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Research Review Article

Paclobutrazol use in perennial fruit crops and its residual effects: A review

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ABSTRACT

Paclobutrazol (PBZ), a triazole derivative, has been effectively used to induce and manipulate flowering, fruiting and tree vigour in several perennial fruit crops. However its use in mango is quite common. 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. PBZ 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, its residue could not be detected above quantifiable level (0.01 ppm) in soils and fruits when applied in optimized rate. 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.

Key words: Environmentally stable, Flowering manipulation, Mango, Paclobutrazol, Residual effect

Perennial fruit crops like mango, citrus, avocado, litchi, temperate fruits, nuts, etc. suffer from the intricate problem of irregular bearing or cropping periodicity as well as staggered or erratic flowering behaviour, leading to considerable loss of their production potential (Singh 1971, Jonkers 1979). Some of the fruit crops are worst sufferers of cropping periodicity. The erratic rhythm of flowering could be due to environmental factors, crop genetics, orchard management practices or hormonal imbalances, either alone or in combination. In addition to irregular bearing, management of tree vigour and canopy, especially under tropical climate has become a challenge (Iyer and Subramanyam 1993, Kurian *et al*. 2013, Kohne and Kremer-Kohne 1990). Of the several strategies suggested to overcome the problems of flowering periodicity and tree vigour in sub-tropical and tropical regions, such as the use of dwarfing rootstock, shoot pruning and growth regulators the use of PGRs is the most promising approach for managing canopy and ensuring regularity in flowering and enhancing fruit yield under commercial cultivation (Olivier *et al*. 1990).

Paclobutrazol, a gibberellins inhibitor, has been effectively used in reducing canopy volume and increasing flower intensity in peach (Allan *et al*. 1993), plum (Olivier *et al*. 1990), almond (Koukourikou-Petridou 1996), grapes (Christov *et al.* 1995) and mango (Kulkarni 1988, Kurian and Iyer 1993, Nartvaranant *et al*. 2000). Paclobutrazol 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 action of plant growth regulators (PGRs) is highly specific to plant species, cultivar and stage of development, and strongly dependent on its rate of application and environmental conditions (Hoffmann 1992). Thus, paclobutazol holds considerable promise in manipulation of flowering, yield and vigour in fruit crops. However, its high potency, hazardous nature and slow mobility raise genuine concerns over its long term use (USEPA 2007). Hence, an effort was made to review the research work on the efficacy of the paclobutrazol application in different perennial crops and its residual aspect.

PROPERTIES OF PACLOBUTRAZOL

Paclobutrazol (PBZ), a non-polar broad spectrum growth regulator, has been characterized as an environmentally stable compound in soil and water environments (Table 1) with a long half-life under both aerobic and anaerobic conditions. Moreover PBZ is unlikely to volatilize to any significant extent owing to a low estimated vapour pressure (1.9×10^{-6} Pa). Paclobutrazol is translocated acropetally via xylem in plants (Hamid and Williams 1997, Wang *et al*. 1986), although phloem

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Table 1 Environmental fate properties for mobility and persistence of paclobutrazol

Parameter	Value	Source
Hydrolysis	Stable: <6% degradation after 30 d at pH 4,7, and 9	USEPA (2007)
Photolysis in water	Stable: < 5% degradation after 10 d at pH 7	USEPA (2007)
Aerobic soil metabolism (half-life)	> 1 yr	USEPA (2007)
Anaerobic soil metabolism (half-life)	> 1 yr	USEPA (2007)
Field dissipation (half-life)	450-950 days in orchard US soils 175-252 days in agricultural US soils	USEPA (2007) EFSA (2006)
Aquatic metabolism (half-life)	164 days	EFSA (2006)
Soil Adsorption Coefficient (K_D) (mL/g)	1.3–23.0 0.8–21.3 (mean of 4.3)	USEPA (2007) EFSA (2006)

translocation has also been reported (Witchard 1997).

Paclobutrazol has been registered in 1985 (cultar, ICI Americas, Goldsboro, NC), however it has now been permitted for use on food crops in Australia, New Zealand, South Africa, India, Philippines, Vietnam, Canada, USA (California), Finland, Hungry, Greece, Cyprus, Denmark and Netherlands (Davis and Curry 1992). In India PBZ has been registered as a plant growth regulator under the section 9(3) of Insecticides Act, 1968 in November 2009 by Central Insecticides Board & Registration Committee (Kegley *et al*. 2010) and is available in the market with various trade names.

EFFECTS OF PACLOBUTRAZOL

Paclobutrazol has demonstrated its usefulness by regulating traits of agronomic interest in various crops including cereal, vegetables, fruits and ornamentals (Rademacher and Bucci 2002). It has been effectively used for flower regulation, yield and quality improvement in various perennial fruit crops (Nartvaranant *et al*. 2000, Koukourikou-Petridou 1996, Adato 1990).

Regulation of flowering and yield

Floral induction is considered to be the result of elevated levels of up-regulated florigenic promoter (FP) and down-regulated vegetative promoter (VP), primarily gibberellins, whereas the reverse condition promotes vegetative growth (Nartvaranant *et al*. 2000, Davenport 2007). The production of vegetative shoots in place of reproductive shoots is due to the elevated level of gibberellin which is considered as a vegetative promoter (Núñez-Eliséa and Davenport 1995). Paclobutrazol, a gibberellin inhibitor, reduces VP level and thereby increases FP/VP ratio which stimulates flowering shoots in weakly inductive shoots of fruit crops (Voon *et al*. 1991, Yeshitela *et al*. 2004, Adil *et al*. 2011, Iglesius *et al*. 2007). It is effective not only in flower induction but also in regulating vegetative growth in perennial crops which has been described in Table 2.

The application of paclobutrazol 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, Karki and Dakal 2003, Husen *et al*. 2012, Negi and Sharma 2009). Apart from enhancing flowering intensity, PBZ has also been effective in increasing sex ratio, cauliflory and axillary flowering in mango (Singh 2000). Foliar application of paclobutrazol (200 ppm) was effective in increasing yield and minimizing fruit drop and fruit cracking in ber (Singh 2000). The efficacy of PBZ increases in terms of panicle initiation when combined with nitrate salt of potassium and ammonium (Rebolledo *et al*. 2008, Medina-Urrutia and Núñez 1997). The effectiveness of PBZ was dependant on stage of development as the application of paclobutrazol at bud bursting and two weeks before anthesis of grape increased the yield significantly (Christov *et al*. 1995). 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 PBZ 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 (Ram and Sirohi 1991, Kulkarni *et al.* 2006, Ram and Tripathi 1993). On the other hand, Yeshitela (2004) reported that application of PBZ 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 PBZ varied with cultivar and crop load. The shoot retarding effect of PBZ 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 (Oosthuyse and Jacobs 1997). Paclobutrazol showed differential genotypic effect in mango (Singh and Bhattacharjee 2005). The effectiveness of PBZ in promoting flowering in *Citrus* sp. depends on the crop load as the heavy fruit load trees scarcely flowered. In medium to low

Table 2 Efficacy of paclobutrazol in perennial crops

Crop	PBZ concentration	Mode of application	Effect	Source
Mango	1.0 g a. i./m canopy	Soil application	Growth reduction, flower induction	Burondkar and Gunjate (1993)
	20-40 g/tree		Growth reduction, increased sex ratio, flowering and yield	Singh (2000)
	2.0 ml/plant		Yield enhancement	Ram (1996)
Pineapple	150 (mg/L)	Foliar spray	Delayed harvesting and yield improvement	Antunes *et al*. (2008)
Litchi	5 g/m^2 plant spread	Soil application	Growth reduction, enhanced flowering and yield	Faizan *et al*. (2000)
Mexican lime	15 g a.i./plant		Enhanced flowering	Medina-Urrutia and Buenrostro-Nova (1995)
Mandarin	1.0-2.0 g		Growth regulation	dos Santos *et al*. (2004)
Grape	0.5-1.0 g a.i./vine			Christov *et al*. (1995)
Peach	0.5-2.0 g a.i./tree			Allan *et al*. (1993), Arzani *et al*. (2009)
Avocado	1.0%	Foliar application	Yield enhancement	Adato (1990) Salazar-Garcia *et al*. (2013)
Cashew nut	1-3 g/plant	Soil application	Growth regulation and nut yield	Meena *et al*. (2014)
Apricot	0.5-2.0 g a.i/plant		Growth reduction,enhanced flowering and yield	Arzani and Roosta (2004)
Apple	0.5 – 1.0g			Estabrooks (1993)
Guava	1.0 g/plant		Yield improvement	Brar and Bal (2011)
Ber	200 ppm	Foliar application		Singh (2000)
Sapota	5.0 g/plant	Soil application		Reddy and Khan (2001)

fruit load trees PBZ significantly increased the percentage of sprouted buds and floral shoots and reduced the number of vegetative shoots (Martínez-Fuentes *et al*. 2013).

Effect on fruit quality

Fruit quality of mango and lemon (TSS and acid content) increases with paclobutrazol application (Jain *et al*. 2002, Burondkar *et al*. 2013). On the other hand paclobutrazol had shown no improvement in fruit quality in citrus (Monselise 1986), grapes (Intrieri *et al*. 1986, Christov *et al*. 1995), strawberries (Lolaei *et al*. 2012), apple (Steffens *et al*. 1985) and peach (Arzani *et al*. 2009). Fruit weight, pulp: stone ratio, TSS and shelf-life increased at lower dose of paclobutrazol in ber (Singh 2000). Jamalian *et al*. (2008) reported that paclobutrazol improved the fruit quality of strawberry under salt stress condition.

Tree architecture

Now-a-days, reduced canopy size has become an integral part of modern fruit production; it is evident that apart from flower induction, paclobutrazol also restricts tree vigour hence trees should be allowed to develop a good canopy before treatment commences. The efficacy of paclobutrazol in regulating canopy size of mango has been reported by many workers (Voon *et al*. 1991, Kurian and Iyer 1993). Charnvichit *et al*. (1994) reported that PBZ effectively regulated tree canopy and induced flowering in six year old pruned mango trees planted under high density system (2.5m × 2.5m). The canopy regulation was due to the shortening of third and fourth flushes and internodal lengths of the treated trees. The treated plants not only flowered more profusely but also were considerably earlier than the controls. However the treatment effect lasted for only one year. Paclobutrazol was found effective in reducing tree vigour and in promoting flowering, fruit set and yield in Dashehari and Tommy Atkins (Singh 2000, Medina-Urrutia 1995). Paclobutrazol has also been reported to be effective in regulating vegetative growth of peach, apple, citrus and guava (Arzani *et al.* 2009, Mauk *et al*. 1990, Aron *et al.* 1985, Brar 2010, Baskaran 2011). Garcia De Niz *et al*. (2014) assessed the effect of pruning and paclobutrazol treatment on the vegetative growth and fruit yield of mango and reported that the efficacy of paclobutrazol in terms of shoot growth and production efficiency depends on the time of pruning.

Root activity and nutrient level

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). Growth regulators greatly influence root activity and vegetative growth which implies demand for certain elements and additional decrease of others and in turn alter the mineral uptake and plant nutrition (Atkinson 1986, Pequerul *et al*. 1997). The role of PBZ in regulating root activity has been reported in different crops. 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. Paclobutrazol also initiated more fibrous roots in satsuma mandarin (Yamshita *et al*. 1997). Rieger and Scalabrelli (1990) reported that PBZ decreased N, P, K, Fe and Mo and increased the levels of Ca, Mg, B and Mn in peach. 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 PBZ treated mango trees. Arzani and Roosta (2004) reported that PBZ decreased the leaf N content in almond without affecting the concentration of P, K and Ca. Whereas the leaf N and P was not influenced by PBZ treatments in peach, but Ca and K concentrations were increased (Arzani *et al*. 2009). On the contrary, Wieland and Wample (1985) observed no influence of PBZ on foliar content of N, P, K and Mg in apple trees. Soil application of paclobutrazol (2.0 - 8.0 g a i) for two consecutive years in mango increased the levels of phosphorus, potassium and calcium at lower doses but decreased at higher dose. A similar trend was recorded in soil microbial level. 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. In addition to leaf nutrient content paclobutrazol also influences soil properties.

Hormones and metabolites

Plant hormones and metabolites play a crucial role in regulation of plant growth, development, and reproduction. 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 GA_3-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 GA_3-like substance between control and treated plants one year after the treatment. This suggests the need for repeat application of PBZ (Protacio *et al*. 2000). Kurian *et al.* (1994) reported reduced butanol soluble cytokinin levels and elevated butanol insoluble cytokinin and total phenolic compounds levels in leaves of paclobutrazol treated mango trees. Starch and sucrose levels in most of the cases were increased by the paclobutrazol treatment which suggest the role of tested hormones and nonstructural carbohydrates on mango flowering. Upreti *et al*. (2013) reported that paclobutrazol 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 PBZ-tereated trees of mango during the floral induction period. Whereas, gibberellins (GA_{1+3+20}) and auxin (IAA) were decreased during the same period. Phadung *et al*. (2011) reported that PBZ had comparable flowering, total non-structural carbohydrates and C/N ratio to the water stressed trees of pummelo (*Citrus grandis*). They further reported that under water stress condition PBZ along with nitrogen effectively induced flowering in pummelo. PBZ 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 (Steffens *et al*. 1985, Fletcher and Hofstra 1988, Blanco *et al*. 1998, Chaney 2005, Fernandez *et al*. 2006).

RESIDUAL EFFECT AND RISK ASSESSMENT OF PBZ

Residual effect on plant growth

Although paclobutrazol has been found efficacious in flower induction and canopy management, its residual property needs due attention. Concerns have been expressed over the use of paclobutrazol as it inhibits gibberellin bio-synthesis which is responsible for cell elongation and internode extension. The treated tree produces compressed panicle which does not dry out well and can develop powdery mildew or anthracnose even with the slight increase in the humidity. Furthermore application of PBZ may cause severe stunting of plants if pruning is anticipated (Davenport 1993). The stunting effect may sustain for seven years as paclobutrazol persists in the soil. The residual effect of PBZ was also observed in *Citrus* sp. on the subsequent growth of the scions with the application of PBZ @ 200 ppm (Hadlow and Allan 1989), however lower dose had no residual effect on the growing scions. No residual or cumulative effect of PBZ was detected in avocado with regards to tree vigour, and yield (Adato 1990). PBZ reduced the root hydraulic conductivity and altered the nutrient uptake in peach which appeared to be side-effects of PBZ treatment (Reiger and Scalabrelli 1990). Paclobutrazol causes morphological alteration in young roots of citrus and peach by increasing thickness and decreasing length. Such morphological alteration may influence water and nutrient uptake as these processes occur most actively in young roots. Furthermore, PBZ treatment may reduce drought avoidance of under rainfed condition by decreasing the volume of rhizosphere (Bausher and Yelenosky 1986, Williamson *et al*. 1986).

Residual effect on fruits

Paclobutrazol has prolonged persistence in plant system due to its slow rate of metabolism (Sterrett 1985). However it has differential translocation rate among different plant parts. Neidhart *et al*. (2006) and Costa *et al.* (2012) observed that PBZ did not translocate into the mango fruits, as assumed from its mode of translocation. On the other hand, Srivastav and Ram (1999) confirmed the translocation of PBZ into fruits and seeds of Dashehari, Langra, Chausa and Fazli though the concentration was below permissible limits. Similar findings were also obtained by Sharma and Awasthi (2005) who reported 0.05 ppm residue of PBZ (the maximum residual level for stone fruits) in unripe mango with the application of PBZ @ 5 to 10 g a.i. per tree for three consecutive years. Moreover the level further decreased to 0.001 mg/kg at fruit maturity.

Residual effect in soil

Paclobutrazol is characterized by moderate potential of mobility in soil and water environments (30-35 µg/ml) 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 and 175-252 days in agricultural soils (Table 1) which indicates poor degradation rate of PBZ. Paclobutrazol showed low soil adsorption coefficient (K_D = 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) and Winston (1992) reported the persistence of PBZ residue up to 12 months. The residue level of PBZ persisted for 3 years in apple orchard when soil drench method was employed (Mauk *et al*. 1990). Ochoa *et al*. (2009) expressed the possibility of environmental contamination with the regular application of paclobutrazol in containarized 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.

Effect on microorganism and earthworm

Hampton (1988) and Jackson *et al*. (1996) reported that paclobutrazol may remain active for many years in soils if applied directly, and can severely affect the growth and development of subsequent crops or even interact, in a harmful way, with soil microorganisms. Silva *et al.* (2003) reported that the soil application of paclobutrazol (160 µg a.i./g) in mango orchards, affected negatively the soil microbial community by reducing total number of bacteria (58%), fungi (28%) and actinomycetes (28%) and additionally affected the dehydrogenase activity. However lower dose (16 µg a.i./g) has neither affected soil microbial community nor dehydrogenase activity. Singh *et al.* (2005) also reported that higher doses of paclobutrazol had negative impact on microbiological status of soil and suggested the use of optimum dose for better soil health and soil properties. Studies on the impact of PBZ on the activity of earthworm (*Eisenia foetida*) showed that there was no death and behavioural abnormality in the earthworm with the concentration of 1000 mg/kg soil, however 20 per cent reduction in body weight was observed after 14 days (MDAR 2012). The residual effect of paclobutrazol on microbes and earthworms may alter the microbial population balance and level of soil fertility.

Residual effect on ground water

Much work has not been carried out on the role of PBZ in ground water contamination. Modelling study on ground water exposure to PBZ showed that the concentration of the degradate did not exceed 0.1 µg/L except in one of the six scenarios. The study concluded that the potential for the degradate hydroxyl triazole to reach groundwater at high concentrations is low (EFSA 2010). Long term studies on the potential of paclobutrazol to impact groundwater from its use on turf areas indicated low rate of ground water contamination as only 0.68% of water sample had highest detection level of 4200 mg/l (Baris *et al*. 2010). However the maximum allowable concentration of PBZ in drinking water is 66.0 μg/L (EFSA 2010).

Residual effect on aquatic life

Paclobutrazol has been found hazardous to aquatic life. Significant increase in the enzymatic activity of lactate dehydrogenase (LDH) and glutathione S-transferase (GST) was observed in the liver of Brazilain fish (*Metynnis argenteus*) when fish was exposed to paclobutrazol contaminated water for 28 days. Moreover PBZ residues in fish muscle reached 166 mg/kg at the end of the exposure period and suspected significant risk to humans consuming contaminated fish (Jonsson 2002). He suggested that the measure of LDH and GST activities could be used as biomarkers of paclobutrazol exposure. Paclobutrazol has high octanol-water partitioning coefficient (log KoW=3.2) which indicates its potential to bioaccumulate in fish (EFSA 2010). Therefore much caution has to be exercised to prevent contamination of the water bodies with paclobutrazol while using it for certain advantages in mango cultivation. To avoid soil and water contamination, trunk injection and bark application have been attempted (Sterrett 1985, Jacyna and Dodds 1999). Bark application of paclobutrazol has been effective in sweet cherry to avoid contamination of soil (Jacyna and Dodds 1999). Sachs *et al*. (1967) reported that bark application of growth retardants was simple, efficient and environmatally safe, but not many tree species responded to this. Exploring the possibility of alternate methods of application of PBZ (trunk injection and bark application) could be a feasible approach in minimising the soil and water contamination.

Effect on human health

According to the "Globally Harmonized System of Classification and Labeling of Chemicals" (GHS), paclobutrazol has been classified under category 4 and considered moderately hazardous for human being (WHO 2010). It can cause harmful effect if enters either through oral route (LD_{50} = 300 – 2000 mg/kg bw) or dermal route (LD_{50} = 1000 – 2000 mg/kg bw). Skin irritation studies indicated that PBZ is mildly irritating to skin and eye and is not a skin sensitizer. On the other hand, paclobutrazol was neither found genotoxic nor carcinogenic and developmental toxicant up to maternally toxic dose levels (USEPA 2007). Based on *in vitro* and *in vivo* mutagenicity tests, it was concluded that PBZ is not genotoxic. There was no evidence of bioaccumulation and bio-retention of PBZ. It also has a low potential for volatilization with an estimated atmospheric half-life of less than 2 days. Therefore, long-range transport through the atmosphere is not expected (EPSA 2010). PBZ is unlikely to volatilize to any significant extent owing to a low estimated vapour pressure. The possible route of ecological contamination of paclobutrazol has been schematically described (Fig 1). After entering soil system, paclobutrazol can have multi-directional movement; a) absorption by plants, b) soil adsorption, c) movement towards groundwater through percolation and leaching, d) movement towards water bodies through run off and sub-surface flow and e) vapourization. However, slow mobility and low vapour pressure limit the movement of residue of PBZ in groundwater and water bodies, and in the air. The residue of paclobutrazol may reach to the human being by following ways; a) through direct contact, b) through contaminated groundwater, c) through contaminated water bodies, d) by consuming contaminated fish, e) by consuming fruits containing residue and f) through inhalation and may affect human health. Findings clearly indicate that application of optimal dose of PBZ significantly minimises the chance of contamination but the residue may impose a risk to human health if applied in high dose. Moreover the chance of contamination of groundwater and water bodies can be aggravated with the increase in the slope of the land and intensity of rainfall and irrigation (MDAR 2012).

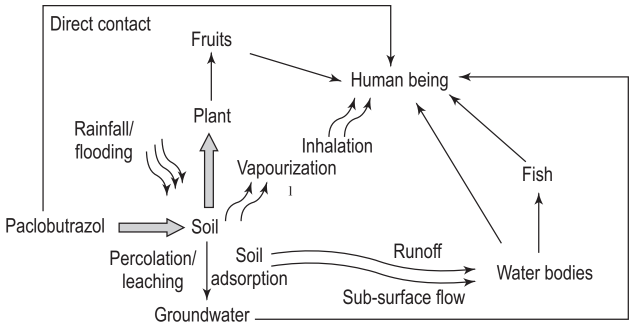

Fig 1 Schematic presentation of paclobutrazol residue movement in the environment

CONCLUSIONS AND FUTURE WORK

This review clearly indicated the usefulness of paclobutrazol for regularity and synchronization in flowering, yield enhancement and tree vigour. On the other hand, if used excessively, it can cause stunting effect to plants and may affect the root and microbial activities in soil. In spite of low mobility, paclobutrazol residue has been detected in soil and fruits, though below quantifiable levels in stray cases. It has low potential to contaminate, surface water and groundwater; however the risk to aquatic life is high and consequently significant risk is suspected if human consumes contaminated fish though paclobutrazol has been considered moderately hazardous for human being with remote chance of being genotoxic and carcinogenic. The important question is whether the continuous use of paclobutrazol is safe or not? Though paclobutrazol has remote chance of ecological contamination due to its low mobility and high persistence, the risk cannot be completely ruled out. In order to minimise residue threats substantially, it is advisable to use the optimal dose at the right time. Due care should be taken to avoid indiscriminate soil application especially in sloppy areas as treated soil is likely to be washed away by rainfall or irrigation runoff. All care should be taken in such areas to avoid erosion of contaminated soil to water bodies. Moreover terracing and bunds could be the effective approach in such locations. The chance of environmental contamination may also be minimized if soil properties, varietal response and climatic conditions are taken into consideration before extensive commercial adoption of PBZ. Alternate methods of paclobutrazol application such as bark application or trunk injection may also be attempted for their effectiveness.

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