A review on: Paclobutrazol a boon for fruit crop production

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Abstract
The ability of the crops to produce fruits throughout the year is of great interest in recent years. The biennial bearing is a very serious problem in fruit crop production. Therefore, application of paclobutrazol is most widely studied in view of its high potential for controlling plant growth and development of fruit crops in general. Usually it is applied as a soil application in the month of September-November in case of mango. It inhibits gibberellin biosynthesis at kaurene stage and has proved to be a reduction of vegetative growth, promising for flower initiation in shoot bud, giving early and profuse flowering, increases fruit yield and improving quality regularly in alternate bearing cultivars. The main aim of this review is to focus upon contemporary information about paclobutrazol in fruit production.

Keywords: Paclobutrazol, PBZ

Introduction
Plant growth retardants are being used widely in chemical manipulation of growth and development by modifying associated biochemical and physiological processes. Among them, paclobutrazol is considered as one of the most versatile plant growth retardant which restricts vegetative growth and induce flowering in many fruit crops like apple and pear (Williams and Edgerton, 1983) [66], peach (Erez, 1984) [12], citrus (Aron et al., 1985) [4] and mango (Sarkar and Rahim, 2012) [48]. It restricts induced tree vigour and flowering responses which have been reported as the consequences of modifications in physiological activities as well as changes in cellular metabolites (Upeti et al., 2014) [63]. Among the cellular metabolites, accumulation of phenols in vegetative organs and altered biochemical balance are important in restriction of vigour in mango (Murti et al., 2000) [33] and also induction of flowering (Patil et al., 1992) [37]. Paclobutrazol (PBZ) is a triazole derivative with the empirical formula \((2RS, 3Rs)\) \(\text{C}_2\text{H}_2\text{O}_2\text{N}_3\text{C}_10\text{H}_9\text{N}_3\text{O}_2\) - (4-chlorophenyl) 4.4-dimethyl-2- \((1H-1, 2, 4\text{-triazole-1-yl})\) pentan-3-ol, which plays an important role in regulating excessive vegetative growth, enhancing and advancing flowering, inducing early bearing, managing biennial bearing tendency, establishing a high density plantation. The application of paclobutrazol to soil promotes flowering and increasing yield in many fruit crops. Besides decreasing gibberellins level, paclobutrazol increases cytokinin contents, root activity and C: N ratio, whereas its influence on nutrient uptake lacks consistency. It also affects microbial population and dehydrogenase activity in soil.

PBZ has been characterized as an environmentally stable compound in soil and water environments with a half-life of more than a year under both aerobic and anaerobic conditions. However, when it is applied in optimized rate the residual concentration detected will not be above quantifiable level (0.01 ppm) in soils and fruits.

Mode of action
Paclobutrazol inhibits gibberellins biosynthesis by blocking the conversion of kaurene and kaurenolic acid, which inhibits cell elongation and internode extension and ultimately retards plant growth. Gibberellins stimulate cell elongation. When gibberellin production is inhibited, cell division still occurs, but the new cells do not elongate. That result in the production of shoots with the same numbers of leaves and internodes compressed into a shorter length. Even reduction in the diameter of the trunk is noticed. Paclobutrazol treated trees show increased production of the hormone abscisic acid and the chlorophyll component phytol, which are beneficial to tree growth and health. It also induce morphological modifications of leaves, such as smaller stomatal pores, increased number and size of surface appendages, thicker leaves, and increased root density that may provide improved environmental stress tolerance and disease resistance and it also has some fungicidal activity due to its capacity as a triazole to inhibit sterol biosynthesis (Chaney, 2005) [11].
Translocation of PBZ in plant
PBZ is applied as a soil drench (application to roots, more popular and convenient) through trunk injection (directly to the vascular system of the stem using pressure). Through xylem it translocate to other parts of plant, however a few research evidences have been provided to support this assumption. Gas chromatography-mass spectrometry confirmed that PBZ was taken up by roots and transported primarily through xylem to stems and accumulated in leaves.

Effects of PBZ on various tree attributes
In tropical fruit orchards, it is desirable to control the vegetative growth and to reduce the canopy size since small trees capture and convert the sunlight into fruit biomass in a better way than larger trees because of more surface area. Increase in production with enhanced fruit quality can be achieved by managing the tree canopy. Manipulation in tree physiology with the use of chemical growth retardants has been considered as an important determinant of productivity enhancement in many fruit crops. Application of paclobutrazol in the soil has been commercialized for early and enhanced flowering in some of the fruit crops.

Effect on vegetative growth
Many investigations have revealed the beneficial effects of PBZ in restricting vegetative growth and successful induction of flowering in apple, mango, grape etc. The application of paclobutrazol (1500 to 3000 ppm) at full bloom and 21 days after full bloom resulted in the reduction of shoot growth in ‘Golden Delicious’ apple (Greene, 1982) [15]. Quinlan and Richardson (1984) [41] inferred that application of paclobutrazol at 500 ppm alone was effective in reducing the shoot length (9.5 cm) and the combination with GA3 was not effective in apple seedlings. Five-year-old MM.106 (Malus domestica Borkh.) trees growing under a high-density (10000 trees/ha) planting system treated with paclobutrazol at 250 mg per tree in August by Khurshid et al., 1997 [24] showed reduced number of total shoots and buds. This showed that PBZ can be used to manipulate apple tree growth in a high-density apple production system.

Paclobutrazol when applied during early summer has been observed as an effective suppressant of stem growth in sweet cherry (Quinlan and Webster, 1982) [42]. Similarly, Webster et al. (1986) [65] reported that application of paclobutrazol at 1.6 g a.i. tree-1 and followed by 0.8 g a.i. in next year inhibited extension of growth in young cherry trees on either colt or FB22 rootstocks. 2-year-old nashi trees treated with paclobutrazol as soil drench and foliar sprays (Klinac et al., 1991) [25]. The cultivars treated were ‘Hosui’, ‘Kosui’, ‘Nijisseiki’, and ‘Shinsui’. All cultivars showed a significant reduction in vegetative growth within the first season and for up to 4 years after initial application. Most reduction in growth was obtained from soil applications. Least reduction in growth was from a foliar application at the lower rate of 125ppm.

Application of paclobutrazol on ‘Redhaven’ cultivar of peach reduced terminal growth and advanced leaf fall (Young, 1983) [69]. Similarly, the vigour of mango was consistently reduced with paclobutrazol application in a range of Indian cultivars (Kulkarni, 1988) [26]. The soil drenching with paclobutrazol at the rates of 12, 10, and 8 g a.i. suppressed the vegetative growth, canopy volume, and flush length of reproductive shoots, fruit setting, panicle length as compared to control in mango (Nafeez et al., 2010) [34]. Similar results were observed by Teferi et al. (2010) [61] in Tommy Atkins mango with maximum effect at 8.25 g a.i. per tree.

Soil application of paclobutrazol recorded significant reduction in canopy volume by noticeable reduction in number of shoots per terminal and also checked the growth of new shoots (Tandel and Patel, 2011) [60]. Similarly, the growth inhibitory response of PBZ reported in different varieties of mango (Sarkar and Rahim, 2012) [48] could be the consequences of modification in photosynthesis rate (Gonzalez and Blaikie, 2003) [14] and carbohydrates (Upreti et al., 2014) [63] besides reductions in gibberellins (Upreti et al., 2013) [62].

PBZ effect on flowering parameters and yield
The fruit set was increased in paclobutrazol treated trees @ 1500 and 3000 ppm due to an increase in initial fruit set in delicious apple (Greene, 1986) similar results was observed by Elflying et al. (1990) [11] in McIntosh apples that the foliar application of paclobutrazol reduced pre harvest drop when applied within 5 weeks after full bloom. Stan et al. (1989) [57] reported that foliar and soil application of paclobutrazol enhanced the flower bud formation and fruit set in high density planting of sweet cherry. In avocado, paclobutrazol enhanced the fruit set by increasing the portioning of dry matter to fruits (Wolsstenholme et al., 1990) [67]. Jindal and Chandle (1996) [26] 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 paclobutrazol.

Matra and Bist (1997) [45] reported that application of 0.15 g a.i. paclobutrazol cm-1 trunk diameter increased fruit yield of ‘Gala’ pear and during the next year, yield was significantly increased with the same application. They also noticed that paclobutrazol 0.3 g a.i. cm-1 trunk diameter increased the yield by more than 1.35 times during both the years. Arzani et al. (2000) [5] reported that paclobutrazol application advanced flowering of five year old vigorous ‘Sundrop’ apricot trees by 2-4 days and also increased the fruit set, final fruit number, crop density and yield efficiency. Selva strawberry cultivar using paclobutrazol (0,100 mg/l) and other nutrient combination indicated that vegetative growth was reduced with application of paclobutrazol and highest vitamin C was obtained at concentration of 0.100 mg l-1 PP333 (Abdollahi et al., 2010) [3]. Kulkarni (1988) [26] observed that there was a significant increase in yield of mango per tree by the soil application of paclobutrazol (10 g a.i./tree). In terms of fruit size and quality for at least two years in five years old bearing trees.

Effect of PBZ on promotion of flowering in citrus was studied by Fuentes et al. (2013) and result revealed that PBZ significantly increased the percentage of sprouted buds and leafless floral shoots (both single flowered shoots and inflorescence) and reduced the number of vegetative shoots. The application of paclobutrazol at 1 g a.i./m of canopy diameter increased the female inflorescence production (18.10%) without negative effect on fruit set (90.68%) in ‘Evacar Sweet’ cv. of jackfruit. Female inflorescences were produced in the off-season (August and September) which was not observed in untreated trees. (Lina and Protacio, 2015) [29]. Among the chemicals suggested, paclobutrazol is considered as one of the most versatile plant growth retardant which restricted vegetative growth and induced flowering in many fruit crops like apple and pear (Williams and Edgerton, 1983) [66], peach (Erez, 1984) [12], citrus (Aron et al., 1985) [42] and
mango (Sarkar and Rahim, 2012) [48]. Early and intense flowering induced by PBZ may be the consequence of early shoot maturity and increased photosynthesis rate (Singh and Singh 2003) [55], carbohydrate accumulation (Abdel Rahim et al., 2011) [2] and decline in flowering reducing hormone, gibberellins (Upreti et al., 2013) [62].

The effects of PBZ on different flowering parameters such as regular, profuse and early flowering (Kulkarni, 1988; Nartvanranant et al., 2000; Jogande and Choudary, 2001; Karki and Dhakal, 2003; Yeshila et al., 2004; Blaikie et al., 2004; Singh and Ranganath, 2006; Reddy and Kurian, 2008; Hussen et al., 2012; Reddy et al., 2014) [26, 35, 21, 23, 68, 9, 51, 47, 17, 46], reduced panicle length (Vijayalaksmi and Srinivasan, 2000; Hoda et al., 2001; Nafeez et al., 2010; Sarkar and Rahim, 2012) [64, 16, 34, 48], increased the number of perfect flowers and fruit set (Burondkar and Gunjate, 1993; Kurian and Iyer, 1993; Hoda et al., 2001; Singh et al., 2000) [10, 28, 16, 56] were reported in various fruit crops.

All the available evidences opined that carbohydrate reserves played an important role in flower bud differentiation and they provide conditions favorable for the synthesis of substances which are required for flower bud differentiation (Suryanarayana, 1987; Pongboon et al., 1997) [59, 39]. The high C: N ratio during flower bud differentiation was ascribed to the increased carbohydrate availability (Ito et al., 2004) [18] and is considered as an important factor in regulation of flowering in fruit crops (Jyothi et al., 2000; Palanichamy et al., 2012) [22, 36]. Paclobutrazol is known to decrease vegetative growth rate through early cessation of growth, which results in the accumulation of carbohydrates in trees and slightly decreasing the total nitrogen in the terminal shoots, which favours flowering by maintaining high C: N ratio in the shoots. The C: N ratio differs with growth of shoots in the varieties revealing its dependence on environmental conditions and prevailing metabolic balance. The paclobutrazol induced enhancement in C: N ratio has been reported in mango (Subhadrabhandu et al., 1997; Protacio et al., 2000; Abdel Rahim et al., 2011, Rakshe and Nigade, 2013; Upreti et al., 2013; Upreti et al., 2014) [39, 40, 2, 43, 62, 63] and in pummelo (Phadung et al., 2011) [38]. Distinct differences in carbohydrate pattern are seen in vegetatively growing shoots and flowering shoots. Shoots that are going to differentiate into flower buds are the growing sinks and the actively dividing cells of induced flower buds require high energy (Davenport, 2007). Apparent increase in sugar levels during floral induction period has been reported in mango by several researchers (Jyothi et al., 2000; Abdel Rahim et al., 2008; Palanichamy et al., 2012) [22, 2, 36]. Consistently higher production of total sugars and reducing sugars with peak availability at bud burst in apical buds of paclobutrazol treated trees is reported in mango (Shivu Prasad et al., 2014; Upreti et al., 2014) [50, 63]. Paclobutrazol induced increase in soluble sugars at flowering has also been reported in mango (Abdel Rahim et al., 2011) [2].

Among the cellular metabolites, accumulation of phenols in vegetative organs has been depicted as one of the important in imparting of vigour restriction effects in mango (Murti et al., 2001; Murti and Upreti, 2003) [31, 33] and also for induction in flowering (Patil et al., 1992) [37]. The possible mechanism by which phenols exert its effects on tree vigour and regulation of flowering in mango are less understood. However, steady increase in phenol content with advancement of flowering bud differentiation has been reported in mango by Palanichamy et al. (2012) [56] and Kumar et al. (2014) [27]. The paclobutrazol induced tree vigour restriction and flowering responses have been reported as the consequences of changes in cellular metabolites (Abdel Rahim et al., 2011; Upreti et al., 2013) [2]. High phenol content in terminal buds due to paclobutrazol application restricted the vigour and enhanced the flowering has also been reported by Kurian and Iyer (1993) [28].

**PBZ effect on fruit quality**

Fruit quality improvement with respect to pulp content, TSS, TSS to acid ratio, total sugars and reducing sugars in response to PBZ application can be related to the assimilate partitioning in plant. The greater suppression of vegetative growth causes assimilates demand in unidirectional manner to the developing fruit, resulting in high quality fruits from PBZ treated plants.

Application of paclobutrazol @ 0.33, 0.50, 0.66 and 1.32 g a.i. as soil application to ‘Flavorest’ peach hastened the fruit colour than control (Martin et al., 1987) [30]. Similarly, application of 500 mg l−1 paclobutrazol sprayed within 5 weeks after full bloom to ‘McIntosh’ apples gave high percentage of fruit with acceptable red color at harvest (Elfying et al., 1990) [11]. Singh and Dillon (1992) reported that soil application of PBZ to Dashehari mango recorded higher fruit yield and high TSS: acid ratio compared to foliar application, while fruit weight: stone and pulp: stone ratio did not differ significantly. Vijayalaxmi and Srinivasan (2000) [64] in an experiment with 10 years old Alphonso mango trees treated with paclobutrazol (10 ml), KNO3 (1%,) urea (1%), ethrel (200 ppm), NAA (20 ppm) and meipiquat chloride (500 ppm) found that among all the treatments, paclobutrazol (10 ml) resulted in increased ascorbic acid content, total sugars and reducing sugars, TSS, acidity and sugar: acid ratio in harvested fruits.

A significant improvement in the fruit quality of cv. Langra in terms of total soluble solids (TSS), total acidity, total chlorophyll, total carotenoids and α-amylase activity due to paclobutrazol @ 6 g a.i./tree in comparison to control was reported by Singh and Saini (2001) [54]. Further they evaluated the efficacy of soil applied paclobutrazol (2, 4, 6 and 8 g a.i./tree) on Langra cultivar of mango for three consecutive years at Lucknow and reported a significant increase in fruit set, fruit retention per panicle and yield per tree due to PBZ @ 6 g a.i./tree. Saxena et al. (2013) [49] reported that paclobutrazol, a flower inducing chemical, enhanced the catalase and peroxidase activities over the untreated control and maximum enhancement was recorded at 8 g a.i. The decreasing trend of protein with paclobutrazol treatment was recorded in adjacent leaves of flower buds. The results implicated the possible role of catalase and peroxidase and other associated biochemical changes in paclobutrazol induced flowering in mango.

The soil drenching of paclobutrazol at 3.0 ml m−1 canopy diameter to the mango cv. Totapuri was done in order to study the role of carbohydrates in the paclobutrazol induced floral initiation by Upreti et al. (2014) [63]. The results indicated that paclobutrazol induced flowering was accompanied by an increase in starch in leaf concomitant with increased insoluble sugars like sucrose, glucose and fructose in apical buds as well as inhibition in the amylase activity in association with increase in the activities of acid invertase, sucorse phosphate synthase and sucrose synthase in the apical buds. Similarly in CO 2 papaya (dioecious) there was increase in amino acids, total carotenoids, TSS, sugars, ascorbic acid and sugar:acid ratio as compared to control, the response being linear with the increasing concentrations PP333 as soil drench at two levels viz., 25 and 50 mg a.i./plant (Auxcilia et al., 2010) [6].
The improvement in fruit quality parameters such as high edible portion, longer shelf life, higher TSS, increased vitamin C, lower titratable acidity, high dry matter content and high reducing and total sugars with PBZ was reported by Vijayalakshmi and Srinivasan (2000) [69], Hoda et al. (2001) [16], Bamini et al. (2009) [6], Sarkar and Rahim (2012) [48] and Reddy et al. (2014) [46] in different varieties of mango. An increase in the contents of ascobic acid and carotenoids which are documented as potential antioxidants with PBZ application has also been reported in mango (Reddy et al., 2014) [46], papaya (Auxcilia et al., 2010) [6], guava (Jain and Dashora, 2011) [19]. However, non-significant effect on fruit quality with PBZ application was reported by Tandel and Patel (2011) [60] and Upeti et al. (2013) [62].

**Effects on physiological attributes**

**Effect on leaf water potential (Ψw)**
The PBZ induced increase in Ψw is speculated as the result of increased root hydraulic conductivity, reduced transpiration and increased ABA levels. Increased ABA reduces the transpirational losses by inducing stomatal closure (Hauser et al., 1990). As ABA is known to induce stomatal closure, and is expected to reduce the water loss through transpiration. The increased water levels due increased ABA are expected to induce bud dormancy which could be of relevance to flower bud differentiation in mango (Abdel Rahim et al., 2011; Upeti et al., 2013; Murti et al., 2001) [2, 62, 32].

**Influence of nureint uptake**
Werner (1993) reported that, cultar treated mango trees showed an increase in N, Ca, Mn, Zn and B contents and decreased contents of P, K and Cu. On the other hand, the significant increase in the root activity to the trunk and close to soil surface and sparser root activity in the subsoil zone and in drip line area in paclobutrazol treated mango plants was observed by Kotur (2006). Paclobutrazol also promotes the avoidance of salt stress in mango by increasing the levels of photosynthetic pigments, water content, K+ uptake and uptake of harmful Na+ and Cl- ions (Kishor et al., 2015).

**Efficacy of paclobutrazol on reduction of tree canopy**
Garcia (2014) opined that the efficacy of cultar in terms of shoot growth and production efficiency depends on the time of pruning. Ram et al., (2005) [44] observed reduction in tree height, shoot length, shoot girth and intermodal length when paclobutrazol (12 and 16 ml) applied with pruning (4 or 5 m height) of mango cv. Dashehari trees. Singh et al., (2005) [52] reported that paclobutrazol as soil drenched reduced tree height, shoot length, tree spread and panicle size in mango cv Dashehari.

**Regulation of flowering in off season**
Soil application of paclobutrazol at 5 g/tree was most effective to induce more number of flowering shoots in mango cv. Gulab Khas (Singh and Singh, 2006) [53]. Similar reports were obtained by Bagel et al., (2004) in 10-year-old mango cv. Langra trees. Soil application of Cultar promoted flowering, along with cauliflower and axillary flowering (Singh et al., 2000) [56].

**Degradation and persistences in orchard soil**
Reddy and Kurian (2008) [47] also observed residual influence of PBZ in soil if applied continuously for three consecutive years and suggested discontinuation of application or to taper down its dose. Singh (2005) [52] also detected paclobutrazol residue below permissible limit (0.4898-1.0005 μg/g) in the rhizosphere after two years of application.

**Conclusions**
Paclobutrazol is a growth inhibitor and also belong to triazol group. It inhibit the biosynthesis of GA; at kaurense stage and it is most commonly used for the induction of flowering in off season, control tree vigour for HDP (canopy managment), increase fruit set and yield, improve fruit quality when applied to the soil. Studies aiming to adjust the amount of application dose of paclobutrazol to each crops will allow the formulation of recommendations for more efficient applications, which can not only provide quality fruit production throughout the year but also reduce the risk of residues in orchard soil, tree, fruit and environment.

**References**


