Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(3): 2686-2691
Received: 10-03-2019
Accepted: 12-04-2019

**Gollagi SG**
Department of Crop Physiology, University of Horticultural Sciences, Bagalkot, Karnataka, India

**Jasmitha BG**
Department of Fruit Science, University of Horticultural Sciences, Bagalkot, Karnataka, India

**Sreekanth HS**
Department of Fruit Science, University of Horticultural Sciences, Bagalkot, Karnataka, India

**Correspondence**
**Gollagi SG**
Department of Crop Physiology, University of Horticultural Sciences, Bagalkot, Karnataka, India

# A review on: Paclobutrazol a boon for fruit crop production

**Gollagi SG, Jasmitha BG and Sreekanth HS**

**Abstract**
The ability of the crops to produce fruits throughout year is of great interest in recent years. The biennial bearing is 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 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 (Upreti *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) -1 - (4-chlorophenyl) 4.4-dimethyl-2- (1H-1, 2, 4-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 reducing 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 kaurenoic 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 shows 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 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 $GA_3$ 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.

Paclobutrzol 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 $FB_{22}$ 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 tress @ 1500 and 3000 ppm due to an increase in initial fruit set in delicious apple (Greene, 1986) similar results was observed by Elfying *et al.* (1990) [11] in McInthosh 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 (Wolstenholme *et al.*, 1990) [67]. Jindal and Chandel (1996) [20] 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.

Ratna 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 mgl$^{-1}$) and other nutrient combination indicated that vegetative growth was reduced with application of paclobutrazol and highest vitamin C was obtained at concentration of0-100 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 'Eviarc Sweet' *cv*. of jackfruit. Female inflorescences were produced in the offseason (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) [4] 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; Nartvaranant *et al*., 2000; Jogande and Choudary, 2001; Karki and Dhakal, 2003; Yeshitela *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; Pongomboon *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 (Subhadrabandhu *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 flower bud differentiation has been reported in mango by Palanichamy *et al.* (2012) [36] 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, 62]. 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. Vijaylaxmi and Srinivasan (2000) [64] in an experiment with 10 years old Alphonso mango trees treated with paclobutrazol (10 ml), $KNO_3$ (1%), urea (1%), ethrel (200 ppm), NAA (20 ppm) or mepiquat 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, sucrose 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 titrable acidity, high dry matter content and high reducing and total sugars with PBZ was reported by Vijaylakshmi and Srinivasan (2000) [64], Hoda *et al.* (2001) [16], Bamini *et al.* (2009) [8], Sarkar and Rahim (2012) [48] and Reddy *et al.* (2014) [46] in different varieties of mango. An increase in the contents of ascorbic 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 Upreti *et al.* (2013) [62].

**Effects on physiological attributes**

**Effect on leaf water potential ($\Psi$w)**

The PBZ induced increase in $\Psi$w 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; Upreti *et al*., 2013; Murti *et al*., 2001) [2, 62, 32].

**Influnecs the mechanism of nureint uptake**

Werner (1993) reported that, cultar treated mango trees showed an increase of 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 towards 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 internodal 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 $GA_3$ at kaurene 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**


1. Abdel AAOS, Elamin OM, Bangerth FK. Effects of paclobutrazol on floral induction and correlated phyto-hormonal changes in grafted seedlings of different mango (*Mangifera indica* L.) cultivars. Sudan J Agri. Res. 2008; 11:111-120.
2. Abdel RAOS, Osman ME, Fritz KB. Effect of paclobutrazol (PBZ) on floral induction and associated hormonal and metabolic changes of biennially bearing mango (*Mangifera indica* L.) cultivars during off year. ARPN. J Agri. Bio. Sci. 2011; 6(2):55-67.
3. Abdollahi M, Eshghi S, Tafazoli E. Interaction of paclobutrazol, boron and zinc on vegetative growth, yield and fruit quality of strawberry (*Fragaria* × *Ananassa* Duch. *cv*. Selva). J Biol. Environ. Sci. 2010; 4(11):67-75.
4. Aron Y, Monselise SP, Goren R, Costo J. Chemical control of vegetative growth in citrus trees by paclobutrazol. Hort. Sci. 1985; 20:96-98.
5. Arzani K, Wood DES, Lawes GS. Influence of first season application of paclobutrazol, root- pruning and regulated deficit irrigation on second season flowering and fruiting of mature Sundrop apricot trees. Acta Hort. 2000; 516:75-82.
6. Auxcilia J, Sathiamoorthy S, Jeyakumar P, Kumar N, Balamohan TN. Effect of paclobutrazol (PP333) on yield and quality of fruit and latex of Papaya var. CO-2. Acta Hort. 2010; 851:413-418.
7. Bagel BS, Tiwari R, Gupta N. Effect of cultar and NAA on flowering and fruiting of mango (*Mangifera indica* L.) cv. Langra. South Ind. Hort. 2004; 52(6):302-304.
8. Bamini T, Parphiban S, Manivanan MI. Effect of pruning and paclobutrazol on yield and quality of mango (*Mangifera indica* var. Neelum). Asian Sci. 2009; 4(1 & 2):65-68.
9. Blaikie SJ, Kulkarni VJ, Muller WJ. Effects of morphactin and paclobutrazol flowering treatments on shoot and root phenology in mango *cv*. Kensington Pride. Sci. Hort. 2004; 101(1-2):51-68.
10. Burondkar MM, Gunjate RT. Control of vegetative growth and induction of regular and early cropping in ‘Alphonso’ mango with paclobutrazol. Acta Hort.1993; 341:206-215.
11. Chaney WR. Growth retardants: A promising tool for managing urban trees. Purdue Extension document FNR-252-W.2005.
12. Davenport TL. Reproductive physiology. In: Litz R.E. (ed). The Mango. Wallingford, CAB International. 2007; 97-169.

13. Elfying DC, Lougheed EC, Chu CL, Cline RA. Effects of diaminozide, paclobutrazol and uniconazole treatment on ‘McInthosh’ apples at harvest and following storage. J American Society Hortl. Sci. 1990; 115:750-756.
14. Erez A. Dwarfing peaches by pruning and by paclobutrazol. Acta Hort. 1984; 146:235-241.
15. Fuentes AM, Mesejo. C, Fambuena NM, Reig C, Mas MCG, Iglesias DJ. Fruit load restricts the flowering promotion effect of paclobutrazol in alternate bearing *citrus* spp. Scientia Horticulturae. 2013; 151:122-127.
16. Gonzalez A, Blaikie SJ. Seasonal variation in carbon assimilation in mango (cv. Kensington Pride): Effect of flowering treatments. Australian J Agri. Res. 2003; 54:309-321.
17. Gracia DA. Vegetative and reproductive development of ‘Ataulfo’ mango under pruning and paclobutrazol management. J. Agril. Sci. Tecnol. 2014; 16(2): 385-393.
18. Greene DW. Effect of PP333 and its analogs on vegetative growth and fruit quality of Delicious apple. Hort. Sci. 1982; 17(3):474.
19. Hauser C. Kwiatkowski J. Rademacher W. Gossman, K. Regulation of endogenous abscisic acid levels and transportation in oilseed rape by plant growth retardants. J. Pl. Physiol. 1990; 137: 201-207.
20. Hoda MN, Sanjay S, Jayant S. Effect of cultar on flowering, fruiting and fruit quality of mango *cv*. Langra. Indian J Hort. 2001; 58:224-227.
21. Hussen S, Kuswanto Ashari S, Basuki N. Induction of flowering and yield of mango hybrids using paclobutrazol. J Agril. Food Tech. 2012; 2(9):153-158.
22. Ito A, Hayama H, Kashimura Y. Possible role of sugar concentration and its metabolism in the regulation of flower bud formation in Japanese pear (*Pyrus pyrifolia*). Acta Hort. 2004; 636:365-373.
23. Jain MC, Dashora VX. Effect of plant growth regulators on physico-chemical characters and yield of guava *cv*. Sardar under high density planting system. Indian J Hort. 2011; 68(2):259-261.
24. Jindal KK, Chadel JS. Effect of triacontanol and paclobutrazol on fruit set, growth and quality of *Prunus saliciana*. Indian J Hort. 1996; 53(4):262-268.
25. Jogande AO, Chowdhary KG. Seasonal changes in abscissic acid content and its role in flowering in mango (*Mangifera indica* L.). Orissa J Hort. 2001; 29(1):46-49.
26. Jyothi MH, Ravindra S, Suresh E, Soppin R, Ekbote S. Biochemical changes in the leaf of bearing and non-bearing trees of some mango (*Mangifera indica* L.) varieties/hybrids. Adv. Agri. Res. India. 2000; 10:17-23.
27. Karki KB, Dhakal DD. Effect of paclobutrazol on off-year induction of flowers in mango. J Inst. Agri. Anim. Sci.2003; 24:51-57.
28. Khurshid T, Mcneil DL, Trought MCT.Effect of foliar-applied gibberellins and soil-applied paclobutrazol on reproductive and vegetative growth of ‘Braebum’ apple trees growing under a high-density planting system. New Zealand J Crop Hortl. Sci. 1997; 25:49-58.
29. Kishore K, Singh HS, Kurian RM. Paclobutrazol use in perennial fruit crops and its residual effects: A review. Indian J. Agril. Sci., 2015; 85(7):863-72.
30. Klinac DJ, Rohitha H, Pevreal JC. Effects of cultar (paclobutrazol) on vegetative growth and fruit production by Nashi (*Pyrus seratina* Rehd.). New Zealand J Crop Hortl. Sci. 1991; 19:229-235.
31. Kotur SC. Effect of paclobutrazol on root activity of mango (*Mangifera indica*). Ind. J Agril. Sci. 2006; 5:75-80.
32. Kulkarni VJ. Chemical control of tree vigour and the promotion of flowering and fruiting in mango (*Mangifera indica* L.) using paclobutrazol. J Hort. Sci. 1988; 63:557-566.
33. Kumar M, Ponnuswami V, Jeya Kumar, Saraswathy S. Influence of season affecting flowering and physiological parameters in mango. Sci. Res. Essays. 2014; 9(1):11-16.
34. Kurian RM, Iyer CPA. Stem anatomical characteristics in relation to tree vigour in mango (*Mangifera indica* L.). Sci. Hort. 1993; 50:245-253.
35. Lina DP, Protacio CM. Phenology of jackfruit (*Artocarpus heterophyllus* lam.) and effects of paclobutrazol on off-season fruit production. Acta Hort. 2015; 1088:495-500.
36. Martin GC, Yoshikawa F, James HL. Effect of soil application of paclobutrazol on growth, pruning time, flowering, yield and quality of ‘Flavorerest’ peach. J American society for Hortl. Sci. 1987; 112(6):915-921.
37. Murti GSR, Upreti KK. Endogenous hormones and phenols in rootstock seedlings of mango cultivars and their relationship with seedlings of mango cultivars and their relationship with seedling vigour. European J Hort. Sci. 2003; 68(1):2-7.
38. Murti GSR, Upreti KK, Kurian RM, Reddy YTN. Paclobutrazol modifies tree vigour and flowering in mango *cv*. Alphonso. Indian J Plant Physiol. 2001; 6(4):355-360.
39. MurtiGSR, Upreti KK, Reddy YTN, Kurian RM. Cytokinins and abscissic acid in xylem sap of mango *cv*. Alphonso grafted on rootstocks of contrasting vigour. Indian J Hort. 2000; 57:221-223.
40. Nafeez M, Faqueer M, Ahmad S, Khan M, Jamil M, Aslam M. Paclobutrazol soil drenching supresses vegetative growth, reduces malformation and increases production in mango. Int. J Fruit Sci. 2010; 10:431-440.
41. Nartvaranant P, Subhadrabandhu S, Tongumpai P. Practical aspect in producing off-season mango in Thailand. Acta Hort. 2000; 509:661-668.
42. Palanichamy V, Reddy NN, Babu S, Selvaraj E Aranganathan, Mitra B. Determination of time period of fruit bud differentiation and the associated histological and biochemical changes in mango hybrids. Res. JPharm. Bio. Chem. Sci.2012; 31(2):271-289.
43. Patil PB, Rao MM, Srinivasan CN, Basarkar PW, Nalwadi VG. Physiological and biochemical factors associated with fruit bud differentiation in Alphonso mango; V-total phenols and polyphenol oxidase. Karnataka J Agric. Sci. 1992; 5(4):338-342.
44. Phadung T, Krisanapook K, Phavaphutanon L. Paclobutrazol, water stress and nitrogen induced flowering in ‘Khao Nam Phueng’ pummelo. Kasetsart J Nat. Sci. 2011; 45:189-200.
45. Pongomboon W, Subhadrabandhu S, Stephenson RA. Some aspects of the ecophysiology of flowering intensity of mango (*Mangifera indica* L.) *cv*. Nam Dok Mai in a semi-tropical monsoon Asian climate. Sci. Hort. 1997; 70:45-56.
46. Protacio C, Cunjate R, Quinto J, Molinyawe G, Paelmo G. Regulation of flowering in Carabaomango trees by paclobutrazol. Philippine. J Crop Sci. 2000; 25:14.

47. Quinlan JD, Richardson PJ. Effect of paclobutrazol ($PP_{333}$) on apple shoots growth. Acta Hort. 1984; 146:105-111.
48. Quinlan JD, Webster AD. Effect of the growth retardant PP333 on growth of plums and cherries. Int. Society Hort. Sci. 1982; 1:1071.
49. Rakshe MV, Nigade PM. Pre and post flowering physiological behaviour of Alphonso mango leaves as influenced by stem girdling, root pruning and chemicals. Bioinfolet. 2013; 10(3B):979-982.
50. Ram RB, Vismil RS, Lal B. Effect of pruning severities and paclobutrazol on bearing behaviour of rejuvenated mango trees cv. Dashehari. New Agriculturist. 2005; 16:1-9.
51. Ratna J, Bist LD. Effect of cultar on growth, yield and fruit quality in grown up Gola pear trees. Indian J Hort. 1997; 54:111-115.
52. Reddy YTN, Upreti KK, Prasad SR. Response of paclobutrazol treatment on flowering, fruit maturity, yield and quality of mango (*Mangifera indica* L.) cv. Totapuri. Indian J Agic. Sci. 2014; 84(10):1231-1235.
53. Reddy YTN, Kurian RM. Cumulative and residual effects of paclobutrazol on growth, yield and fruit quality of 'Alphonso' mango. Journal of Horticultural Sciences. 2008; 3(2):119-122.
54. Sarkar CB, Rahim MA. Vegetative growth, harvesting time, yield and quality of mango (*Mangifera indica* L.) as influenced by soil drench application of paclobutrazol. Bangladesh J Agri. 2012; 37(2):335-348.
55. Saxena P, Singh VK, Pathak N. Antioxidative enzymes and biochemical changes in paclobutrazol induced flowering in mango (*Mangifera indica*) cultivars. J Envi. Bio. 2013; 35:1061-1066.
56. Shivu SR, Reddy YTN, Upreti KK, Rajeshwara AN. studies on changes in carbohydrate metabolism in regular bearing and “off” season bearing cultivars of mango (*Mangifera indica* L.) during flowering. Int. J Sci. 2014; 52:148-152.
57. Singh DB, Ranganath HR. Induction of regular and early fruiting in mango by paclobutrazol under tropical humid climate. Indian J Hort. 2006; 63(3):248-250.
58. Singh Z, Dhillon BS. Effect of paclobutrazol on floral malformation, yield and quality of mango (*Mangifera indica* L.). Acta Hortic. 1992, 296, 51–53.
59. Singh NP, Malhi CS, Sharma RC. Effect of plant bio regulators (PBRs) on flowering, fruit yield and quality in mango cv. Dashehari. Horti. J. 2005; 18(1):10-12.
60. Singh S, Singh AK. Regulation of shoot growth and flowering in mango cv. Gulab Khas by paclobutrazol. Annals of Agricultural Research. 2006; 27(1):4-8.
61. Singh VK, Saini JP. Regulation of flowering and fruiting in mango (*Mangifera indica* L.) with paclobutrazol. Indian Society plant physiology, 2001, 61-68.
62. Singh VK, Singh A. Effect of paclobutrazol on regularity of bearing in mango (*Mangifera indica* L.). Physiol. Mol. Biol. Pl. 2003; 9(2):239-248.
63. Singh Z. Effects of (2RS, 3RS) paclobutrazol on tree vigour, flowering, fruit set and yield in mango. Acta Hort. 2000; 525:459-462.
64. Stan S, Burloi N, Popescu I, Fenesanu N, Cotorobia M. Performance of paclobutrazol (cultar) in controlling vegetative growth and cropping of store fruits. Acta Hort. 1989; 239:221-228.
65. Subhadrabandhu S, Tongumpai P, Kesta S, Suppkitjarak N. Study of paclobutrazol on mango (*Mangifera indica)* *cv*. Khiew Sawoey. II. Effect on total nonstructural carbohydrates, reducing sugars and total nitrogen contents in terminal shoots. Thai. J Agric. Sci. 1997; 30:269-282.
66. Suryanarayana V. Seasonal changes in sugars, starch, nitrogen and C: N ratio in relation to flowering in mango. Pl. Biochem. J. 1987; 5:108-117.
67. Tandel YN, Patel NL. Effect of chemicals on growth, yield and economics of mango (*Mangifera indica* L.). Karnataka J Agric. Sci. 2011; 24(3):362-365.
68. Teferi Y, Robbertse PJ, Stassen PJC. Paclobutrazol suppressed vegetative growth and improved yield as well as fruit quality of Tommy Atkins mango (*Mangifera indica* L.) in Ethiopia. New Zealand J Crop. Hort. Sci. 2010; 32(3):281-293.
69. Upreti KK, Reddy YTN, Shivu Prasad SR, Bindu GV, Jayaram HL, Rajan S. Hormonal changes in response to paclobutrazol induced early floering in mango *cv*. Totapuri. Sci. Hort. 2013; 150:414-418.
70. Upreti KK, Shivu Prasad SR, Reddy YTN, Rajeswara AN. Paclobutrazol induced changes in carbohydrates and some associated enzymes during floral initiation in mango (*Mangifera indica* L.) *cv*. Totapuri. Indian J Pl. Physiol. 2014; 19:317-323.
71. Vijaylakshmi D, Srinivasan PS. Improving the quality attributes of ‘off’ year ‘Alphonso’ mango through chemical and growth regulators. Orissa J Hort. 2000; 28:27-31.
72. Webster AD, Quinlan JD, Richardson PJ. The influence of paclobutrazol on growth and cropping of sweet cherry cultivar. J Hortl. Sci. 1986; 61(4):471-478.
73. Werner H. Influence of paclobutrazol on growth and leaf nutrient content of mango. Acta Horticulturae. 1993; 341: 255-259.
74. Williams MW, Edgerton LJ. Vegetative growth control of apple and pear trees with ICI P-33 (paclobutrazol) a chemical analog of bayleton. Acta Hort. 1983; 137:11-16.
75. Wolstenholme BN, Whiley AW, Saranah JB. Manipulating vegetative, reproductive growth in avocado (*Persea americana* Mill) with paclobutrazol foliar sprays. Scientia Hort. 1990; 41:315-327.
76. Yeshitela T, Robbertse PJ, Stassen PJC. Paclobutrazol suppressed vegetative growth and improved yield as well as fruit quality of ‘Tommy Atkins’ mango (*Mangifera indica*) in Ethiopia. New Zealand J Crop Hort. Sci.2004; 32:281-293.
77. Young PS. Peach growth response from $PP_{333}$ (paclobutrazol). In: proceedings of tenth annual meeting plant growth regulator soc of america. East lansing, USA. PGR Society America, 1983, 192-194.