Chapter

Response of Growth Inhibitor Paclobutrazol in Fruit Crops

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Abstract

Paclobutrazol (PBZ; IUPAC name: (2RS, 3RS)-1-(4-chlorophenyl)-4, 4-dimethyl-2-(1H-1, 2, 4-triazol-1-yl) pentan-3-ol) is a triazol derivative and an antagonist of gibberellins. It has been shown to inhibit shoot growth in various perennial fruit trees. Paclobutrazol application reduced the number of shoots, transforming trees into a more desirable, spur-type growth habit as the vegetative sink was reduced. This compound induces an early and intense flowering, diminishing vegetative growth and reducing the extension of buds, allowing for ripening and the initiation of apical buds inflorescence. Besides, it also increases fruit set, the years following application as a carryover effect. An increase in return bloom is a common response to paclobutrazol treatment and has been reported for various fruit crops. Paclobutrazol is widely used to advance harvest maturity in various fruit crops and it improves fruit quality in terms of accelerated colour development, delayed and synchronized fruit maturation and control of preharvest fruit drop. It is known to improve fruit physical and fruit chemical characteristics. Fruit calcium is increased for 2–3 years due to carry over effect. It helps in the maintenance of better fruit quality during storage and influences nutrient uptake in various fruit crops including stone fruits. It has been characterized as an environmentally stable compound in soil and water environments with a long half-life under both aerobic and anaerobic conditions.

Keywords: fruit set, paclobutrazol, flowering, shoot growth, fruit quality

1. Introduction

One of the most important elements in fruit orchard management is growth control. Excessive vigour reduces light penetration, yield, fruit quality and an increase in cost of pruning and pest control [1]. On the other hand, many cultivars may set very large number of fruits with unacceptably smaller size and often serious reduction in return bloom and fruit set may occur in the following year leading to biennial bearing. About 20–80% of the fruit which initially sets drop-off from the tree during various stages of development. Thus, various plant growth regulators are used for the control of vegetative growth, flowering of young trees, thinning of flowers and fruits, delaying fruit abscission, regulation of fruit ripening and improvement of fruit production and quality in bearing trees [2]. Various chemicals are used in horticulturally advanced countries to reduce the amount of pruning. Among the various growth control chemicals tested, paclobutrazol (PB) is one of the most successful and widely used in fruit trees that can retard tree growth. Besides this, it also increases fruit set the years following application as a carryover effect. Paclobutrazol treatments have also shown to increase Delicious fruit firmness at harvest, [3]. Paclobutrazol, a gibberellins inhibitor, has been effectively used in reducing canopy volume and increasing flower intensity in peach [4], plum [5], almond [6], grapes [7] and mango [8]. Paclobutrazol is effective not only in flower induction but also in early and off season flower induction in mango [9, 10]. Paclobutrazol application in McIntosh apple trees shortly after full bloom affected fruit quality characteristics with respect to accelerated colour development, delayed and synchronised fruit maturation, control of preharvest fruit drop and maintenance of better fruit quality during storage [11]. Sebastian et al. [12] also reported that the foliar application of plant growth regulators improves the yield and quality of fruit crops. However, the action of plant growth regulators (PGRs) is highly specific to plant species, cultivar and stage of development, and strongly dependent on its rate of application and environmental conditions [13].

2. Nature of paclobutrazol

The plant growth regulator, [(2RS, 3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)-pentan-3-ol] (paclobutrazol; PP333) with chemical formula $C_{15}H_{20}ClN_3O$, is a triazole derivative and has been shown to inhibit shoot growth on apple trees [14]. The ancymidol blocks the oxidative steps with high specificity leading from ent-kaurene to ent-kaurenoic acid in the pathway of GA biosynthesis. The same oxidative steps are thought to be inhibited by the active triazol derivatives. Paclobutrazol has been reported to inhibit GA biosynthesis in plants by inhibiting kaurene oxidase, a Cyt P-450 oxidase, thus blocking the oxidation of kaurene to kaurenoic acid [15]. The inhibitory activity of paclobutrazol can be reversed by GA [14]. Besides reducing gibberellins level, PBZ increases cytokinin contents, root activity and C:N ratio, whereas its influence on nutrient uptake lacks consistency [16]. Paclobutrazol was also shown to shift assimilate partitioning from leaves to roots, increase carbohydrates in all parts of apple seedlings, increase chlorophyll content, soluble protein and mineral element concentration in leaf tissue, increase root respiration and reduce water use [17]. Browning et al. [18] investigated the effect of PBZ on the translocation of endogenous IAA (indol-3-acetic acid) in Doyenne du Comice pear cultivar and found that PBZ caused a slower movement of IAA in shoot tips. The usual application of paclobutrazol has been either by foliar spray or soil drenching. With foliar spray applications, absorption through mature leaves was limited and PBZ may be taken up through stem absorption [19] or from excess dripping onto the soil. Elfving and Proctor [20] have reported that protecting the soil from foliar drip reduced the PBZ-induced inhibition of extension growth in apples. When applied to the soil, a continuous supply of PBZ taken up by the roots is translocated acropetally via the xylem, thus maintaining the concentration of PBZ above the threshold required for the inhibition of gibberellins biosynthesis [21], although phloem translocation has also been reported [22].

Paclobutrazol (PBZ), a non-polar broad spectrum growth regulator, has been characterised as an environmentally stable compound in soil and water environments with a long half-life under both aerobic and anaerobic conditions. Moreover, PBZ is unlikely to volatilise to any significant extent owing to a low estimated vapour pressure (1.9×10^{-6} Pa). Paclobutrazol has been registered in 1985 (cultar, ICI Americas, Goldsboro, NC), however it has now been permitted for use on food crops in Australia, New Zealand, South Africa, India, Philippines, Vietnam, Canada, USA (California), Finland, Hungry, Greece, Cyprus, Denmark and Netherlands [23]. In India PBZ has been registered as a plant growth regulator under the Section 9(3) of Insecticides Act, 1968 in November 2009 by Central Insecticides Board & Registration Committee [24] and is available in the market with various trade names.

3. Tree growth and vigour

Paclobutrazol when applied during early summer has been observed as effective suppressant of stem growth in sweet cherry [25]. Young [26] reported that paclobutrazol when sprayed on 'Redhaven' cultivar of peach reduced terminal growth and advanced leaf fall. Webster and his associates [27] observed that application of 1.6 g a.i. tree^{-1} paclobutrazol to cherry trees followed by 0.8 g a. i. paclobutrazol in next year inhibited extension growth of young trees on either colt or FB_{22} rootstocks. Gaash [28] stated that 1000–4000 ppm of paclobutrazol on 'Canino' apricot cultivar decreased the lateral shoot length. Foliar spray of 1000 ppm paclobutrazol to sweet cherry trees suppressed shoot growth and delay in fruit colour [29]. Blanco [30] stated that paclobutrazol decreased the shoot development of 'Crimson Gold' nectarines. Kaska et al. [31] observed that application of paclobutrazol decreased shoot elongation in cherries when applied on the vegetative and reproductive parts. Shoot extension growth was reduced by 57% at stone hardening and by 47.6% at harvest following soil and collar drench of cultar (2.0 g a.i. PP333/tree) applied in autumn in peach cv. Flordaprince [32]. Kuden et al. [33] observed that 250 ppm of paclobutrazol decreased the shoot growth by about 34.1–42.4% in apricot. Leaf chlorophyll of almonds was increased with the application of 50 and 100 ppm paclobutrazol [34]. Arzani and Roosta [35] reported that paclobutrazol significantly reduced vegetative growth in apricot. They also reported that the total pruning dry weight, shoot growth and trunk cross sectional area (TCSA) of treated trees were lower than those of the control. Pant and Kumar [36] reported that the application of different concentrations of paclobutrazol and chloromequat at 250, 500, 1000 and 5000 ppm to 'Red Delicious' apple decreased the extension growth and leaf area of trees. Wani [37] applied paclobutrazol through soil to the basin of tree on trunk diameter basis. The investigation was carried out under two independent experiments. In one experiment, treatments were applied for two years consecutively and in another during first year only in order to assess carryover effect during second year. Application of paclobutrazol decreased yearly increment of tree trunk cross-sectional area, tree spread, volume and internodal length in sweet cherry. Gupta and Bist [38] noticed that soil application of paclobutrazol @ 10 ml/lit on high density pear plantation effectively controlled the excessive and vigorous growth. They also observed that the vegetative growth was inhibited by paclobutrazol. Asin et al. [39] observed that paclobutrazol resulted in shortest shoot length in pear. Sharma and Joolka [40] recorded reduced extension growth, plant height and plant spread with paclobutrazol in nonpareil almond plants. Abdollahi et al. [41] reported that paclobutrazol reduced vegetative growth by reducing both fresh and dry weights of shoots and the leaf area was also significantly decreased in strawberry cv. Selva. Mir et al. [42] reported that paclobutrazol significantly retarded the shoot growth, shoot diameter and trunk cross-sectional of 'Roundel' apricot trees growing under low density planting system. Ashraf et al. [43, 44] revealed that apple trees cv. Red Delicious treated with paclobutrazol @ 750 ppm and summer pruning resulted in minimum vegetative growth and vigour in terms of tree height, trunk diameter, annual shoot extension growth, tree spread and leaf area in comparison to control and other treatments. Reduction in growth is attributed to paclobutrazol, which is a triazol that inhibits gibberellin biosynthesis especially three steps in the oxidation of the GA precursors ent-kaurene to ent-kaurenoic acid [15, 45].

4. Fruit set and yield

Webster et al. [27] reported that application of paclobutrazol @ 1.6 g a.i. tree $^{-1}$ in 'Early Rivers' sweet cherry doubled the floral buds per unit shoot length in 1982 and trebled the number in 1983. Both the number of floral buds per fruiting spur and the number of flowers per floral bud increased by 26.8 and 5.6%, respectively. However, Webster and Quinlan [46] applied paclobutrazol to European plum trees and noticed reduction in yield and this effect was partially alleviated by sprays of 75 mg GA_3 + 10 mg 2, 4, 5-TP at fruit set. Gaash [28] stated that the application of 1000–4000 ppm of paclobutrazol on 'Canino' apricot cultivar increased the yield. Increased number of vegetative and floral buds in 'Flavorcrest' peach was noticed by Martin et al. [47] by the application of 1.32 g a.i. paclobutrazol. Blanco [30] stated that paclobutrazol increased the average fruit size and yield of 'Crimson gold' nectarines. Stan et al. [48] revealed that foliar and soil application of paclobutrazol enhanced the flower bud formation and fruit set in high density planting of sweet cherry, peach and plum. In avocado, paclobutrazol enhanced the fruit set by increasing the partitioning of dry matter to fruits [49]. Kaska et al. [31] observed that application of paclobutrazol decreased flower bud formation in cherries when applied on the vegetative and reproductive parts. Kuden et al. [33] observed that 250 ppm of paclobutrazol increased the number of fruit buds in 'Canino' and 'Precoce de Colomer' apricot cultivars. Jindal and Chandel [50] reported that the application of paclobutrazol increased fruit set in 'Santa Rosa' plum and they further observed that maximum fruit set was observed by the application of 20 ppm TRIA followed by 500 ppm paclobutrazol. Arzani et al. [51] reported that paclobutrazol application advanced flowering of 5-year-old vigorous 'Sundrop' apricot trees by 2–4 days and also increased the fruit set, final fruit number, crop density and yield efficiency. Pant and Ratan [36] reported maximum number of fruit spurs, bloom per branch and yield with cultar @ 1000 ppm in 'Red Delicious' apple. Increased flowering by paclobutrazol application is because of the fact that paclobutrazol acts as inhibitor of gibberellin biosynthesis which changes the sink-source relationship by reallocating carbohydrate to other organs. Davenport [52] reported that more gibberellins were exported from apple fruit to spurs in biennial bearing cultivars than in regular flowering cultivars, concluding that endogenous gibberellins have inhibitory effect on flowering. Increased flowering by application of paclobutrazol was also reported by Wani [37] in sweet cherry and Pant and Ratan [36] in 'Red Delicious' apple. Application of paclobutrazol initiates flowering in fruit plants by the decrease of gibberellins levels and increase of auxins and cytokinins levels in shoot tip [53]. They also observed that flowering date was advanced slightly with application of paclobutrazol. Similar results were recorded by [8, 54–57] in mango. Carreno et al. [58] reported that the application of paclobutrazol before blooming increased fruit set in grapes. The higher fruit set by paclobutrazol application may be attributed to increased partitioning of dry matter to fruits [49]. Abdel Rahim et al. [54] observed that paclobutrazol application advanced off season flowering of regular bearing mango cultivars, Baladi Abu Zaid (26.7%) and Baladi Burai (30.7%) by almost 60 and 70 days, respectively, as compared to the control. They also reported that the flowering percentage in the paclobutrazol treated trees were 50%, and 100% at 60, and 90 days, respectively for all tested cultivars. Similar results on the positive effects of paclobutrazol on mango flowering were reported in many tropical and subtropical regions of the world [16, 55]. Ashraf et al. [43, 44] reported that the highest yield of 101.0 kg tree^{-1} was obtained in treatment 750 ppm paclobutrazol +2 summer prunings in comparison to control in Red Delicious apples. Paclobutrazol (80 ml/tree) produced earlier flowers (125.79 days) with respect to panicle emergence in mango cv. Alphonso compared to control (165.04 days) [59]. Paclobutrazol is effective in enhancing the yield of several horticultural crops as it inhibits gibberellic acid (GA) biosynthesis which changes the sink-source relationship by reallocating carbohydrate to other organs [53]. Huang et al. [60] reported that soil application of paclobutrazol twice during the year 1989 and 1991 in spring at 1.5 g a.i and 0.75 g a.i., respectively increased the yield efficiency twice than control in apple cultivar 'Aki Fuji' (with average fruit yield of 26.25 kg tree^{-1} compared with 13.95 kg tree^{-1}) which might be due to increased respiration or activation of enzymes or growth promoting substances. Kumar et al. [61] reported that the application of paclobutrazol at 1.0 g in October enhances yield and quality in mango.

5. Return bloom

George and Nissen [62] observed that the return bloom was increased in peach in the subsequent season of paclobutrazol application which may result in a large number of small fruit if a large percentage of flowers set. Asin et al. [63] observed that paclobutrazol and root pruning increased return bloom and yield in 'Blanquilla' pear. Asin et al. [39] reported that foliar application of paclobutrazol resulted in highest return bloom in 'Blanquilla' pear. Wani et al. [64] observed that the soil application of paclobutrazol increased the return bloom significantly in Red Delicious apples. Bill [65] noticed that paclobutrazol application increased the average number of flowers per shoot compared to the control in the 2010–2011 seasons. Flower numbers also increased linearly with an increase in paclobutrazol application rate and noticed that paclobutrazol application increased the return bloom. Application of paclobutrazol initiates flowering in fruit plants by the decrease of gibberellins levels and increase of auxins and cytokinins levels in shoot tip. An increase in return bloom is a common response to paclobutrazol treatment and its application has a carryover effect on return bloom as well which has been reported for various fruit crops, such as peach [66], apple [67] and mango [10].

6. Fruit physical characteristics

Paclobutrazol (PBZ), one such GA inhibitor, is widely used to advance harvest maturity in various fruit crops including mango [68], peach [62] and persimmon [69]. Delayed fruit maturation and increased fruit weight was found in peach by the application of paclobutrazol [70]. Webster et al. [27] reported that application of 1.8 g a.i paclobutrazol per tree of 'Early Rivers' cherry applied at full bloom stage increased the fruit weight. Looney and Mckeller [29] observed that application of 1.15 g paclobutrazol per tree increased weight of individual cherry fruits in the year of application and for the following 3 years. Martin et al. [47] reported that application of paclobutrazol @ 0.5, 0.75, 1.0 and 2.0 kg ha^{-1} in 'Flavorcrest' peach increased the size of fruits significantly than control. Blanco [30] stated that paclobutrazol increased the average fruit size of 'Crimson gold' nectarines. Blanco [71] noticed that 2 g a.i. paclobutrazol dissolved in 1 litre of water and pouring the solution around the trunk of 'Crimson Gold' nectarine tree increased the weight of fruit though not significantly. Jindal and Chandel [50] applied paclobutrazol in ‘Santa Rosa’ plum at 125, 250 and 500 ppm once at full bloom and again at pit hardening stage and reported maximum fruit weight of 24.33 g and fruit volume of 21.6 cc in fruits treated with 500 ppm of paclobutrazol. In persimmons, soil drench application of paclobutrazol accelerated ripening by 2–3 weeks [69]. The increase in fruit length and breadth was due to the reason that application of paclobutrazol reduced vegetative growth (sinks) which in turn, increased the partitioning of nutrients and dry matter towards fruits and thereby, increased the fruit size and weight [49]. Greene [72] reported that foliar application of paclobutrazol to Delicious apples produced fruits with higher flesh and less bitter pit, cork spot and senescence breakdown. Wani [37] reported that fruit acidity, vitamin C, percentage of bruised fruits, incidence of pitting and fruit cracking were reduced by the application of paclobutrazol in sweet cherry. Also, the organoleptic rating, total soluble solids, reducing sugars, total sugars and anthocyanin were increased. Pant and Ratan [36] studied the influence of different concentrations of paclobutrazol and chloromequat at 250, 500, 1000 and 5000 ppm on quality of apple cv. Red Delicious and observed that fruit weight and firmness was increased with both growth retardants. In contrast, in strawberries paclobutrazol application rate had no significant effect on fruit firmness [73]. Carreno et al. [58] found that grape berry size increased linearly with an increase in paclobutrazol application rate. Ashraf et al. [43, 44] observed that treatment 750 ppm paclobutrazol +2 summer prunings resulted in significantly improved fruit size (53.15 cm), weight (188.19 g), volume (188.12 cm^3), colour change (3.40 score), firmness (11.98 kg cm^{-2}), organoleptic rating in terms of taste (3.14 score), texture (3.24 score), flavour (3.12 score) and total soluble solids (14.47°B) whereas acidity (0.23%) was reduced in comparison to control and other treatments during both the years in apple cv. Red Delicious. The improvement in organoleptic rating of fruits may be attributed to the fact that more metabolites were translocated to the fruits in treated trees with paclobutrazol.

7. Fruit colour

Application of paclobutrazol @ 0.33, 0.50, 0.66 and 1.32 g a.i. as soil application to ‘Flavorcrest’ peach hastened the fruit colour than control [47]. Looney and Mckeller [29] reported that paclobutrazol either sprayed once with 1000 ppm or twice with 500 ppm concentration to ‘Lambert’ cherry displayed less red colour as indicated by juice anthocyanin concentration or by visual rating of skin colour and 500 mg l^{-1} paclobutrazol within 5 weeks after full bloom to ‘Mclntosh’ apples gave high percentage of fruit with acceptable red colour at harvest [74]. Santa Rosa plum trees treated with 500 ppm paclobutrazol once at full bloom and repeated at pit hardening stage recorded maximum anthocyanin content (0.299 OD units) which was significantly higher than control [50]. Wani [37] observed that fruit colour was enhanced by the application of paclobutrazol in sweet cherry. Continuous application of paclobutrazol significantly reduces vegetative growth characters of the trees, thereby exposing fruits to direct sunlight which significantly increased red colouration of the fruits. The soil application of paclobutrazol in ‘Red Delicious’ apple fruits increased the fruit anthocyanin by the increasing dose of paclobutrazol [64].

8. Fruit chemical characteristics

Jindal and Chandel [50] observed that application of 500 ppm paclobutrazol to Santa Rosa plum in two successive years increased total sugars significantly from 5.46 to 6.71% in first year and 6.18 to 7.15% in next year. Similarly, reducing sugars also increased to 4.76 and 5.25% respectively, which was significantly higher than control and recorded an average of 3.94 and 4.50% reducing sugars. Also, least acid contents of 2.14 and 3.35% were observed than control which recorded average acid content of 2.45 and 3.13%, respectively. Wani [37] reported that fruit acidity, vitamin C, percentage of bruised fruits, incidence of pitting and fruit cracking were reduced by the application of paclobutrazol in sweet cherry. Also, the organoleptic rating, total soluble solids, reducing sugars, total sugars and anthocyanin were increased. Wani et al. [64] observed that the soil application of paclobutrazol decreased the acidity and ascorbic acid of 'Red Delicious' apple fruits. Also, the fruit total soluble solids, organoleptic rating and fruit calcium was increased by the increasing dose of paclobutrazol. Similar findings were noticed by Sarker et al. [75] in mango. Paclobutrazol application reduced the number of shoots, transforming trees into a more desirable, spur type growth habit and as the vegetative sink was reduced, transport of nutrients including calcium towards fruits was enhanced [72]. Higher uptake of Ca and its relocation to fruits could be attributed to significantly reduced rate of leaf transpiration, thus could favour the supply of Ca towards the fruit [76]. Fruit calcium is increased for 2–3 years due to carry over effect. Andres et al. [77] observed that the acidity content of fruits diminished as a result of the ripening process and the mango fruits treated with paclobutrazol and KNO_3 showed the lowest values for acidity. Ashraf et al. [78] reported that with increase in paclobutrazol concentration and pruning levels, an increase in TSS, TSS/acid ratio, anthocyanin, sugars, fruit calcium and improvement in fruit grade was observed with decrease in fruit acidity in Red Delicious apples. This increased total soluble solids was due to increased sucrose, starch and sugar levels due to reduced vegetative growth and thus the absence of other potentially competitive actively growing sinks which resulted in more nutrient partitioning to fruits [54]. The increased rate of photosynthesis led by more light penetration into the interior tree canopy, increased the soluble solids in fruits harvested from pruned trees. These findings are in conformity with the findings of Kumar et al. [61] in mango.

9. Fruit storage behaviour

Wolstenholme et al. [49] reported that the application of paclobutrazol increased the partitioning of nutrients and dry matter towards fruits and thereby, increased the fruit size and weight. This increase in weight reduced the physiological loss in weight of fruits during storage period. The differences in storage performance may be due to ethylene production, responsible for the changes in texture and firmness and fruit softening [79]. Elfving et al. [80] observed that the fruits of McIntosh apple treated with diaminozide and paclobutrazol and stored for 24 weeks were firmer and displayed less core browning than untreated ones. Elfving et al. [74] reported that foliar application of 500 mg l^{-1} paclobutrazol in McIntosh apples reduced flesh firmness loss and reduced post storage ethylene production in one season. Later applications at 5 and 9 weeks after full bloom affected stem cavity browning with increase in brown core. This may be attributed to reduction in ethylene evolution during storage which induced delay in respiratory climacteric after harvest and storage thereby, the loss in firmness was decreased [81]. The fruit flesh was firm due to retardation in ripening. Several physiological disorders and diseases of apple fruit during storage are related to the calcium content of fruit [82]. Calcium deficiency results in economic losses in fruit. It helps in regulation of metabolism in apple fruit and adequate concentrations maintain fruit flesh firmness and minimise the incidence of physiological disorders like water core, bitter pit and internal breakdown [83]. The increase in calcium generally delays the ripening of the fruit and maintains their quality during prolonged storage. Fruit calcium is increased for 2–3 years due to carry over effect by paclobutrazol application. This increase in fruit calcium reduced bitter pit, cork spot, senescent breakdown so, spoilage of fruits was reduced which in turn enhanced storage life of fruits [17]. Our findings are in conformity with the findings of Wani [37] in sweet cherry and Wani et al. [64] in 'Red Delicious' apple. Paclobutrazol application reduced the number of shoots, transforming trees into a more desirable, spur type growth habit and as the vegetative sink was reduced, transport of nutrients including calcium towards fruits was enhanced.

10. Nutrient uptake

Paclobutrazol application influences the leaf nutrient status of various temperate fruit crops:

Nitrogen: Paclobutrazol application reduced foliar N concentration in Nemaguard [84], Flordaprince [85], Flordaprince and Flordagold peach cultivars [86] and Red Spur Delicious and Vance Delicious apples [87]. However, Sharma and Joolka [40] recorded reduced leaf N content with paclobutrazol in nonpareil almond plants.

Phosphorus: Paclobutrazol application reduced foliar P concentration in Nemaguard [84], Flordaprince [85], Flordaprince and Flordagold peach cultivars [86] and Red Spur Delicious and Vance Delicious apples [87]. Increased foliar P concentration in apple plants treated with PP333 has been reported by Curry [88]. However, Sharma and Joolka [40] recorded reduced leaf P content with paclobutrazol in nonpareil almond plants.

Potassium: Paclobutrazol application reduced foliar K contents in Nemaguard [84], Flordaprince peach [85], stone fruits [89], Red Spur Delicious and Vance Delicious [87]. Contrary to this, Swietlik and Miller [90] observed increase in K uptake with the addition of 0.2 ppm PP333 to a nutrient solution in which 11 month old apple seedlings were grown. However, Sharma and Joolka [40] recorded reduced leaf K content with paclobutrazol in nonpareil almond plants.

Calcium: Increased concentration of foliar Ca with paclobutrazol application was observed in Nemaguard [84], Flordaprince [85], Flordaprince and Flordagold peach cultivars [86] and Red Spur Delicious and Vance Delicious apples [87]. Similar observations regarding the increase in foliar Ca concentrations in various apple cultivars were made by Bonomo et al. [91]. Swietlik and Miller [92] further reported that Ca content in Golden Delicious increased in proportion to the increasing doses of PP333. Sharma and Joolka [40] also recorded increased leaf Ca content with paclobutrazol in nonpareil almond plants.

Magnesium: Foliar Mg content has been reported to increase with paclobutrazol application in Nemaguard [84], Flordaprince [85], Flordaprince and Flordagold peach cultivars [86], Red Spur Delicious and Vance Delicious apples [87] and apple plants [91]. But Curry [88] found reduced levels of foliar Mg in apple plants treated with PP333. However, Sharma and Joolka [40] also recorded increased leaf Mg content with paclobutrazol in nonpareil almond plants.

11. Conclusion

Paclobutrazol (PP333) has been effectively used to manipulate tree vigour in several perennial fruit crops. Paclobutrazol application reduces the amount of pruning which requires skilled labour and is time consuming and costly.

Paclobutrazol is effective not only in flower induction but also in early and off season flower induction which thereby maintains regularity and synchronisation in flowering. Paclobutrazol application affected fruit yield, quality characteristics and helps in maintenance of better fruit quality during storage. It influences the nutrient uptake in various fruit crops. Paclobutrazol was also shown to shift assimilate partitioning from leaves to roots, increase carbohydrates in all parts of fruit seedlings which enhances cold hardiness during winter periods. It increases chlorophyll content, soluble protein and mineral element concentration in leaf tissue which result in compact darker leaves. It also increases root respiration and reduce water use hence such trees are suitable under drought conditions.

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