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Paclobutrazol Boost Up for Fruit Production: A Review

ASHOK KUMAR[1], SANT RAM[2], L.D. BIST[3], C.P. SINGH[4],

[1]Associate Professor, Department of Horticulture, SGT University, Gorgoan, Haryana, [NCR Delhi]
[2]Professor Horticulture, College of Agriculture, G.B.P.U.A &T- Pant Nagar, U.P., India
[3]Professor Horticulture, College of Agriculture, G.B.P.U.A &T- Pant Nagar, U.P., India
[4]Professor Horticulture,College of Agriculture, G.B.P.U.A &T- Pant Nagar, U.P., India

Abstract

Paclobutrazol (PBZ), a triazole derivative, has been effectively used to induce and manipulate flowering, fruiting and tree vigour in several perennial fruit crops. Soil application of paclobutrazol has been efficacious in promoting flowering and increasing yield in many fruit crops. However, there are some conflicting reports on its impact on fruit quality parameters. Besides reducing gibberellins level, PBZ increases cytokinin contents, root activity and C: N ratio, whereas its influence on nutrient uptake lacks consistency. The ability of the crops to produce fruits throughout year is of great interest in recent years. Usually it is applied as a soil application in the month of September-November in case of mango. It inhibits gibberellins 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. The persistence of cultar in orchard soil for a long time and its half-life varies with soil type and climatic conditions, which may severely affect the development of subsequent crops and moved rapidly between the shoot tips and basal nodes both in the acropetal and basipetal directions and persisted for several months. The potential of PBZ to contaminate groundwater at optimum concentrations is low however the risk of its exposure to aquatic life is high. PBZ is considered moderately hazardous for human beings with remote chance of being genotoxic and carcinogenic. In view of the above, optimized use of the PBZ to derive maximum benefit with least undesirable impact on food and environmental safety aspects is suggested.

Keywords: Growth Retardant, Water Relations, Nutrient Uptake, Fruits, PBZ, Cultar Paclobutrazol; PP333; Vegetative Growth; Fruit Production

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), peach (Erez, 1984) , citrus (Aron et al., 1985) and mango (Sarkar and Rahim, 2012). 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) . Mango (Mangifera indica L.) belonging to the family Anacardiaceae, is the most important commercial fruit of India and considered as King of fruit, because of its rich, luscious, aromatic flavor and a delicious taste in which sweetness and acidity are delightfully blended. It is the most popular and the choicest fruit and occupies a prominent place among the fruits of the world. In India it is grown on an area of 2.516 million hectares with annual production of 18.431 million tone having productivity of 7.3 metric tons per hectare Anonymous (2017). Although, alternate bearing is a major problems in mango production and its means "a condition at which high or optimum fruit production in on year or higher and certain year bear little or no fruit (off year), but growth regulators such as cultar reported to be effective on inducing flowering mango off year (Sinde et al., 2000).

The alternate flowering in mango might be due to improper orchard management practices, environmental factors, varietal character, or imbalance of hormone, either alone or in combination. The ability to produce crops throughout the entire year is of great interest for mango production under sub-tropical and semi-arid conditions. The biennial bearing is very serious problem in north, east and central Indian commercial cultivars, while most of the south Indian varieties bear regularly. Therefore, application of cultar is most widely studied in view of its high potential for controlling plant growth and development of fruit crops in general and mango production in particular. It is applied either in the soil or as foliar spray in the September-November. The persistence of cultar in orchard soil for a long time and its half-life varies with soil type and climatic conditions, which may severely affect the development of subsequent crops and moved rapidly between the shoot tips and basal nodes both in the acropetal and basipetal directions and persisted for several months. 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 cultar in mango production. There are several strategies that control the problems of flowering periodicity and tree vigor in tropical and sub-tropical region such as the use of shoot pruning practices, dwarfing rootstock and growth regulators, the use of plant bio regulator is the most promising approach for managing canopy and ensuring regularity in flowering and enhancing fruit yield under commercial cultivation (Olivier et al., 1990). 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)] and also induction of flowering (Patil et al., 1992) .

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. Cultar is effective not only in flower induction but also in early and off season flower induction in mango (Protacio et al., 2000, Blaikie et al., 2004, Yeshitela et al., 2004, Nafees et al., 2010, Burondkar et al., 2013). However, the Mode of action of plant growth regulators such as cultar, is highly specific to cultivar, rate of application, cultivar, developmental stages and climatic condition (Hoffmann1992). Thus, cultar holds considerable promise in manipulation of flowering, yield and vigour in fruit crops. However, its high potency for harmful to nature, slow mobility in the orchard soil, persistence in soil and fruit over its long term use (USEPA 2007). Hence, an effort was made to review the research work on the use of cultar in mango production. Physical and chemical properties of cultar Cultar is a plant growth inhibitor belonging to the triazole group.

Application Methods of Cultar

There are four application methods of cultar such as soil application, foliar application, trunk application, injection methods, out of which soil and foliar application mostly use in mango orchard. The application of cultar to soil as a drench around the tree trunk (TSLP) is the most effective method, as it ensures proper uptake by the tree. The required quantity is mixed in approximately one litre of water and poured onto the soil around the trunk in a circular band. It is a trizol derivative being capable to inhibit the biosynthesis of gibberellins potentially (Sinde et al., 2000) and has been effectively used in reducing canopy volume and increasing flower intensity in mango (Nartvaranant et al., 2000). Cultar is effective not only in flower induction but also in early and off season flower induction in mango (Protacio et al., 2000, Blaikie et al., 2004, Yeshitela et al., 2004, Nafees et al., 2010, Burondkar et al., 2013). However, the Mode of action of plant growth regulators such as cultar, is highly specific to cultivar, rate of application, cultivar, developmental stages and climatic condition (Hoffmann1992). Thus, cultar holds considerable promise in manipulation of flowering, yield and vigour in fruit crops. However, its high potency for harmful to nature, slow mobility in the orchard soil, persistence in soil and fruit over its long term use (USEPA 2007). Hence, an effort was made to review the research work on the use of cultar in mango production. Physical and chemical properties of cultar Cultar is a plant growth inhibitor belonging to the triazole group. Fonseca (2004) reported that the effects of cultar (0.5, 1.0, 1.5 and 2.0 ml), applied either in the soil or as foliar spray, on the flowering and yield of mango cv. Tommy Atkins Therefore, soil application by trunk soil line pour (TSLP) (Tukey, 1983; Ferree and Schmid, 1988; Kim et al., 1990) and soil drench (Steffens et al., 1991) methods were attempted

The Mode of Action

Paclobutrazol inhibits gibberellins biosynthesis by blocking the conversion of kaurene and kaurenoic acid,

Figure 1: Mango (Fruit Growth and Quality)

Which inhibits cell elongation and internodes extension and ultimately retards plant growth. Gibberellins stimulate cell elongation. When gibberellins 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)

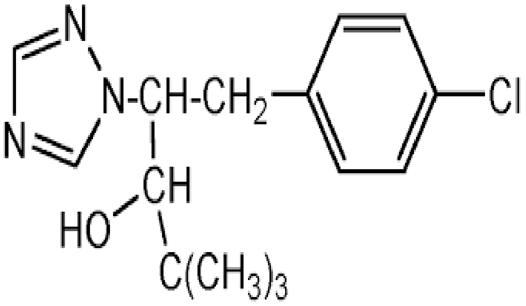

Figure 2: [Paclobutrazol (PBZ), [2RS, 3RS]-1-[4-chlorophenyl]-4, 4-dimethyl-2-(1H-1, 2, 4-triazol-1-yl) pentan-3-ol].

Figure 3: Paclobutrazol (PBZ) Packaging in Dust Form.

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 translocates 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.

Influences the mechanism of nutrient uptake The ability of roots to draw nutrients from the soil and to deliver these to the aerial plant tissues at a rate that matches the needs of growth is key to ensure physiological growth and development of plant, Whereas mismatch between the demand of the shoot and the supply from the roots can affect productivity (Tester and Leigh 2001). Kotur (2006) observed 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. On the other hand, Werner (1993) observed an increase of N, Ca, Mn, Zn and B contents and decrease of P, K and Cu contents in cultar treated mango trees. Soil application of cultar (2.0-8.0 g ai) for two consecutive years in mango increased the levels of phosphorus, potassium and calcium at lower doses but decreased at higher dose. The findings indicate inhibitory effect of paclobutrazol at higher concentration on soil nutrient status and microbial population (Singh et al., 2005). PBZ 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., 2009). The influence of paclobutrazol on leaf nutrient content lacks consistency as it showed variation with the crop species and soil conditions. Alter the phytoharmone/ endogenous hormone Phytohormones play a crucial role in regulation of plant growth and development. There is an increasing evidence for a decisive function of certain hormones in the establishment of developmental programs of plants. Gibberellins are destined for vegetative growth, whereas cytokinin induces reproductive phase (Alabadí et al., 2009). The relative concentration of gibberellin and cytokinin decides the fate of the shoot. A significant decline in the GA3-like compounds was observed in the shoots of PBZ-treated plants after two months of application in mango and there was no difference in the level of GA3-like substance between control and treated plants one year after the treatment. This suggests the need for repeat application of cultar (Protacio et al., 2000). Upreti et al., (2013) reported that cultar besides affecting gibberellins also increases ABA and cytokinin, viz. zeatin (Z), zeatin riboside (ZR) and dihydrozeatin riboside (DHZR), contents concomitant with C: N ratio and leaf water potential in mango buds to elicit flowering responses.

In a similar findings, Singh and Sharma (2008) recorded increase in C:N ratio, leaf water potential, chlorophyll content, total sugar, total protein, nitrate reductase activity, ABA and cytokinins – zeatin (Z), zeatin riboside (ZR) and dihydrozeatin riboside (DHZR) in paclobutrazol treated mango. Adil et al., (2011) also recorded enhancement in the levels of zeatin (z), zeatin riboside (zr), isopentenyl Adenosine (i-Ado), isopentenyl Adenine (i- Ade), and abscisic acid (ABA), through at low level, along with the increase in startch and sugar contents in cultar treated trees of mango during the floral induction period. Whereas, gibberellins (GA1+3+20) and auxin (IAA) were decreased during the same period. Cultar also induces morphological modifications such as enhanced leaf specific weight, stomatal density, leaf thickness, root-to-shoot ratio and root density that strengthen stress tolerance capacity in plants. Addionally, it has also fungicidal activity due to its inhibition of sterol biosynthesis (Chaney 2005, Fernandez et al., 2006)

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.

Figure 3 & 4: [Paclobutrazol (PBZ), [2RS, 3RS]-1-[4-chlorophenyl]-4, 4-dimethyl-2-(1H-1, 2, 4-triazol-1-yl) pentan-3-ol]

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.

Plant Growth and Vigour

Paclobutrazol prevents stem elongation (Hedden and Martin, 1985). PP333 decreased the elongation of new shoots in peach and the effect increased with increasing concentration from 500 to 1500 ppm (Zhang, 1990) .

Historic Plant Growth Retardant

- ✓ Inhibit stem growth
- ✓ Stimulate tillering
- ✓ Improve lodging resistance
- ✓ Stimulate folowering&fruiting
- ✓ Widely used

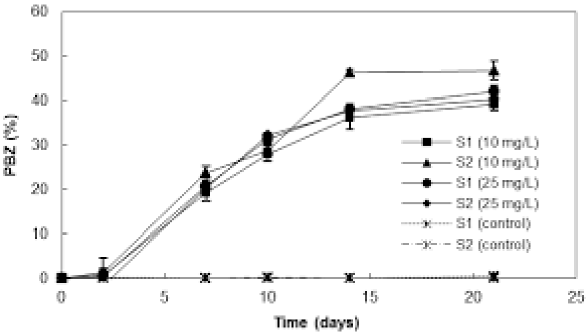

Figure 4: Plant Growth Regulator used in Mango Cvs. Dashhari, Langra, Chausa and Fazali.

Chen et al. (1995) also noted that foliar sprays of PP333 at 1000 or 2000 mg a.i. per litre suppressed peach seedling growth. Allan et al. (1993) also observed significant reduction in competitive early vegetative growth by a soil drench of PP333 in peach cv. Flordaprince. Similarly, Biasi et al. (1989) and George et al. (1993) observed reduction in growth following PP333 treatment in peach and nectarine, respectively. Lever et al. (1982) found more than 50 per cent reduction in shoot growth of Red Delicious apple following PP333 foliar spray at the rate of 750 ppm. However, the effectiveness of PP333 varied with the dose, time and method of application. Irving and Pallesen (1989) found that on two year old apple 1000 ppm of PP333 had very little effect on vegetative growth and remained effective up to 82 days of application. But Stinchcombe et al. (1984)

reported that, in Cider apple, PP333 at 2000 ppm remained effective in the following year also. ElKhoreiby et al. (1990) recorded maximum retardation in growth when PP333 was applied 21 days after petal fall. The reduction in shoot length of Fuji apples was also reported by Kim et al. (1990). Greene (1986) observed the growth retardation effect of PP333 continuously for three years on apple trees when it was applied at higher rates of 1500-3000 ppm as foliar sprays. Mavrodiev and Manolov (1989) reported that PP333 was less effective in controlling growth during the year of application but more effective during the following year.

Quinlan and Richardson (1986) found that 14C PP333 translocated acropetally when applied to young stem internodes and to a lesser degree, from the youngest unrolled leaf, however, there was no label moved from mature leaves. Paclobutrazol is also reported to regulate the vegetative growth of peach and cherry (Arzani et al. 2009; Brar, 2010). Sharma and Joolka (2002a) [38] and Sharma and Joolka (2011) recorded reduced extension growth, plant height and plant spread with paclobutrazol in Non Pareil almond plants. Mir et al. (2015) reported that paclobutrazol significantly retarded the shoot growth, shoot diameter and trunk cross-sectional of 'Roundel' apricot trees growing under low density planting system.

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). Quinlan and Richardson (1984) 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 showed reduced number of total shoots and buds. This showed that PBZ can be used to manipulate apple tree growth in a highdensity 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).

Similarly, Webster et al. (1986) 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). 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). Similarly, the vigour of mango was consistently reduced with paclobutrazol application in a range of Indian cultivars (Kulkarni, 1988). 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). Similar result were observed by Teferi et al. (2010) 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). Similarly, the growth inhibitory response of PBZ reported in different varieties of mango (Sarkar and Rahim, 2012) could be the consequences of modification in photosynthesis rate (Gonzalez and Blaikie, 2003) and carbohydrates (Upreti et al., 2014) besides reductions in gibberellins (Upreti et al., 2013) .

Leaf area: Biasi et al. (1989) applied 0.1 g PP333 per seedling as soil drench to Nemaguard peach and noted reduction in leaf area. Curry and Williams (1983) found reduced leaf size of Well Spur Delicious apple with the application of 20 g PP333 per 9.5 m2 as soil drench. Similar observations in apple have been made by Stinchcombe et al. (1984), Swietlik and Miller (1985) , Chogtu (1986) Greene (1986), Abod and Webster (1991), Bhatia (1992) and Xia et al. (1994) , Val et al. (1999) reported 40 per cent reduction in leaf area and 29 per cent reduction in dry weight of peach with paclobutrazol application. Root growth: Soil drenching with 0.1 g of PP333 per plant resulted in reduced fresh and dry weight of root in containerized peach cv. Nemaguard seedlings (Biasi et al. 1989). Contrary to this, promotion in the root growth of apple trees with PP333 has been reported by Lenz (1984), Steffens et al. (1984) and Lehman et al. (1990). ElHodairi et al. (1988) found an increased root: shoot ratio and this was associated with a redistribution of 14C-labelled assimilates in the plant. Dry matter accumulation in the roots, particularly in lateral and fibrous roots, increased with 1.5 g a.i. and 0.75 g a.i. PP333 applied in spring as soil drench in Aki Fuji apples (Huang et al. 1995). Similarly, Curry and Williams (1990) recorded an increased root dry weight with the lower dose of PP333 but not with its higher dose. Whereas, Swietlik and Miller (1984) reported that total root surface of apple seedling was not affected by PP333. Similarly, Abod and Webster (1991) found no effect of 500 ppm PP333 spray on the root weight of

MM106 apple rootstock. Bhatia (1992) recorded reduced root length in MM109 apple rootstock treated with 1.0 g PP333 as soil drench. Similarly, Zeller et al. (1991a) observed decrease in root growth of potted plants of Smoothee Golden Delicious apple when treated with 1, 10 or 100 mg PP333 per plant. Sharma and Joolka (2002a) recorded reduced total root length and roots dry weight with paclobutrazol in Non Pareil almond plants.

Flower Bud Differentiation

Flowering in mango is preceded by the differentiation of the flower bud in the shoots. Physiological maturity appears directly related with flower bud differentiation (Muhammad et al., 1999). In Indian sub-continent, the time of the flower bud differentiation has been reported by various workers to varying from October to December. In Baramasi mango bud differentiation, most often, takes place twice a year, i.e. during May- June and SeptemberOctober. Fluctuation in the time of flower bud differentiation is dependent on genetic, environmental and endogenous tree factors (Chaco, 1991; Schaffer et al., 1994). Thus, flower bud differentiation seems to be depending on the fluctuations in temperatures and the fruit load borne by the tree during previous year. Ravishankar et al., (1979) fond that flower bud differentiation in Alphonso mango, a irregular or erratic bearing cultivar grown under the mild tropical climate of Dharwar (India) was initiated in early October and reached a peak by November. Singh (1959) reported the last week of December to be the critical time for flower bud differentiation under north Indian climate. Regulation of flowering in off season The application of cultar before flower bud differentiation or three months earlier than anticipated flowering has been effective in inducing flowering in mango without accompanying reduction in shoot length. However higher concentration leads to canopy and panicle compaction (Shinde et al., 2000) . Chusri et al., (2008) reported that in the PBZ treated trees bud break occurred 18-22 days earlier than in the control trees in 'Irwin' mango. Apical bud breaking exceeded 98% in the PBZ-treated trees compared with only 42% in the control trees.

More than 96% of the PBZ-treated trees produced floral shoots, compared with only 35% of the control trees. The panicles of the PBZ-treated trees were shorter than those of the control trees. Apart from enhancing flowering intensity, cultar has also been effective in increasing sex ratio, cauliflory and axillary flowering in mango (Singh 2000). Cardoso (2007) observed that there was a higher percentage of flowering and fruit production as compared with the control. The PBZ treatment also anticipated flower initiation and fruit harvest, which means that out of season production, provides higher prices and more profitability. Reddy and Kurian (2008) observed that under tropical climate, application of paclobutrazol for three consecutive years and then its discontinuation for the subsequent three years appears in twenty years old mango trees to be appropriate. However, the continous optimum use of cultar in high density planting is imperative to manage canopy and to induce precocious flowering as it was also observed that young plants respond better than old ones. Soil application around the tree trunk (collar drench) was more efficacious than foliar application as it ensures proper uptake in inducing flowering and fruiting (Kulkarni et al., 2006). On the other hand, Yeshitela (2004) reported that application of cultar both as a soil drench and foliar application were effective in suppressing vegetative growth and enhancing flowering, yield, fruit quality as well as number of hermaphrodite flowers in mango. The response to cultar varied with cultivar and crop load. The shoot retarding effect of cultar was generally limited in mango var. Sensation, but was pronounced in Tommy Atkin. Moreover the average fruit weight and yield were increased with the rate of paclobutrazol in Sensation, whereas fruit weight and yield were reduced in Tommy Atkin (Singh and Bhattacharjee 2005). Singh et al., (2005) reported soil application of PBZ at 5 and 10 g/tree considerably increased the percentage of panicles and hermaphrodite flowers on twenty five year old Dashehari mango trees. 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).

Mouco et al., (2005) observed that Paclobutrazol promoted flowering in mango trees in any season of the year, under tropical semi-arid conditions, but its efficiency was related to the maximum and minimum air temperatures at the time of bud break. Bagel et al., (2004) observed maximum number of flowering shoots/m2 (n=30.32) and percentage of flowering shoots (96.15%) when Cultar applied alone (2.50, 3.75 and 5.00 g/ha) and in combination with NAA (20 ppm), on the flowering and fruiting of 10-year-old mango cv. Langra trees and they recorded flowering and fruiting was significantly increased by 7- 30%. Soil application of Cultar promoted flowering, along with cauliflory and axillary flowering (Singh et al., 2000). Four months later and monthly thereafter, 10 shoots were dipped in 2% potassium nitrate to assess flowering response. Flowering started only by November or 6 months after paclobutrazol application. By December, all trees treated with 1 gram paclobutrazol per canopy diameter flowered in contrast to only 38% of the control trees. Starch content increased in stems of paclobutrazol-treated trees, suggesting that paclobutrazol promotes flowering by increasing starch accumulation (Protacio et al., 2000). The panicle size was reduced with the application of Cultar whereas the percentage of hermaphrodite flowers, fruit set and yield was increased.

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) 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) 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). 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) 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). Kulkarni (1988) 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). 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) , peach (Erez, 1984), citrus (Aron et al., 1985) and mango (Sarkar and Rahim, 2012) . Early and intense flowering induced by PBZ may be the consequence of early shoot maturity and increased photosynthesis rate (Singh and Singh 2003), carbohydrate accumulation (Abdel Rahim et al., 2011) and decline in flowering reducing hormone, gibberellins (Upreti et al., 2013) . 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, reduced panicle length (Vijayalaksmi and Srinivasan, 2000; Hoda et al.,2001; Nafeez et al., 2010; Sarkar and Rahim, 2012), 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) 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). The high C: N ratio during flower bud differentiation was ascribed to the increased carbohydrate availability (Ito et al., 2004) and is considered as an important factor in regulation of flowering in fruit crops (Jyothi et al., 2000; Palanichamy et al., 2012) .

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) and in pummelo (Phadung et al., 2011) 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. 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). 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) and also for induction in flowering (Patil et al., 1992). 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). 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). 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) .

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). 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). 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) 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) 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) 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) .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), Hoda et al. (2001), Bamini et al. (2009), Sarkar and Rahim (2012) and Reddy et al. (2014) 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) , papaya (Auxcilia et al., 2010) , guava (Jain and Dashora, 2011). However, non-significant effect on fruit quality with PBZ application was reported by Tandel and Patel (2011) and Upreti et al. (2013) .

Increase Fruit Set and Yield

Bagel et al., (2004) were recorded maximum yield per tree (68.12 kg), yield per hectare (106.25 q/ha), and yield increase over the control (29.85%) of 10 year old mango cv. Langra trees applied with Cultar at 5.00 g/ha in combination with 20 ppm NAA. Soil application of paclobutrazol at 5 g/tree was most effective to improve the fruit set and Int.J.Curr.Microbiol.App.Sci (2018) 7(2): 1552-1562 1558 fruit retention during the off year. The highest yields of 70.50 and 68.70 kg per tree during the off year were recorded under soil application of paclobutrazol at 5 and 10 g/tree, respectively (Singh and Singh, 2006). Increase in fruit set per panicle is due to retardation of plant vigour by growth retardant. Benjawan (2005) reported that PBZ had no significant effect in extending number of days from flower initiation up to full bloom. PBZ also had no significant effect in delaying fruit maturity age but fruit sets were significantly increased with PBZ rates applied. PBZ had a highly significant effect on fruit length but significantly decreased fruit thickness. Fruit yields were significantly increased with PBZ application.

The best application rate of PBZ was found with T< sub>7 (1000 ppm/plant) with an extended flower raceme length of 5 cm. This treatment gave the highest mango edible fruit yield of 48 281.25 kg ha-1. Paclobutrazol was applied in mango cvs. Chausa, Dashehari and Langra as soil drench @ 2, 4, 6 and 8 g/tree and recorded maximum fruits set per panicle, fruit number and fruit yield per tree in 4 g/tree treated Dashehari tree whereas 6 g/tree of PP333 was found more effective in cvs. Chausa and Langra (Singh and Singh, 2003). Soil drenching of PP333, 5 or 10 ml at 120, 90 and 60 days before bud break on mango cv. Neelum and recorded the maximum number of fruits (380) and fruit yield per tree (91.65 kg) both in off season and main season (302 fruits and 72.85 kg per tree) with 5 ml of PP333, 90 days before bud break (Anbu et al., 2001).

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; Upreti et al., 2013; Murti et al., 2001). Improve Fruit Quality Due to cultar application chemical composition of fruits was considerably enhanced in terms of TSS, total sugars, ascorbic acid, TSS/acid ratio, however, there was depletion in titratable acidity in freshly harvested fruits. These results are in conformity with the reports of Vijaylakshmi and Srinivasan (2000) in mango.

Fruit quality of mango (TSS and acid content) increases with paclobutrazol application (Burondkar et al., 2013). The effect was more pronounced in fruits that received 2000 or 3000 mg l-1 than lower doses. These treatments attained better quality as judged from the total soluble solids, total acidity, ascorbic acid content, total chlorophyll, total carotenoids, and amylase and peroxidase activity from harvest to 12 days of storage at ambient conditions. Chemical parameters of fruits (Reddy and Kurian, 2008) such as TSS and acidity were not affected by cultar but average weight of a fruit was less in the case of cultar treatments. The effects of cultar applications on fruit size in mango cv. Sensation, and on fruit retention in Tommy Atkins, were investigated in the Northern Province of South Africa. One or 10 ml of paclobutrazol (as Cultar) was diluted with water to 100 ml (0.25 or 2.50 g a.i.), and was applied to a 60-cm-diameter ring of soil around the trunk of 2-year-old trees prior to the initiation of postharvest flushing. In Sensation, the average fruit weight (final fruit size) and tree revenue increased with increasing rates of paclobutrazol applied. The number of fruits retained and yields were not affected. In Tommy Atkins, the number of fruits retained, average fruit weight, yield and tree revenue decreased with increasing rates of cultar applied (Oosthuyse et al., 1997). The treatment also improved the fruit quality in terms of total soluble solids (TSS), total acidity, total chlorophyll, total carotenoids, alpha-amylase and peroxidase activity. The relation of cultar on the water use in terms of soil moisture content, gas exchange attributes of Dashehari mango was also studied indicated that the cultar has capacity to retain the moisture to some extent and the trees are less sensitive to fluctuation in water supply and may be better able to withstand drought conditions (Singh and Singh, 2003).

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).

Carbohydrate Content

PP333 influences the carbohydrate contents in plants. Pith and xylem starch deposits in Sudanell1 peach increased with PP333 (Aguirre and Blanco, 1992) . Vance Delicious and Red Spur Delicious apples had more leaf total sugar with 0.5 g PP333 and leaf starch with 1.0 g PP333 per plant applied as soil drench (Bhatia, 1992). However, Xia et al. (1994) recorded increased leaf sugar and starch contents in Fuji and Starking apples on treatment with 1000 ppm Chenghuabao (PP333). In Spartan apples treated with PP333, Steffens et al. (1985) found higher leaf starch and static sugar contents. Whereas in Top Red Delicious plants treated with PP333, Wieland and Wample (1985) observed reduction in reducing sugars with 150 mg, increase in starch with 25 and 50 mg than those with 150 mg dose of PP333. In apple plants PP333 treatments resulted in the depletion of carbohydrates (Curry, 1988) and starch in shoots (Bonomo et al. 1989) . However, Sharma and Joolka (2003) observed increased leaf total carbohydrates content with paclobutrazol in Non Pareil almond plants. Nutrient uptake PP333 influence the leaf nutrient status of various temperate fruit crops. Nitrogen: PP333 treatment reduced foliar N concentration in Nemaguard (Rieger, 1990), Flordaprince (Allan et al. 1993, 1995) , Flordaprince and Flordagold peach cultivars (Huett et al. 1997) and Red Spur Delicious and Vance Delicious apples (Bhatia, 1992).

However, Atikson and Crisp (1983) found increased foliar N concentration in apple plants treated with PP333. But Swietlik and Miller (1985)] could not find any effect of PP333 on the foliar N levels of Golden Delicious apples. However, Sharma and Joolka (2011) recorded reduced leaf N content with paclobutrazol in Non Pareil almond plants. Phosphorus: PP333 treatment reduced foliar P concentration in Nemaguard, (Rieger, 1990), Flordaprince (Allan et al. 1993, 1995), Flordaprince and Flordagold peach cultivars (Huett et al. 1997) and Red Spur Delicious and Vance Delicious apples (Bhatia, 1992). Increased foliar P concentration in apple plants treated with PP333 has been reported by Atikson and Crisp (1983) and Curry (1988). However, Sharma and Joolka (2011) recorded reduced leaf P content with paclobutrazol in Non Pareil almond plants. Potassium: PP333 treatment reduced foliar K contents in Nemaguard (Rieger, 1990) , Flordaprince peach (Allan et al. 1993, 1995) , stone fruits (Lichou et al. 1988), Red Spur Delicious, Vance Delicious (Bhatia, 1992) and Ace Delicious apple (Curry, 1988). Contrary to this, Swietlik and Miller (1984) [46] 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 (2011) recorded reduced leaf K content with paclobutrazol in Non Pareil almond plants. Calcium: Increased concentration of foliar Ca with PP333 treatment was observed in Nemaguard (Rieger, 1990), Flordaprince (Allan et al. 1993, 1995) , Flordaprince and Flordagold peach cultivars (Huett et al. 1997) and Red Spur Delicious and Vance Delicious apples (Bhatia, 1992) .

Similar observations regarding the increase in foliar Ca concentrations in various apple cultivars were made by Atikson and Crisp (1983), Swietlik and Miller (1984) , Curry (1988) and Bonomo et al. (1989) . Swietlik and Miller (1985) further reported that Ca content in Golden Delicious increased in proportion to the increasing doses of PP333. Sharma and Joolka (2011) also recorded increased leaf Ca content with paclobutrazol in Non Pareil almond plants. Magnesium: Foliar Mg content has been reported to increase with PP333 treatment in Nemaguard (Rieger, 1990) , Flordaprince (Allan et al. 1993, 1995) , Flordaprince and Flordagold peach cultivars (Huett et al. 1997) , Red Spur Delicious and Vance Delicious apples (Bhatia, 1992) and apple plants (Bonomo et al. 1989). But Curry (1988) found reduced levels of foliar Mg in apple plants treated with PP333. However, Sharma and Joolka (2011) also recorded increased leaf Mg content with paclobutrazol in Non Pareil almond plants.

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) 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) 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). 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) .

Degradation and Persistences in Orchard Soil

Reddy and Kurian (2008) 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) also detected paclobutrazol residue below permissible limit (0.4898-1.0005 μg/g) in the rhizosphere after two years of application. Degradation and persistences in orchard soil Paclobutrazol is characterized by moderate potential of mobility in soil which enables it is applied in soil unlike other growth regulators (Costa et al., 2012), however its mobility varied with the soil type. Studies conducted in USA indicate that half-lives of paclobutrazol residues ranged from 450-950 days for orchard soils which indicates poor degradation rate of PBZ. Paclobutrazol showed low soil adsorption coefficient (KD= 1.3 to 23.0 ml/g), however adsorption appeared to increase with soil organic matter and a decrease in soil pH. Studies conducted in USA revealed that less than 10% of total PBZ applied were detected in soils between the depths of 60-120 cm, whereas the PBZ ketone metabolite was predominately detected in the subsurface soil layers though at insignificant levels. Sharma and Awasthi (2005) detected residues of paclobutrazol in the tree basin soil (0- 15 cm) at the end of each season followed by a slight increase in the amount of residues with the year of applications. Reddy and Kurian (2008) 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. Sharma et al., (2008) could not detect paclobutrazol residues above quantifiable levels (0.01 ppm) either in tree basin surface soils or in the fruits even after more than five years continuous application. However, they further reported that the residues increased to 0.34 ppm with the increase of the application rate (20 g a. i./tree).

Singh and Bhattacharjee (2005) also detected paclobutrazol residue below permissible limit (0.4898–1.0005 μg/g) in the rhizosphere after two years of application. Jaradrattanapaiboon et al., (2008) reported spatial difference of paclobutrazol residue in soils as they observed high concentration of PBZ residue in upper soil layer (0-5 cm) and low residue level in lower soil layer (10- 20 cm). They further reported that PBZ persisted for about 3-5 months. On the other hand, Narvaranant et al., (2000) reported the persistence of PBZ residue up to 12 months Ochoa et al., (2009) expressed the possibility of environmental contamination with the regular application of paclobutrazol in containerized oleander production due the leaching of PBZ into the nursery soil with the irrigation water. The adsorption and leaching of the residues is dependent upon the soil physical and chemical characteristics as well as environmental factors such as rainfall. Wu et al., (2013) have reported that paclobutrazol was more persistent in greenhouse than in open field soil; leaching by rainfall being responsible for the difference in dissipation. Paclobutrazol is also known to leach in soil with high sand content

Conclusions

Paclobutrazol is a growth inhibitor and also belong to triazol group. It inhibit the biosynthesis of GA3 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. The cultar 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 but has the drawback of relatively high persistence in both soil and fruit in mango. Studies aiming to adjust the amount of application dose of cultar to each cultivar 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 the mango orchard soil, tree, fruit and environment.

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