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USE OF PACLOBUTRAZOL IN HORTICULTURAL CROPS - A REVIEW

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ABSTRACT

In India auxin, gibberellin and cytokinins are mostly used as plant growth regulators and there is limited use of the plant growth retardants but in many countries they have become an integral part of crop production system. American Society for Horticultural Science has listed chemical growth regulation as one of the eight major research priorities for horticultural sciences. The recent development of a number of highly active growth retardants have further enhanced the potential of chemical growth regulation in horticulture. Paclobutrazol (pp333), a triazole is one of the most important representatives. It is extensively studies due to its high potential for controlling plant growth and development. The available literatures on effect of paclobutrazol on seed treatment and seed germination, vegetative growth, flowering, fruit set and development, fruit yield, fruit quality and resistance to biotic and abiotic stresses in horticultural crops have been reviewed in this paper.

Paclobutrazol {β-(4-chlorophenyl) methyl} - α - (1,1, -dimethyl) - 1H-1, 2,4-triazole-1-ethanol (Fig. 1); which is also known as different commercial names such as pp333, cultar, bonzi; sadabahar, parley, clipper etc, is an important growth retardant. It has been effective in controlling the growth of a wide range of horticultural crops by inhibiting both sterol (Dalziel and Lawrence, 1984; Wiggins and Baldwin, 1984) and gibberellin biosynthesis (Raese and Burtz, 1983). Studies with cell free system indicate that the chemical inhibits especially three steps in the oxidation of the GA precursors ent-kaurene to ent-kaurenoic acid with KI 50 for the mixture of 2RS and 3RS ent-antiomers of $2x10^{-8}$ m (Hedden and Greebe, 1985). The main effect of paclobutrazol in the plant is the inhibition of gibberellin biosynthesis, which reduces change in the sink source relationship by reallocating the carbohydrate source towards other organs of the plant than the shoot apex (Steffens *et al.*, 1985 and Ramina and Tonutti, 1985). Several methods namely foliar application (Quinlan and Webster, 1982), soil application (Atkinson *et al.*, 1983; Williams, 1984), TSLP (Turkey, 1983), injection method (Street, 1985) and by incorporating in nutrient solution (Quinlan and Richardson, 1984) have been used for paclobutrazol application with varying successes. Soil application has been found to have lasting effect in growth retardant, whereas several foliar applications have been advocated to the similar effects (Lurssen, and Reisser, 1985). It has been observed that paclobutrazol is translocated acropetally **and**

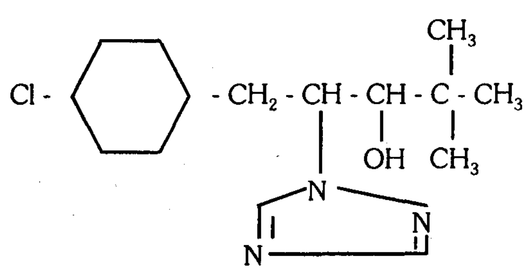

Fig. 1. Chemical structure of paclobutrazol

it is taken up through roots and after that translocated primarily in the xylem through the stem and accumulated in leaves. Reed *et al.* (1989) observed that the concentration of paclobutrazol was the highest in leaves (478 dpm/mg FW) followed by stem (141dpm/mg FW).

Guideline for use

- Paclobutrazol should be applied on healthy plants/trees.
- Tree base should be kept weed free before and after its application.
- Adequate moisture in the soil at the time of application and for the following 40-50 days is essential. Absorption of paclobutrazol in the plant system is better. To compensate for adequate rainfall, crop should be irrigated.
- Paclobutrazol treated plant/trees start producing inflorescence in 3-4 months of application. This flush of inflorescence as well as new vegetabtiive flushes and flowers should be regularly protected from the attack of insect, pest and diseases.
- Paclobutrazol treated plants/trees are expected to bear a good crop every year. Therefore, twice the recommended dose of fertilizers and orgnic manures should be fed to the tree/plant from the second year of paclobutrazol application.

Effect of paclobutrazol on various attributes of horticultural crops

The effect of paclobutrazol on various attributes of horticultural crops has been described below.

Seed treatment and seed germination

A novel seed treatment technology that enables efficient use of paclobutrazol has been developed recently (Fletcher and Gilley, 2000). The paclobutrazols are administered via imbibition followed by acclimation and these 'programmed' seeds developed seedlings that express a high degree of resistance to a variety of environmental stresses. Depending on the species, seeds were imbibed for a period of 2 to 16 hours at room temperature. Cereals, tomato and pepper were imbibed for as long as 16 hours, whereas canola, which tend to split imbibed for shorter periods (1 to 4 hours). The imbibed seeds were dried, stored and germinated when required. Addition of potassium to the paclobutrazol solution and exposure of seeds to a heat shock (acclimation) during the imbibition period further enhance the PGR effects and improved the efficacy of the paclobutrazol induced protection against various stresses. This seed treatment also eliminates fungicides seed coating treatment since the paclobutrazol itself is a potent fungicide. Seed treatment of tomato and cucumber has reduced irrigation needs (Fletcher and Gilley, 2000).

Paclobutrazol inhibits and/or delays germination of seed and pollen grain tube. It has no effect on rate of germination of stratified seeds of peach. The inhibition of germination could be due to blockage or counteraction of gibberellin synthesis and activity, because gibberellin plays primary role in germination of seeds. Vivipary was observed in paclobutrazol treated trees of late maturing Fazri mango when treated with 2g per meter canopy radius (Fletcher and Gilley, 2000).

Vegetative growth

Paclobutrazol is more potent than most other growth retardants and relatively low rates are required to inhibit shoot growth. However, even at high application rates they generally are not phytotoxic. The most pronounced effect of paclobutrazol on plant is the reduction in height, with the treated plant being greener and more compact. The plant becomes greener due to increased chlorophyll content per unit leaf area (Fletcher and Gilley, 2000). Reduction in shoot growth by paclobutrazol occurs primarily as a consequence of reduced internode elongation. Paclobutrazol induced inhibition in tree vigour in mango cv. Alphonso is not only associated with GA biosyntheses inhibition but also with its influence on other hormones such as ABA, cytokinin and IAA and as also on phenol (Murti, 2001). Paclobutrazol has several morphological effects on leaves. It reduce leaf area, but increases epicuticular wax, width and thickness and hence, leaf dry weight per unit area is increased (Davis and Shankhla, 1987). Various concentrations of paclobutrazol have reduced the vegetative growth by checking the apical dominance and shortening the internodal length when applied either through soil or foliar application in citrus (Aron *et al.*, 1985), mango (Pandey and Sharma, 1986), grape (Ahmedullah *et al.*, 1988 and Andrew and Reynolds, 1988), apples (Quinlan and Webster, 1982; Greene and Murray, 1983; Raese and Burtz, 1983; Edgerten, 1985, Quinlan and Richardson, 1984; Elfving and Proctor, 1986 and Jones *et al.*, 1988), pear (Lever *et al.*, 1982; Raese and Burtz, 1983; Tymaszuk and Mika, 1986; Dheim and Browning, 1987 and Rai and Bist, 1992), peach (Marini,1986; Early and Martin,1988 and Aguirre and Blanco, 1992), Plum (Webster and Andrewsil,1985), cherry (Bargioni *et al.*, 1986), almond and cocoa (Vitagliano and Viti (1989), tomato (Kozlowska and Borowski,1995 and Arora *et al.*, 1989), capsicum (Mojecka and Kerin, 1995), cucumber (Borowski *et al.*, 1997), muskmelon (Baruah, 1995), faba bean (Hugi and Keller, 1990 and Xia, 1990), snap melon (El-Sayed, 1991), chicory (Dameulemeester *et al*, 1995), cauliflower (Rodrigues-Otubo *et al.*, 1998) and broccoli (Million *et al* , 1998). Paclobutrazol has been found effective in controlling growth and promoting compactness of a number of flowers, ornamentals including chrysanthemum, Morifolium, *Episcia cupreata*, *Hydrangea macrophylla*, Lilium and Tulip. It may prolong the life of foliage plants in interior landscapes and thereby reduces the frequency of replacement (Davis *et al.*, 1986). Twenty per cent reduction in plant size was observed in paclobutrazol treated flowering plants like bigonia, chrysanthemum, pitunia etc (Millon *et al.*, 1999).

Flower initiation

Photosynthetic input, energy flow and redistribution of assimilates play a large role in flower initiation. Application of paclobutrazol initiates flowering in fruit plants by the decrease of gibberellin levels and increase of auxins and cytokinins levels in shoot tip. Currently the application of paclobutrazol to control size and stimulate early flowering is mango is being tested widely in south east Asia, Australia, Africa, Mexico and other areas of the tropics and Central America (Fletcher and Gilley, 2000). Early flowering in a major objective of mango growers because it provides precious early seasons fruit harvests and increased yield. The various concentrations of paclobutrazol was found effective in stimulating the flower initiation via inhibition of shoot growth, has been reported in mango (Kurian and Iyer, 1993), citrus (Snowball *et al.*, 1994), apples (Stinchcombe *et al.*, 1984; Shearing *et al.*, 1986 and Jones *et al.*, 1988), pear (Krienken and Van Lindenberg, 1984; Curry and William, 1986; Jaumien *et al*, 1986 and Rai and Bist, 1992), peach (Erez, 1986; Strydom and Honeyborne, 1986 and Luis, 1988), plum (Luis, 1988), Cherry (Jacyna *et al.*,1986), crane berry (Mc Arther and Eaton, 1988), Kiwi (Burge *et al.*, 1990). Paclobutrazol effectively restricted the inflorescence growth below the first flower in orchid. Flower size and stalk thickness were unaffected by the treatment and foliage applications were less effective than dipping. Paclobutrazol was also found quite effective in reducing leaf length, width and thickness in *Cymbidium sinense* (Fletcher and Gilley, 2000). Paclobutrazol induced earlier flowering and a higher percentage of flowerings in several horticultural crops. Paclobutrazol induced percentage of flowering shoots in mango cv. Alphonso (Murti, 2001). It increases the total number of panicles, the number of flowers per panicles in spices. In fenugreek (*Trigonella foennum graecum* L.), it increases leaf pigmentation and shoot branching (Fletcher and Gilley, 2000). Highest increase in the number of flowers per plant in *Jasminum sambac* was found by 20 ppm paclobutrazol (Swaminathan *et al.*, 1999).

Yield and quality

Paclobutrazol is also effective in increasing the yield of several horticultural crops by the inhibition of GA biosynthesis, which changes the sink-sources relationship by reallocating the carbohydrate source towards other organs. In mango, soil drench of 10 g paclobutrazol per tree is reported to increase 16% fruit yield (Kulkarni, 1988). Foliar application of 2500-3000 ppm paclobutrazol three weeks after full bloom increased fruit number, fruit weight, yield, TSS and reduced acidity in apple (Shearing *et al.*, 1986; Tymaszuk and Mika, 1986), peach (Marini, 1986) and cherries (Webster *et al.*, 1986). However, Elfving and Proctor (1986) and Bonoma and Tiezzi (1986) reported that 2000 ppm paclobutrazol sprayed on apple tree significantly reduced mean fruit weight. While on the other hand fruit and quality of pear fruit remain unaffected when 1000 ppm paclobutrazol was applied either monthly or bimonthly intervals on pear trees (Stan *et al.*, 1986). Similar results were obtained when 1000-2000 ppm paclobutrazol/tree was sprayed on Michelin apple (Stinchcombe *et al.*, 1984). Increase in fruit weight, yield and TSS with reduction in pedicel length, sugar and acidity was also noticed by different concentrations of paclobutrazol applied either soil or foliar in pear (Thomas, 1983 and Rai, 1991), apple (Kim, 1991 and Jones *et al.*, 1988), pecan (Wood, 1987; Marquard, 1985 and Anderson and Aldrich, 1987), persimon (Lee and Kim, 1991), cherry (Looney and McKellar, 1987), appricot (Mehta *et al.*, 1990), plum (Chandel and Jindal, 1991) and peach (Erez, 1986). Paclobutrazol did not affect sugar, pH, colour, K or glucose-fructose ratio in grape (Zoeckllein *et al* 1991), amino cyclo propane, carboxyllic acid, ethylene, sorbitol, fructose, and maleic acid in apple (Wang and Steffens, 1987). However, Bargioni *et al.* (1986) had observed that soil application of paclobutrazol @ 0.5 g/tree in Gorgia cherry tree reduced the yield and fruit numbers. Paclobutrazol 50 mg per litre was found to produce maximum number of suckers per plant (3.86 in rainy season and 4.06 in dry season) of required size and quality in least days (21.7 in rainy season and 19.33 in dry season), which ultimately increased the yiled per plant at CARI, Port Blair (Singh, 2002). Increased mean fruit weight and yield of papaya var. CO_2 was recorded with 50 mg/L of paclobutrazolin combination with 300 g Nitrogen (Auxcilia and Sathiamoorthy, 1999). Application of 5g of paclobutrazol through soil enabled to induce early and regular fruiting with 2.8 times increase in yield in mango var. Alphonso (Patil and Talathi, 1999).

Paclobutrazol 150 ppm was applied in tomato at 20 days after transplanting produced the highest individual fruit weight, number of fruits and early and total yield (Baruah *et al.*, 1995) and increased yield of *Beta vulgaris* by about 0.6 t/ha (Jaggard *et al.*, 1982). The cloves of garlic cultivar Quiteria were soaked in different concentrations of paclobutrazol increased the yield with increased concentration (Rosende *et al.*, 1993). Arora *et al.* (1989) found that paclobutrazol 25-100 ppm applied at 2-4 leaf stage increased early yield, number of fruits/ plant and total yield. Paclobutrazol @150 mg/ L in bottlegourd, 100 mg/L in bittergourd, 150 mg/L in French bean, 125 mg/L in cucumber and 40 mg/L in tomato increased the yield and quality of fruits (Rai *et al.* 2002). Similarly Pang *et al.* (1999) also found increased yield of paclobutrazol treated cucumber plants.

Paclobutrazol (100 ppm) increased total yield of tomato by increasing fruit set percentage on 1st and IInd trusses (Baruah *et al.* (1995). Improvement in fruit quality in terms of increse in TSS and ascorbic acid has also been reported in tomato by Kozlowska and Borowski (1995) and increase in Ca, Fe and Vit C in summer lettuce (Que *et al.*, 1995). Madey *et al.* (1995) reported that protein level per unit area of leaves increased but chlorophyll and carotenoid levels remained nearly constant in paclobutrazol treated plant of French bean.

Diseases and physiological disorders

Paclobutrazol reduced the incidence of fruit rot in grape (Zoeckllein *et al.*, 1991) pulp spot and vascular browning in avocado (Symons and Wolstenholme, 1990), cracking in apple (Visai *et al.*, 1989) and freckle pit and cork spot in pear fruit (Raese and Burtz, 1983). Floral malformation of mango was highly reduced by continuous application of paclobutrazol for six years in high density planting. Paclobutrazol reduced senescence break down of apple fruit, perhaps due to increased calcium content of flesh (Greene, 1986). However, paclobutrazol increased the incidence of resetting (Steffens *et al.*, 1993), bitter pit, water core (Visai *et al.*, 1989), stem cavity, browning and brown core in apple (Elfving *et al.*, 1990), physiological floral bud disorder in pear (Klinac *et al.*, 1991) and botrytis rot in grape (Forlani and Cappola, 1992). Paclobutrazol spray in pepper at full bloom stage showed that plants were able to increase tolerance to low temperature (Lurie *et al.*, 1995). Lurie *et al.* (1994) also reported that protection of sweet pepper against chilling injury was due to its effect on fruit morphology and protection of the lipid against oxidative stem. Paclobutrazol reduced the incidence of tip burn in different varieties of lettuce from 12.9% to 64.5% in comparison to control (Obispo, 1997).

Rooting and root growth

Effect of paclobutrazol on plant roots have not been studied in as much detail as on shoots. Although the effect on root growth may vary, a higher root shoot ratio is usually a characteristic of paclobutrazol treated plants, primarily due to the drastic reduction in shoot growth (Davis and Shankhla, 1987). The roots of Paclobutrazol treated seedlings not only continued to grow and produce new roots under moisture deprivation, but on rewatering a very rapid regeneration of new roots occurred. This may have a role in plant survival under moisture stress. Paclobutrazol treated plants have often exhibited numerous thickened, fleshy roots due to increased root diameter and decreased root length (Bausher and Yelenosky, 1987). Reduced root growth have been reported in several fruit crops like apple (Zeller *et al.*, 1991), cashewnut (Misra *et al.*, 1991) and citrus (Peng *et al.*, 1992). In strawberry paclobutrazol reduced root diameter and increased the number of root hairs (Stang and Weis, 1984). The weight, diameter and length of fibrous roots have increased when only tops of apple seedlings were treated with paclobutrazol (Steffens *et al.*, 1983). Treatment of apple seedling with paclobutrazol enhanced lateral root formation (Wang and Faust, 1986). Root biomass was increased by paclobutrazol in apple (Ma *et al.*, 1990), citrus (Vu and Yelenosky, 1992) and ber (Kim and Lee, 1988). It increased rooting in citrus (Bausher and Yelenosky 1987), guava (Hafeezur Rahman *et al.*, 1991), papaya (Allan and McMillan, 1991), pomegranate (Reddy and Reddy, 1989) and peach (Weisman *et al.*, 1989). Thick and short roots were obtained in citrus seedling in *in vitro* propagation (Mishra, 1999). Rooting percentage was reduced from 66.7 to 1.5% in paclobutrazol treated seedlings of French bean (Tari and Nagy, 1996). Paclobutrazol inhibited root extension, promoted swelling and increased cell volume in pea (Wang and Lin, 1992).

***In vitro* responses**

The influence of paclobutrazol compounds on the growth and development of in vitro culture has been studies very little. Paclobutrazol is helpful in stimulating the process of somatic embryogenesis suppressed by GA_3 in culture (Spiegel Roy and Saad, 1986). Paclobutrazol promoted adventitious root formation in cutting from a number of species (Davis and Sankhla, 1987). Bausher and Yelenosky (1987) observed that paclobutrazol promoted adventitious root formation on leaf petioles of *Citrus sinensis*. *In vitro* study of *Allium trifoliatum* plantlets produced through clonal propagation by applying high concentration of paclobutrazol exhibited doubling in the alcohol dehydragenase profile (Viterbo *et al.*, 1994). Paclobutrazol did not affect the total number of somatic embryo when applied for somatic embryogenesis of asparagus (Li and Wolyn, 1995). Biddington *et al.* (1992) reported that paclobutrazol inhibited embryo production in anther culture of brussels sprouts. In cell suspension culture of carrot, highest increase in anthocyanin content was reported by paclobutrazol in all seven growth retardants (Ilan and Dougall, 1992). Three growth retardants (uniconazole, paclobutrazol and cycocel) were added in different concentration in culture media. Pacloburazol and uniconazole 2 mg/lit were found effective in increasing dwarfism without reducing leaf number and inducing phytotoxicity symptoms (Rodrigues *et al.*, 1998). Chicory root explants were cultured *in vitro* by using different retardants. Paclobutrazol and compound belonging to the cyclohexanetrione group such as daminozlide clearly reduced flowering shoot growth under light conditions and vegetative shoot growth under dark conditions (Dameulemeester *et al.*, 1995).

Stress protection

The environmental stresses affect plant growth, development and ultimately yield. Paclobutrazol has been found to be highly effective in protecting plants from various environmental stresses. Studies with *Phaseolus vulgaris* showed that paclobutrazol reduces transpiration under water stress conditions. Reduction of transpiration and protection from drought is associated with a reduction in shoot weight and length, leaf area and increased diffusive resistance, indicating partial closure of stomata's and a transient rise in ABA levels (Asare-Boamah *et al.*, 1986). With affected seedlings, water uptake was reduced by root applied paclobutrazol even when expressed on a leaf area basis (Steffens and Wang, 1984). Similarly it has been found that soil applied paclobutrazol increased stomatal diffusive resistance of *Lycopersicon esculentum* (Fletcher and Hafstra, 1985) and *Phaseolus vulgaris* (Asare Boamah *et al.*, 1986). The paclobutrazol is highly effective in protecting crop from early frosting. It increases the level of antioxidants, tocopherol and ascorbic acid in tomato seedlings and it has been suggested that membranes damage is the result of oxygen free radicals generated by low temperatures and that paclobutrazol protects membranes by preventing a reducing oxidative injury. Soil applied paclobutrazol has been found effective in delaying symptom of chilling injury in *Cucumis sativus* (Wang, 1985). Apple (Coleman *et al.*, 1992), cherry (Webster *et al.*, 1986), citrus (Mikaberidge and Mardaleishvili, 1990) and raspberry (KurYata *et al.*, 1991). It is also effective in protecting plants from a combination of heat and drought. Paclobutrazol can decrease the injury due to air pollutants by enhancing the activity of antioxidant enzymes like ascorbate, peroxidase, monodehydroascorbate reductase and glutathione reductase and catalase (Sankhla *et al.*, 1986).

CONCLUSION

The above review revealed that

paclobutrazol is very much useful not only in shortening of stem internodes, which reduces plant height to prevent lodging but also it can be used very effectively in increasing number of flowers and fruit set. It improves the fruit quality in terms of colour development, increases carbohydrates, TSS, juice percentage, improves post harvest quality of horticultural crops and decreases acidity. It reduces evapo-transpiration and decreases plant moisture stress by enhancing the relative water content (RWC) of leaf area and develops resistance in the plants against biotic and abiotic stresses. Besides above, it acts as highly active systemic fungicide and used against several economically important fungal diseases.

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