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Effectiveness of Paclobutrazol to Augment Fruits Production – A Review

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ABSTRACT

Paclobutrazol is a potent gibberellin synthesis inhibitor that effectively controls the vegetative growth of fruit plants when applied at appropriate quantities and timing. It basically inhibited the activity of mono-oxygenases. As a result, the conversion of GA_{53} into GA_1 (the active form of gibberellic acid) was stopped. Paclobutrazol application increases antioxidant potential, changes biennial bearing problems, inhibits plant growth, reduces internodal distance, inhibits shoot elongation, reduces leaf area, and increases root to shoot ratio. It is reportedly effective in inducing flowering in many tropical, subtropical, and temperate fruit crops. Paclobutrazol is also testified to defend plants from several environmental stresses, viz., drought stress, low and high temperature stress, etc. The available literature on the effectiveness of paclobutrazol on vegetative development, blooming, fruit set, quality yield and nutrient uptake has been reviewed in this paper.

Keywords Paclobutrazol, Fruit quality, Flowering, Return bloom, Nutrient uptake.

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INTRODUCTION

Several techniques are used to inhibit excessive vegetative growth and to maintain canopy size in fruit trees, as the majority of tree cultivars, if allowed to develop naturally, produce larger trees of more than ten metres in height and spread (Webster 2006). Excessive vegetative growth in bearing orchards results in overcrowding and reduces the light penetration into the canopy, which further leads to a reduction in blossoming and ultimately, economic yield in fruit crops (Lal *et al*. 2020). By changing the underlying biochemical and physiological processes, numerous plant growth retardants are commonly employed to manipulate the growth and development of plants. According to the different studies, it was clear that among all the growth retardants, Paclobutrazol is one of the most potent plant growth regulators, limiting vegetative progress and promoting blooming in fruit crops such as apples (Sha *et al*. 2021, Gollagi *et al*. 2019, Wani *et al*. 2007), citrus (Fuentes *et al*. 2013) and peaches (Arzani *et al*. 2009).

Paclobutrazol (PBZ) is a trizol derivative that inhibits gibberellic acid biosynthesis (Klinac *et al*. 2012). It is also known by different trade names viz., Cultar, PP333, Parlay. Its major role is to bring change in the sink source relationship by triazole-1-ethanol, which is also known for reallocating the carbohydrate source towards other organs of the plant rather than the shoot apex and maintaining the lower wilting point (LWP) during stress conditions (Phadung *et al*. 2011). Various methods, viz. soil application, foliar application, injection technique, and trunk application, are being used in the fruit crops for restricting excessive vegetative growth, of which the soil application method is the most commercially applied, followed by the foliar application method. Gollagi *et al*. (2019) explained that, in contrast to the other types of retardants, which are often given as foliar sprays, PBZ is typically applied to the soil due to its low solubility and lengthy residual action. Sherif and Assad (2014) reported that LeConte pear showed a significant improvement in fruit quality with an increased application of paclobutrazol. However, studies have also reported that foliar spray is also found to be effective in controlling the vegetative growth of some fruit plants (Sebastian *et al*. 2019). Application of paclobutrazol through the soil helps in promotion of flowering and increases fruit yield in many fruit crops like mango, citrus, apple, pear, apricot. Also, it has been said that paclobutrazol decreases gibberellin acid biosynthesis and increases cytokinin content, root activity, the ratio of roots to shoots and the C:N ratio in many fruit crops (Gollagi *et al*. 2019).

In 1985, Cultar became a legal entity (Cultar, ICI Americas, Goldsboro, NC). Several nations, including Australia, South Africa, India, the Philippines, the United States and Hungary, now allow it to be used on food crops (Davis *et al*. 1991). Section 9(3) of India's Insecticides Act of 1968 approved paclobutrazol as a plant growth regulator (Kegley *et al*. 2010).

Some important considerations in the use of paclobutrazol

Paclobutrazol: How to use it, and when to use it

Paclobutrazol should be applied to the soil around the tree trunk as a drench to ensure proper uptake by the plant. A liter of water is used to dilute the needed amount and apply it to the ground around the trunk in a circular pattern. The best period to apply paclobutrazol in the top end is between harvest and the beginning of January. A modest watering after application is recommended in dry weather. The soil application method has been found to be more effective than the foliar method.

Age of the tree

First-application tree size is crucial, determined by age and tree spacing. Paclobutrazol, a flowering initiator, limits tree size. Before treatment, trees should grow a good canopy. In dense tree populations with close spacing, apply paclobutrazol when trees are 3 years old. Paclobutrazol reduces canopy size and fruit bearing area when trees are placed 10 meters apart. When trees are 5 years old, treatment can begin. Large, seedling-origin plants respond more slowly than young, bearing grafted trees. Tree size, not age, determines dose.

Tree health and nutrition

Good management practises should accompany any form of treatment that results in an increase in production. Nutrients, irrigation, disease prevention, weed management, and pruning are all part of this process. Pruning and skirting trees after harvesting is a good idea before treatment.

Application methods of paclobutrazol

There are four ways to use paclobutrazol, viz., in the soil, on the leaves, in the trunk, or by injecting it into the plant. Soil and leaves are the most common ways to use paclobutrazol. The most efficient way is to soak paclobutrazol into the soil surrounding the tree trunk (TSLP). With a circular band around the trunk,

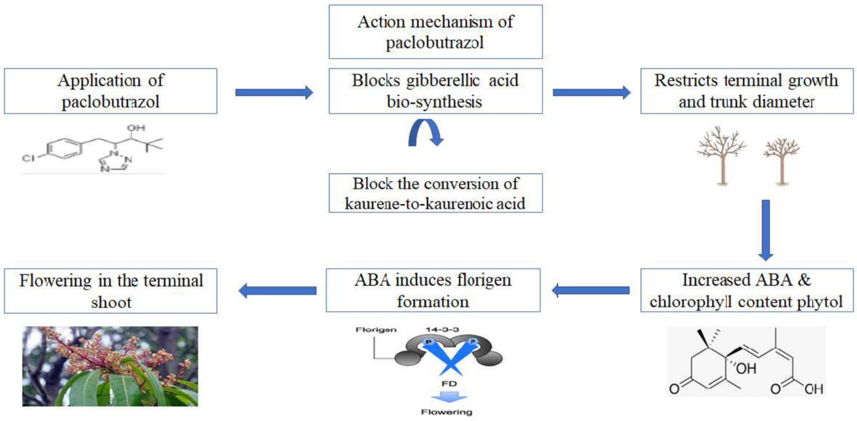

Fig. 1. Action mechanism of paclobutrazol.

combine the needed amount in one liter of water. It's a trizol derivative that inhibits gibberellin production and reduces canopy volume but increases bloom intensity in plants (Sha *et al*. 2021). Paclobutrazol induces mango flowers early and off-season. Paclobutrazol's mechanism of action depends on cultivar, application rate, cultivar, developmental stages, and climate (Nartvaranant *et al*. 2000). So, Cultar shows a lot of promise for controlling flowering, crop yield and plant health in fruit crops.

Mode of action of Paclobutrazol

It basically stops the biosynthesis of gibberellins acid by stopping the transformation of kaurene to kaurenoic acid (Fig. 1). This stops the process of cell elongation and slows the plant's vegetative growth (Lolaei *et al*. 2013). Gibberellin is known to promote cell elongation. When gibberellin production is blocked, cell division still occurs, but the newly produced cells do not extend as well. It results in the formation of new shoots that are shorter and have a shorter internodal spacing. It promotes morphological changes in leaves, such as smaller stomata pores, more surface appendages, thicker leaves, and greater root density, which may improve plant stress and disease resistance (Gollagi *et al*. 2019). It was also reported that xylem tissues take up Cultar and translocate it acropetally to the sub-apical meristem, where it exerts a persistant impact, although phloem translocation has also been reported (Chaney 2005).

Response of Fruit crops To Paclobutrazol application

Some of the main effects and physiological changes that have been linked to the use of paclobutrazol are the production of gibberellins, the stimulation of flowering, the increase of chlorophyll, the slowing of transpiration (by closing stomata) and the activation of antioxidant enzymes (superoxide dismutase, catalase, ascorbate peroxidase and peroxidase) that help reduce oxidative stress. It is applied via foliar and soil at concentrations ranging from 1-200 and 0.1-8.0 mg^{-1}, respectively. The response of paclobutrazol to various attributes of fruit crops has been described below.

Vegetative growth

The most noticeable effects of paclobutrazol on fruit plants are a reduction in plant height, a shortening of the distance between nodes, a slowing of the growth of the shoots, and a greener, more compact plant. The plant becomes greenish due to increased chlorophyll levels per unit leaf area (Fletcher *et al*. 2000). It causes a reduction in shoot growth because of the reduction in the internodal distance and hence shorter shoot growth (Sherif and Assad 2014). Such reports have also been proven by Arzani and Roosta (2004). Paclobutrazol (1-20 g a.i./tree) applied through soil application to mango trees reduced annual shoot extension and internodal length as compared to untreated plants (Mitra 2018). Root pruning + paclobutrazol improved shoot length, internodal length, leaf number, leaf area, fresh leaf weight, maximum nodes, dry leaf weight, and percent bloom (Raja *et al*. 2018). PBZ at 3.0 g a.i./plant showed less plant height (23.67 cm) and canopy spread in the north-south (38.50 cm) and east-west (50.83 cm) directions of jamun plants (Hedge *et al*. 2018). Paclobutrazol at 10 g/plant retarded Roundel apricot tree shoot development, trunk diameter, and trunk cross-section (Mir *et al*. 2015). Garcia *et al*. (2014) also reported the efficacy of paclobutrazol as it leads to inhibition in shoot growth and increases the production efficiency of plants, which largely depends on accurate pruning time. Paclobutrazol is a powerful specific inhibitor of GA_3 biosynthesis that reduces shoot length and internodal distance in greenhouse grown bananas (Lolaei *et al*. 2013). Kundu *et al*. (2013) noted that paclobutrazol at 250 mg/liter along with other regulators at complete petal fall stage showed a significant reduction in the shy bearing habit of sub-tropical pear plants. Klinac *et al*. (2012) reported that there was a marked rate of reduction in the annual shoot length and internodal distance of nashi tree cultivars viz., Hosui, Kosui, Nijisseiki, and Shinsui when paclobutrazol was applied at 125 ppm. Sharma *et al*. (2002) recorded a significant reduction in the annual shoot development, plant height as well as plant spread with the application of 10 g/plant paclobutrazol in Non-Pareil almond plants. Soil application of paclobutrazol (1.5 g/tree) reduces trunk cross-sectional area (33.2 and 37.4 cm^2) in comparison to control (43.1 and 52.6 cm^2) in JH Hale and Red Skin peach varieties, respectively (Arzani *et al*. 2009). Soil application of paclobutrazol at 500 ppm decreased new shoot percent, terminal shoot length and diameter, number of leaves and leaf area, according to Barun and Kumar (2008).

Phenotypic fruit characteristics

Paclobutrazol (PBZ) is a plant growth retardant that is known for inhibiting gibberellin acid biosynthesis. As a result, it stops the vegetative growth in fruit plants like apple, mango, pear, citrus. Reduction in vegetative growth via reduction in the internodal distance causes an increase in the translocation of photosynthetic assimilates toward the developing fruits that further increases fruit yield as well as fruit quality (Sharma *et al*. 2019, Klinac *et al*. 2012).

Prasanna *et al*. (2018) noted that PBZ @ 100 ppm produced the highest fruit weight (865.49 g) without crown, while control plants produced the least (745.04 g). The maximum mean fruit weight (625.20 g) in Banganpalli mango plants was recorded with PBZ at 4 ml/m^{-2} + NAA at 25 ppm (Subbaiah, 2017). Klinac *et al*. (2012) conducted an experiment on two-year-old nashi tree cultivars like Hosui, Kosui, Nijisseiki and Shinsui and reported that all these cultivars showed a significant increase in fruit size and fruit weight. Yadav (2012) reported that application of paclobutrazol at 50 ppm and ethephon at 400 ppm increased fruit weight in cape gooseberry. It was also observed that paclobutrazol had no influence on chemical parameters of fruit quality such as total soluble solids and acidity, but the average weight of a fruit was reduced as a result of PBZ treatment, more so with the soil application (Reddy and Kurian 2008). Increased mean fruit weight was also noticed in papaya cultivar CO-2 with 50 mg/liter of paclobutrazol in combination with 300 g of nitrogen (Auxcilia *et al*. 2010).

Bio-chemical characteristics

As reported by many workers, paclobutrazol (PBZ) was found to be more effective in controlling plant vigour. As a result of the amount of assimilates used for the development of vegetative growth, it will translocate more towards the developing fruit, which further helps in achieving desirable fruit quality (Sharma *et al*. 2019).

Sha *et al*. (2021) demonstrated that a moderate dose of Cultar (1000-1500 mg l^{-1}) may reasonably manage the carbon-nitrogen nutrition of fall branches and fruits, hence boosting fruit quality and the storage nutrient of Fuzi apple trees. Parsana *et al*. (2018) stated that PBZ @ 200 ppm resulted in maximum TSS (16.32 ^{o}Brix), maximum ascorbic acid content (36.8 mg/100g of fruit pulp) and total sugars (12.26%), while PBZ @ 300 ppm recorded maximum reducing sugars (2.93%) in pineapple. Paclobutrazol @ 7500 ppm applied on 15 July or 15 October also resulted in higher edible portion, lower stone pulp ratio, longer shelf life, higher TSS, increased vitamin C, lower titratable acidity, higher dry matter, reducing, non-reducing and total sugar contents (Sarker and Rahim 2018). Souza *et al*. (2016) noted that the doses of paclobutrazol at 1.06 g and 1.09 g of a.i. per linear meter of canopy applied via irrigation increased carbohydrate content in the leaf tissue of mango plants. Sherif and Assad (2014) carried out a study during two successive seasons on five-year-old Le Conte pear trees and reported that fruit quality was significantly increased with the use of paclobutrazol. Upreti *et al*. (2014) indicated that application of paclobutrazol increased the starch level in the leaves of the Totapuri cultivar of mango. In an experiment, it was noted that with the increasing concentration of paclobutrazol, the fruit quality of mango and lemon was increased (Burondkar *et al*. 2013). Kundu *et al*. (2013) noted that PBZ (250 mg/liter) as foliar spray along with other regulators at complete petal fall stage in pear cultivar Gola showed a significant reduction in shy bearing habit with an increase in total sugar content and TSS/acid ratio in fruits.

As a result of paclobutrazol treatment (1.25 g a.i. per meter of canopy diameter), days for 50 % flowering were advanced by 19.3 days, the days from flowering to fruiting reduced by 22 days in Totapuri mango trees (Upreti *et al*. 2012). Yadav (2012) reported that application of paclobutrazol at 50 ppm and ethephon at 400 ppm increased TSS/acid ratio as compared to untreated plants of cape gooseberry. Lolaei *et al*. (2012) reported that in strawberry (*Fragaria ananassa* Duch. cv. Camarosa) foliar application of paclobutrazol and $ZnSO_4$ at 30 mg/liter and 150 mg/liter, respectively, increased the total soluble solid (TSS) by about 8.30 %. Mobli and Baninasab (2008) treated six-year-old almond seedlings with GA_3 followed by paclobutrazol and reported that there was a significant increased level of sugar and starch in the shoots and roots. Whereas it was mismatched with the results of Reddy and Kurian (2008), who noted a reduction in TSS level but an increase in acidity. PBZ treatments, on the other hand, increased TSS per acid ratio while decreasing total sugars in Tommy Atkin mango plants (Yeshtela *et al*. 2004). Singh and Saini (2001) recorded a significant increase in the fruit quality of the Langra cultivar of mango due to the increase in total soluble solids (TSS), total acidity and -amylase activity with the application of paclobutrazol at 6 g a.i./tree. Hoda *et al*. (2001) also conveyed that PBZ improved fruit quality. Jain *et al*. (2002) also reported that the quality of mango and lemon fruits increased with paclobutrazol.

Flowering

Flowering is the transition phase of the plant from vegetative growth to reproductive growth. Photosynthetic input, energy flow, and redistribution of assimilates play a large role in flower initiation. It has been reported that paclobutrazol inductees blossoming in fruit crops by decreasing the gibberellin levels and increasing both auxins and cytokinin content in the shoot tip (Pandey *et al*. 2017).

Morales-Martinez *et al*. (2020) carried out a study to evaluate the effects of potassium, ammonium nitrate and Cultar on flower induction and fruit production in Tommy Atkins mango plants. The study revealed that soil application of Cultar followed by foliar application of potassium nitrate 2, 4 or 6 % induced flowering in just 16 days after the treatment. Further, the maximum number of developed panicles (288.5, 75.17) was also observed with Cultar (1.0 g of a.i. m^{-1}) and potassium nitrate (6%). In a study, it has been reported that 100 and 125 % of the recommended paclobutrazol application were able to induce better flowering of mangosteen and increase the total flower number (1012 and 996 flowers/tree, respectively) as compared to untreated plants, which produce only 472 flowers/tree (Then *et al*. 2019). Upreti *et al*. (2014) also reported that PBZ-induced early and intense flowering in fruit crops may be due to early shoot maturity, increased photosynthesis rate, carbohydrate accumulation, and a decrease in flowering reducing hormone, gibberellins. Spraying PBZ (2-4%) on Hass avocado plants has been shown to increase yield in the off year, followed by a high yield in the previous on year (Mitra 2018). In a study, Pandey *et al*. (2017) reported that the maximum panicles emerging in the canopy are due to 4.0 g PBZ applied through the TSLP method. They also reported that 4.0 g of PBZ through the TSLP method led to the highest percentage of shoots to flower (60%), whereas 3.0 g of PBZ led to the early emergence of panicles in litchi plants. Subbaiah *et al*. (2017) noted maximum percentage of hermaphrodite flower (3.49% and 3.20%) was recorded with 4 ml m^{-2} paclobutrazol followed by 3 ml m^{-2} paclobutrazol. Hedge *et al*. (2018) noted that 2.5 g a.i./plant Cultar showed a greater number of panicles (424), flowers per panicle (51.33) and panicle length (16.16 cm) in jamun plants. Krishna *et al*. (2017) reported that the maximum flowering percentage (14.22) at the initial stage in Banganpalli mango plants planted in a square system was recorded with the application of paclobutrazol (3.0 ml/m^{-1}) while a minimum flowering percentage (7.32) was recorded in the untreated control. However, at 20 days after the initial stage of percent flowering, maximum flowering percentage (54.99%) was recorded with the application of paclobutrazol (3.0 ml/m^{-1}) while a minimum flowering percentage (43.56) was recorded in the untreated control.

Chusri *et al*. (2008) in Irwin mango plants reported that the panicles of paclobutrazol treated trees were considerably shorter than those of control trees. To induce flowering and fruiting in mango plants, PBZ was applied around the trunk using this method rather than the foliar method because it guaranteed proper uptake (Kulkarni *et al*. 2006). The optimal Cultar rate was 1000 ppm/plant with a 5-cm flower raceme (Benjawan *et al*. 2006). Karki and Dhakal (2003) found that putting paclobutrazol on mango plants before the flower buds started to form or three months before they were supposed to flower was a very effective way to get them to bloom without shortening the length of the shoots. Paclobutrazol induced the maximum percentage of flowering shoots in Alphonso mango plants (Murti 2001). Cultar use 90 days before bud break was found to be more efficient than application 60 days before bud break in enhancing fruit crop flowering (Faizan *et al*. 2000).

Fruit set and fruit yield

Paclobutrazol increases the output of numerous fruit crops by inhibiting GA biosynthesis, shifting the carbohydrate source to other organs (Pandey *et al*. 2017). The recommended rate of paclobutrazol application i.e. 100, 125 and 50 % were produced highest number of fruits viz. 36.6, 30.10 and 27.0 kg/tree, respectively at first year as compared to untreated mangosteen trees, which produced only 11.6 kg/tree (Then *et al*. 2019). Paclobutrazol soil drenched @ 7500 or 10000 ppm on 15 July distinctly advanced panicle emergence and fruit harvest by 23 and 22 days, respectively. Further, application of paclobutrazol @ 7500 ppm on 15 July produced the highest number of fruits (185) as well as yield (55.05 kg) per plant (Sarker and Rahim 2018). Among all treatments use of 4.0 ml/ m^{-2} paclobutrazol + 25 ppm NAA was significantly better in getting maximum numbers of fruit (212.33 and 208.33) and maximum yield (88.53 kg and 107.56 kg) in Banganpalli mango plants. However, maximum number of fruit set per panicle (17.7 and 15.4) was recorded with 4.0 ml/ m^{-2} paclobutrazol + 0.02 mM spermidine (Subbaiah 2017). Paclobutrazol @ 100 ppm at 8MAP+9MAP produced the highest fruit yield with crown (51.51 t/ha) when compared to the control (43.03 t/ha) (Prasanna *et al*. 2018). Sherif and Assad (2014) carried out a study during two successive seasons on five-year-old LeConte pear trees and reported that there was significant increase in fruit set percentage in the trees treated with paclobutrazol at 300 ppm. Lolaei *et al*. (2013) also reported that application of paclobutrazol showed a significant increase in fruit yield of banana plants. Lolaei *et al*. (2012) noted 90 mg/liter PBZ + 150 mg/ liter $ZnSO_4$ showed a utmost result for fruit set percentage (87.10), yield/ plant (87.80 g) and fruits quantity (10.10) in Camarosa strawberry plants. Yadav (2012) reported that application of paclobutrazol at 50 ppm and ethephon at 400 ppm increased fruit set and number of fruits per plants in Cape gooseberry. Singh *et al*. (2012) found that PBZ (7.5 ml) suppressed male flower percentage, fruit drop and sex ratio, while PBZ at 2.5 ml and 7.5 ml increased fruit yield in Calcuttia litchi cultivar. Increased mean fruit yield was also noticed in papaya cultivar CO-2 with 50 mg/liter of paclobutrazol in combination with 300 g nitrogen (Auxcilia *et al*. 2010).

In an experiment on cumulative and residual effects of paclobutrazol on growth, yield and fruit quality of Alphonso mango, Reddy and Kurian (2008) noted that with an application of paclobutrazol at 10 g a.i./ tree through drip line resulted in maximum number of fruits per tree (209.40) as compared to control (120.10). Increase in fruit set per panicle in response to paclobutrazol application was also recorded in cultivar Baneshan (Rajkumar *et al*. 2007). Asin *et* *al*. (2006) observed that application of paclobutrazol followed by root pruning increased fruit yield in Blanquilla pear. Bagel *et al*. (2004) recorded maximum yield/ tree, yield/ hectare and yield increase over the control (29.85%) in 10 years-old-mango cultivar Langra with 5.00 g/ha paclobutrazol in combination with 20 ppm NAA. Soil drench method of paclobutrazol (20-40 g/tree) was reported to be the best treatment for promotion of the flowering, fruit set and yield of Dashehari mango plants (Singh *et al*. 2000).

Nutrient uptake

Paclobutrazol (PBZ) has an effect on the nutrient status of numerous fruit crops, including apples, pears, and nectarines. Ashraf *et al*. (2018) reported that application of paclobutrazol along with summer pruning I and summer pruning II resulted in the highest calcium uptake in fruits, with a mean pooled value of 440 ppm as compared to control (220 ppm). It was proved that paclobutrazol is very effective as it increased salt stress by increasing photosynthetic pigments, K^+ uptake and detrimental sodium (Na^+) and chlorine (Cl^-) ions in treated cultivars of mango (Kishore *et al*. 2009). Tamilselvi and Baskaran (2014) reported that paclobutrazol utilization at 2.50 g a.i./ tree accelerated nitrogen content of leaves during the vegetative stage. This trend was continued for two years and resulted in greater N and K content of the leaves when paclobutrazol PBZ was practiced at 3.75 g a.i/tree at the vegetative stage. Upreti *et al*. (2012) reported that paclobutrazol application resulted increase in shoot C:N ratio progressively from 29.5 to 52.4 in the untreated trees to 51.2–67.6 from 30 days before flowering to bud break. Sharma and Joolka (2011) noted reduced P level in leaf with PBZ in almond. Paclobutrazol treatments did not change leaf macronutrient levels (N, P, K and Ca), but micronutrient (Cu, Zn, Fe) levels in treated trees were considerably greater than the control (Yeshitela *et al*. 2004). Arzani and Roosta (2004) reported that PBZ decreased nitrogen (N) content in almond without affecting phosphorus (P), potassium (K) and calcium (Ca). However, the leaf nitrogen (N) and phosphorus (P) were influenced by PBZ treatments in peach, but calcium (Ca) concentrations were increased (Arzani *et al*. 2009). Leal *et al*. (2000) also reported a non-significant effect of paclobutrazol on the macro-nutrient levels of leaves.

CONCLUSION

Paclobutrazol is a triazol growth inhibitor. It lowers GA_3 during the kaurene stage and is used to induce off-season blooming, sustain tree size in HDP and boost fruit quality. By changing the amount of paclobutrazol used on each crop, treatments will be more effective. This will allow for quality fruit production all year long and decrease the amount of residue in orchard soil, trees, fruit and the environment.

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