel during initial stages of pod development but declined later in ground nut (*Arachis hypogea*) (Sharma *et al* 1982). Ethephon application increased protein content per grain and grain protein concentration in barley (Bullman and Smith, 1993; Ma *et al*., 1994). Ethrel treatment has been found to increase protein content and efficient incorporation of amino acids into proteins in wheat (Sekhon and Singh, 1994).

4. Fatty acid

Etephon has been reported to change the relative proportions of fatty acids, reducing the content of linolenic acid and increasing the oleic acid (Leitch and Krat 1999). Ethrel has also shown a primitive effect on conversion of lipid in to sugars through glyoxylate cycle under water stress conditions in soyabean seeds (Sharma *et al*., 1986).

CONCLUSIONS

This study highlights the pivotal part played by the gaseous hormone in the form of ethrel on plant growth and development by affecting various growth parameters like: plant height, leaf number, leaf area, leaf area index, dry weight; photosynthetic parameters like chlorophyll, photosynthesis, photosynthetically active radiation, nutrient uptake in addition to yield parameters like; pod number, seed number, 1000 seed weight, seed yield, biological yield, harvest index, oil yield and quality *parameters like oil content, amino acid content, protein content and fatty acid content.*

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