



## Combating alternate bearing tendency in litchi (*Litchi chinensis*) cultivars through paclobutrazol and potassium nitrate

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### ABSTRACT

A field experiment was conducted during 2018–2020 at ICAR-National Research Centre on Litchi, Muzaffarpur, Bihar to study the effect of paclobutrazol (PBZ) on endogenous hormonal status of shoot buds, flowering, yield and fruit quality attributes of litchi (*Litchi chinensis* Sonn.) cv. Shahi which was also affected by foliar spray of micronutrient solution and amino acids complexes. The trees of litchi cv. China was treated with PBZ (2.5 g a.i./m canopy diameter) and other chemicals like KNO<sub>3</sub> (2.0 %), prohexadion-Ca (pro-Ca) (0.5 g/L), salicylic acid (SA) (2000 ppm), KH<sub>2</sub>PO<sub>4</sub> (0.5%) and spermidine (Spd) (0.01 mM) and girdling. The floral shoots of litchi cv. Shahi had very poor IAA content with high GA<sub>3</sub>, non-floral shoots showed reverse trend, means PBZ (2–3 g) suppressed GA<sub>3</sub> and IAA, and enhanced ABA and cytokinins contents to favour flowering. The 2.0 g PBZ brought highest yield (755.67 fruits/tree), high vitamin C (26 mg/100 g pulp), better TSS over other doses. Micronutrient solution (Zn, Fe, Cu, B, Mn, Mo) and amino acids complexes like ambition-multiplex-ambition (each spray @2 mL/L alternatively as pre-harvest) ensured high tree girth, more floral panicles and significantly higher fruit yield. In alternate bearer litchi cv. China, every year foliar spray of KNO<sub>3</sub> (2.0%) during last week of September month was the most effective way to bring consistency in bearing (2,158 fruits/tree). The KNO<sub>3</sub> (2%) and PBZ (2.5 g) application might bring excellent fruit quality in terms of TSS and vitamin C content in litchi.

**Keywords:** Bio-regulators, Girdling, KNO<sub>3</sub>, PBZ, Prohexadione-Ca, Quality, Yield

In India, erratic flowering, intensive vegetative growth and irregular bearing are typical in most litchi (*Litchi chinensis* Sonn.) orchards especially in variety ‘China’; however ‘Shahi’, although a regular bearing variety, also show shy bearing tendency. The different forms of stress with respect to flower induction was tried to induce flowering in litchi, such as low temperature, drought stress, physical stress (girdling) and chemical stress [application of ethrel and paclobutrazol (PBZ)].

Several research workers have advocated the use of various growth retardants as an alternate approach in litchi to restrict vegetative growth before panicle emergence. One method to manipulate flowering is to use plant growth retardant like PBZ. The post-flushing application of a small amount of PBZ to the soil significantly promotes flowering and fruiting in the following year. According to Singh *et al.* (2017), the harvesting of litchi fruits with few leaves, post-harvest cincturing, use of PBZ/or KNO<sub>3</sub> during September-October is very effective in the sub-tropics to

inhibit winter flushing and induce synchronous flowering. Using salicylic acid can also improve yield as well as fruit quality in different fruit crops. The increased ABA, and decreased CKs (cytokinins) in the buds/ leaves lead to strong bud dormancy and inhibits new flushing (Liu *et al.* 2022) that conducive for flowering. The girdling improves flowering and production during years of poor production ("off" years). However, when conditions are favourable for flower initiation, girdling does not have a marked effect on improvement of flowering and production (Menzel 1983). The spray of PBZ/or KNO<sub>3</sub> induced flowering in ‘China’ litchi (Malhotra *et al.* 2018). Application of PBZ (3 mL a.i./m<sup>2</sup> canopy surface area) advanced the flower emergence by 6–7 days (Singh *et al.* 2017, Singh *et al.* 2025). In fact, the leaf arrangement in litchi cv. China is bushy in appearance which imparts shade on lower leaves, and thereby, shaded leaves had lower net photosynthetic rate (Chang and Lin 2007), which ultimately results to biennial bearing. Litchi cv. Shahi doesn't have such phyllotaxy (i.e. few no. of overlapping leaves meaning sparse foliage).

Looking to the above facts, an investigation was conducted to observe different doses of PBZ in litchi cv. Shahi on endogenous hormonal status and bearing tendencies. Another objective of this investigation was to ascertain regular flowering in litchi cv. China through

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application of PBZ, KNO<sub>3</sub> and other bearing regulating practices. Spray of micronutrient mixtures and amino acid complexes were also tried to overcome shy bearer tendency in litchi cv. Shahi.

#### MATERIALS AND METHODS

The field experiment was conducted during 2018–2020 at ICAR-National Research Centre on Litchi, Muzaffarpur (26°05'87" N, 85°26'64" E; at an elevation of 210 m amsl), Bihar.

*Cultivar selection:* Two important commercial cultivars, 12-year-old 'China' (presumed to be alternate bearer) and 10-year-old 'Shahi' (considered as regular bearer) spaced at 8 m × 8 m were used in the experiment with uniform cultural practices. Three replicate trees were selected for recording observation. The experiment was laid out in randomised block design (RBD).

*Application of PBZ in litchi cv. Shahi:* The trees were exposed to three levels of PBZ ('Cultar' from Indonesian Operations, Jakarta) @1.0, 2.0, 3.0 g a.i./m canopy diameter, applied as soil drench underneath the canopy during first week of October. The control trees were subjected to simple distilled water. The trees were selected to assess endogenous hormonal status in shoot buds for estimation of endogenous hormones [Gibberellic Acid (GA<sub>3</sub>), indole acetic acid (IAA), ABA and CKs in terms of Zeatin (Z), Zeatin riboside (ZR), Dihydrozeatin riboside (DHZR) and isopentenyladenine (iPA)]. The trunk girth was measured at 30 cm above from the base and expressed in cm. The canopy height was taken from place of first branching of main stem to the apex of the canopy and recorded in meter for estimation of TCA as per the following formula.

$$\text{Trunk cross sectional area (TCA) (cm}^2\text{)} = \frac{\text{Trunk circumference (cm)} \times 0.16}{2 \times 3.143}$$

The leaf relative water content (RWC) was measured as per the method suggested by Pieczynski *et al.* (2013). The leaf area (cm<sup>2</sup>) was measured with the use of scanner (Epson Perfection, V 700 Photo, Scanner, Seiko Epson Corporation, Japan). The total number of male flowers/panicle was estimated by counting floral shoots of tagged branches in individual trees. The number of fruits/panicle was estimated by counting number of fruits set on tagged panicle and average of five panicles was taken for final value of the average fruit yield of the tree. Productivity efficiency (kg/cm<sup>2</sup>) was estimated as yield per unit trunk cross-sectional area (TCA). The total soluble solids (TSS) of fully ripened litchi fruit was recorded using hand refractometer and the value was corrected at 20°C and expressed in °Brix. The total acidity of fruits was determined by the titration method as described by Ranganna (1997). TSS:acid ratio was estimated by dividing both of the attributes. Ascorbic acid content was determined as method described by Ranganna (1997). The fruit parameters like fruit weight and pulp (aril) content were measured in the laboratory using electronic balance.

*Application of PBZ and KNO<sub>3</sub> in litchi cv. China:* The four levels of PBZ i.e. 1.0, 2.0, 3.0 and 4.0 g a.i./m canopy

diameter, applied as soil drench underneath the canopy and two levels (1% and 2%) of KNO<sub>3</sub> as foliar spray were used. Here, there were two set of the treatments which were imposed in two rows and each row received alternate year and every year of above treatment. All the treatments were imposed during first week of October. Only bearing (yield as number of fruits/tree) was estimated in this experiment.

*Application of bearing regulating practices in litchi cv. China:* The details of treatments were, foliar spray of KNO<sub>3</sub> (2.0%), pro-Ca (0.5 g a.i./L); PBZ (2.5 g a.i./m canopy diameter); girdling with 3 mm intensity practiced in 75% branches; foliar sprays of SA @2, 000 ppm, KH<sub>2</sub>PO<sub>4</sub> @0.5% and Spd @0.01Mm. All the treatments were imposed during last week of September. The entire experiment was replicated thrice with a single tree assumed as one unit (replication). All the chemicals except PBZ were sprayed in the evening hour with a rocker sprayer (after adding active-20 as a surfactant). For the application of PBZ, a shallow circular trench (10 cm deep) was dug at a radius of 1 m from the base of each tree. The Burondkar and Gunjate (1993) method of soil drenching was followed. Control trees were drenched with distilled water. For girdling, a stripe of bark (2–3 mm width) was removed in a circular fashion around the selected primary branch with the help of a pruning saw. The phloem portion was removed carefully without damaging the xylem. The number of flushes/tree was recorded during second fortnight of December month in all the four directions of the tree. TSS, titratable acidity, TSS:acid ratio, vitamin C, fruit weight and pulp content were assessed as per methods mentioned above in litchi cv. Shahi.

*Effect of micronutrient solution in litchi cv. Shahi:* The tree was spaced at 10 m × 10 m apart and were exposed to four levels of treatments like T<sub>1</sub>, Multiplex (sprayed thrice); T<sub>2</sub>, Ambition-multiplex-ambition; T<sub>3</sub>, Multiplex-ambition-multiplex; and T<sub>4</sub>, Ambition (sprayed thrice). The control trees were sprayed with distilled water. Ambition (mixture of amino acids and fulvic acid) and multiplex [Zn (5%), Fe (0.5%), B (0.5%), Mn (0.2%), Mo (0.02%) and Cu (0.5%)] were taken in different combinations with uniform dose of 2 mL/L. The spraying was done at 15 days interval after fruit set (in between 5<sup>th</sup> April-15<sup>th</sup> May). The flowering, yield and fruit quality attributes were analysed as per standard procedure as mentioned above.

*Methodology adopted for phytohormonal analysis:* The contents of IAA, GA<sub>3</sub>, ABA and cytokinins (Z, ZR, DHZ, DHZR and iPA) were analysed in shoot bud using UPLC (Model: Prominence, Shimadzu, Japan) equipped with PDA detector (SPD-M20A) and Synergy 4 μm fusion RP-C18 column (Phenomenex, USA, 250 × 4.6 mm).

*Estimation of alternate bearing index (I):* It was ranged from 0–1, with 0 = no alternation and 1 = complete yield loss in both the cultivars. The following formula was used to estimate the alternate bearing index (I).

$$I = 1/(n-1) \times \{ |(a_2 - a_1)/(a_2 + a_1)| + |(a_n - a_{(n-1)})/(a_n + a_{(n-1)})| \}$$

Where n, Number of years; a<sub>1</sub>, a<sub>2</sub>, ..., a<sub>(n-1)</sub>, a<sub>(n)</sub>, Yield of corresponding years.

**Statistical analysis:** Selected data were presented as means of all independent experiments ( $n = 3$ ) with three replicates of each sample. The mean was computed for the data on various attributes, whereas a two-factor analysis of variance (ANOVA) using a randomised block design (RBD) was conducted with SAS<sup>®</sup> 9.2 statistical software. The least significant differences (LSDs) between means at  $p=0.05$  and the standard error (SE) of means were computed.

## RESULTS AND DISCUSSION

**Influence of PBZ on the levels of endogenous hormones in shoot buds in litchi cv. Shahi:**  $GA_3$  content was found to decrease progressively, while ABA, cytokinins (Z, ZR and DHZR) level increased significantly with increasing PBZ (Table 1). The lowest  $GA_3$  (14.51 ng/100 mg) was in trees who received PBZ @3.0 g while the highest  $GA_3$  (33.11 ng/100 mg) was in untreated (flowering) trees. The untreated (control) non-flowering (NF) trees showed the highest IAA (160.42 ng/100 mg) with lowest ABA level (40.43 ng/100 mg). Among PBZ treatments, PBZ @2.0 g resulted highest IAA contents (48.34 ng/100 mg). ABA level (103.02 ng/100 mg) was highest in trees with PBZ @3.0 g, followed by PBZ @2.0 g (77.49 ng/100 mg) and 1.0 g (50.92 ng/100 mg). Zeatin (Z) (48.01 ng/100 mg), Zeatin riboside (ZR) (35.91 ng/100 mg), and Dihydrozeatin riboside (DHZR) (30.13 ng/100 mg) were significantly higher in PBZ @3.0 g treated trees. Untreated (NF) trees had the lowest Z (15.15 ng/100 mg) and ZR (11.70 ng/100 mg). The lowest DHZR level was found in untreated flowering trees (10.55 ng/100 mg). The isopentenyladenine (iPA) level was highest in PBZ @2.0 g (36.86 ng/100 mg), followed closely by PBZ @3.0 g (35.12 ng/100 mg), and lowest in untreated trees (around 10.92 ng/100 mg in non-floral trees and 10.97 ng/100 mg in flowering trees). The strongest suppression of  $GA_3$  was observed at the highest concentration of PBZ (3.0 g). The higher dose of PBZ elevates ABA and cytokinins (Z, ZR, DHZR, iPA), favourable for flowering and fruiting. The IAA content was notably highest and CKs were lowest in untreated non-flowering (NF) trees. Among treated trees, moderate PBZ (2.0 g) resulted in a relatively higher IAA

level compared to the other doses, conducive to flowering. According to Cui *et al.* (2013), floral buds contained a higher level of abscisic acid (ABA) and a lower level of GAs than reproductive buds. All CKs levels increased significantly with PBZ application, particularly at the higher doses of PBZ which favour floral differentiation. The reduced  $GA_3$  and IAA, increased ABA and cytokinins created a physiological state favouring flowering in litchi. The untreated non-flowering plant was dominated by high IAA and low ABA/CKs, which likely inhibited floral bud initiation. The balance between ABA,  $GA_3$  and CKs is critical for floral induction. Singh *et al.* (2020) found that lower dose of PBZ (i.e. <2.0 g/m canopy diameter) retained higher IAA and the highest flowered shoots in 'Shahi' litchi. These results implicated that PBZ besides affecting gibberellins also increases ABA and CKs concomitant with C:N ratio and leaf water potential in mango buds to elicit flowering responses (Upreti *et al.* 2012).

**Influence of PBZ on yield attributes and fruit quality in litchi cv. Shahi:** The trunk cross-sectional area (TCA) and relative water content (RWC) were highest in tree applied with PBZ @2.0 g (225.79 cm<sup>2</sup>, 51.66%, respectively) (Table 2). The TCA was lowest in tree receiving PBZ @3.0 g (162.77 cm<sup>2</sup>) with lowest fruit count (14/panicle). The lowest RWC (35.81%) and maximum number of fruits/panicle (28.40) were in tree received PBZ @1.0 g followed by control trees (243.60). On tree basis (three year pooled average), maximum yield (755.67 fruits/tree) was recorded with tree applied with PBZ @2.0 g and lowest yield (108.67 fruits/tree) was with PBZ @3.0 g or control trees (234.00). In preceding year, the PBZ (2.0 g) application in litchi cv. Shahi, the yield was far ahead (1,000–1,134 fruit/tree). For other tree, the yield varied in between 22–500 fruits/tree. The productivity efficiency (kg/cm<sup>2</sup>) was highest in control trees (0.017) and lowest in trees received PBZ @3.0 g (0.003) (Table 2). PBZ @1.0 g was most effective in improving sugar-acid balance and TSS in litchi cv. Shahi. PBZ @2.0 g application showed moderate flowering (91), highest fruit set/panicle (23.6) and highest fruit number/tree (755.67), high vitamin C and better TSS surpassing other treatments.

Table 1 Endogenous hormones level of shoot buds affected by PBZ application in litchi cv. Shahi

*Treatment	$GA_3$ (ng/100 mg)	IAA (ng/100 mg)	ABA (ng/100 mg)	Z (ng/100 mg)	ZR (ng/100 mg)	DHZR (ng/100 mg)	iPA (ng/100 mg)
PBZ @3.0 g	14.51 ± 0.20	40.71 ± 0.22	103.02 ± 0.10	35.91 ± 0.04	48.01 ± 0.076	30.13 ± 0.103	35.12 ± 0.416
PBZ @2.0 g	22.79 ± 0.025	48.34 ± 0.12	77.49 ± 1.40	34.30 ± 0.47	42.50 ± 0.578	20.27 ± 0.305	36.86 ± 0.082
PBZ @1.0 g	28.78 ± 0.47	38.06 ± 0.63	50.92 ± 0.30	27.53 ± 0.11	33.29 ± 0.416	17.73 ± 0.177	12.64 ± 0.023
Un-treated (F)	33.11 ± 0.48	30.23 ± 0.12	57.20 ± 0.36	20.64 ± 0.33	16.78 ± 0.143	10.55 ± 0.151	10.97 ± 0.004
Untreated (NF)	25.36 ± 0.08	160.42 ± 0.95	40.43 ± 0.27	15.15 ± 0.04	11.70 ± 0.206	11.97 ± 0.092	10.92 ± 0.084
CD ( $p=0.05$ )	0.81	1.73	2.19	0.90	0.87	0.56	0.55
SEM±	0.26	0.55	0.70	0.29	0.28	0.18	0.17

PBZ, Paclobutrazol; IAA, Indole Acetic Acid; GA, Gibberellic Acid; ABA, Abscisic Acid; Z, Zeatin; ZR, Zeatin riboside; DHZR, Di-hydrozeatin riboside. \* per meter canopy diameter. Each value is means ± SE from three replicate trees. Each value in one replicate is calculated from three shoot buds/panicles. Analysis was performed by using a one-way ANOVA. Values represent the mean ± SE.

Table 2 Effect of PBZ application on growth, flowering and yield of litchi cv. Shahi

Treatment	TCA (cm <sup>2</sup> )	RWC (%)	Leaf area (cm <sup>2</sup> )	No. of male flower/panicle	No. of fruits/panicle	Yield (No. of fruits/tree)				Productivity efficiency (kg/cm <sup>2</sup> TCA)	*ABI (l)
						2018	2019	2020	Pooled average		
PBZ @3.0 g	162.77 ± 0.49	43.05 ± 0.77	38.66 ± 0.65	40.00 ± 0.41	10.00 ± 0.07	22 ± 0.32	235 ± 5.04	69 ± 1.21	108.67	0.003	0.829
PBZ @2.0 g	225.79 ± 3.29	51.66 ± 0.32	28.66 ± 0.42	91.00 ± 1.18	23.60 ± 0.05	1134 ± 21.84	1008 ± 24.66	125 ± 2.34	755.67	0.007	0.059
PBZ @1.0 g	177.56 ± 3.60	35.81 ± 0.45	36.66 ± 0.54	287.40 ± 3.74	28.40 ± 0.66	36 ± 0.21	528 ± 8.79	227 ± 0.94	263.67	0.016	0.872
Un-treated	193.00 ± 1.40	46.83 ± 0.68	44.33 ± 0.27	243.60 ± 6.21	14.00 ± 0.27	356 ± 3.70	71.00 ± 1.81	275 ± 6.16	234.00	0.017	0.644
CD ( <i>p</i> =0.05)	9.17	2.31	1.228	13.48	1.34	40.15	49.49	13.36	-	-	-
SEM±	2.60	0.65	0.348	3.82	0.38	11.38	14.03	3.78	-	-	-

\*ABI, Alternate bearing index; TCA, Trunk cross-sectional area; RWC, Relative water content.

The highest TSS (16.10°B), highest pulp content (52.09%) and lowest acidity (0.80%) were observed with PBZ @1.0 g (Table 3). Thus, 1.0 g PBZ improved fruit palatability by enhancing sweetness over sourness. The pulp vitamin C was maximum in control trees (27.00 mg/100g) followed by 1–2 g PBZ (26.00 mg/100g in both the treatment), while PBZ @3.0 g caused reduced content (24.00 mg/100g). The average fruit weight was although high (15.59 g) in control trees but PBZ @1.0 g also brought sized (15.26 g) fruits. This may suggest that PBZ @2.0 g produces a higher total

yield in litchi cv. Shahi. Because less no. of fruits/tree was observed in the control trees, it produced heavier fruits with higher pulp and vitamin C content but with a less favourable sugar: acid ratio.

*Regularity in bearing in litchi cv. China through PBZ and KNO<sub>3</sub>*: In litchi cv. China (Table 4), after pooling of two years data, the average yield was highest (2,158 fruits/tree, almost double than the control trees) in tree sprayed with 2.0% KNO<sub>3</sub>. The control trees had only 1,221 fruits/tree that too because of no fruiting at all in preceding year

Table 3 Effect of PBZ on fruit quality parameters in litchi cv. Shahi

Treatment	Fruit weight (g)	*Pulp content (%)	TSS (°B)	Titrateable acidity (%)	Vitamin C (mg/100g pulp)	TSS:acid ratio
PBZ @3.0 g	14.43 ± 0.303	50.38 (45.20)	15.20 ± 0.03	1.00 ± 0.006	24.00 ± 0.28	14.84 ± 0.20
PBZ @2.0 g	14.16 ± 0.006	49.64 (44.77)	15.9 ± 0.04	0.90 ± 0.015	26.00 ± 0.54	17.67 ± 0.20
PBZ @1.0 g	15.26 ± 0.071	52.09 (46.18)	16.10 ± 0.36	0.80 ± 0.003	26.00 ± 0.29	20.13 ± 0.19
Un-treated	15.59 ± 0.104	51.50 (45.84)	15.10 ± 0.20	0.90 ± 0.015	27.003 ± 0.45	16.78 ± 0.07
CD ( <i>p</i> =0.05)	0.58	0.93 (0.534)	0.65	0.04	1.60	0.53
SEM±	0.16	0.264 (0.151)	0.18	0.01	0.45	0.15

\* Value in parenthesis indicates angular transformed values. PBZ, Paclobutrazol.

Table 4 Effect of PBZ and KNO<sub>3</sub> application on litchi yield cv. China

Treatment (per m canopy diameter)	Yield (no. of fruits/tree)				ABI (l)
	2019 (Every year)	2019 (Alternate year)	2020	Pooled average	
1.0 g PBZ	0	220 ± 5.26	3253 ± 23.36	1157.67	1.000
2.0 g PBZ	725 ± 12.45	20 ± 0.46	1897 ± 22.70	880.67	0.447
3.0 g PBZ	255 ± 3.85	80 ± 0.79	522 ± 1.90	285.67	0.344
4.0 g PBZ	21 ± 0.18	2115 ± 37.42	184 ± 4.40	773.33	0.795
1% KNO <sub>3</sub>	45 ± 1.00	85 ± 0.26	1897 ± 16.78	675.67	0.954
2% KNO <sub>3</sub>	2427 ± 6.28	223 ± 1.16	3824 ± 91.54	2158.00	0.223
Un-treated (control)	0	0	3663 ± 83.87	1221.00	1.000
CD ( <i>p</i> =0.05)	16.69	45.04	147.23	-	-
SEM ±	5.35	14.45	47.26	-	-

PBZ, Paclobutrazol; ABI, Alternate bearing index.

(2019) and good fruiting in 2020. This dose (2% KNO<sub>3</sub>) also led to highest yield record (2,427 and 3,824 fruits/tree in 2019 and 2020, respectively) and control trees shown strong alternate bearing tendency with 3,663 fruits/tree (in 2020) and cipher yield in preceding year (2019). Kumari *et al.* (2021) also obtained highest fruit yield (55.42 kg/tree) because of spray of KNO<sub>3</sub> during end-September in litchi cv. China. The control trees yielded 0.80 kg/tree only. PBZ application (4.0 g) although had excellent yield (2,115 fruits) in 2019 (alternate year), but very low (184 fruits) in 2020. Thus, we can say that alternate year application of PBZ (4.0 g) in litchi cv. China was found to be better for stabilising yield (notable yield gain of 52%) (Ray and Rani 2004). Every year application of PBZ (4.0 g) could be deleterious. Every year spray of KNO<sub>3</sub> (2.0%) was best for highest yield record and especially during expected 'off' year, even during 'on' year the highest fruit yield (3,824 fruits/tree) was recorded.

*Bringing regularity in bearing in litchi cv. China through bearing regulated practices:* In a separate experiment (Table 5), KNO<sub>3</sub> (2%), SA (2000 ppm), and Spd had been able to reduce winter flush counts in litchi cv. China. The spray of Spd (0.01 mM) brought highest pooled average no. of panicles/tree (180.16) with a huge jump in 2020 (352). KH<sub>2</sub>PO<sub>4</sub> (0.5%) also showed higher number of panicles/tree (164.66). The spray of 2.0% KNO<sub>3</sub> during end-September month had recorded highest yield (2,427.67, 4,780 fruits/tree, respectively) during both the years of experiment (average: 3,603.84 fruits/tree) which might be attributed to winter flushes inhibition (reduced by 30%). Spray of Pro-Ca and salicylic acid also had high average yields (3,119.34 and 2,319.84 fruits/tree, respectively). Control trees consistently had the lowest yield (1,550 fruits/tree) and number of floral panicles across both years. Thus, for higher yield, we should spray KNO<sub>3</sub> (2%) or Pro-Ca in the trees of litchi cv. China. According to Pires and Yamanishi (2014), the trunk girdling combined with an application of 1,000 mg a.i. PBZ/linear m of canopy in litchi cv. Bengal significantly increased the average yield in two seasons by 6.4-fold and 5.6-fold compared to the control trees.

The highest TSS (20.38°B) and pulp content was in trees, received PBZ @2.5 g, while the lowest TSS (17.99°B) was with Pro-Ca and untreated trees (18.48°B). The control trees (0.50%) had highest acidity and lowest TSS:acid ratio (40.80), vitamin C (26.03 mg/100 g pulp) and average fruit weight (18.41 g) (Table 6). Thus, the application of PBZ (2.5 g) and KNO<sub>3</sub> (2.0%) improved TSS, pulp content, vitamin C and TSS:acid ratio. Control trees were inferior in all aspects.

*Effect of micronutrient solution in litchi cv. Shahi:* Statistical analysis (Supplementary Table 1) revealed that the total no. of fruits/panicle (6.67) and total number of fruits/tree (2,197.67) was highest because of alternate spray of ambition-multiplex-ambition. The lowest yield (5.00 fruits/panicle; 1,006.67 fruits/tree) was recorded with spray of ambition (thrice) with high TSS (20.84°B). The lowest TSS was in the control (20.38°B) trees.

Table 5 Effect of bearing regulated practices on winter flushing and fruit yield in litchi cv. China

Treatments	No. of flushes/tree			No. of panicles/tree			Yield (No. of fruits/tree)			ABI (l)
	2019	2020	Pooled average	2019	2020	Pooled average	2019	2020	Pooled average	
	KNO <sub>3</sub> (2%)	20 ± 0.11	120.00 ± 2.43	70.00	256.66 ± 0.22	158.33 ± 2.26	207.50	2,427.67 ± 11.75	4,780 ± 99.36	
Pro-Ca (0.5 g)	180 ± 1.78	248.33 ± 5.30	214.16	170.66 ± 0.62	241.67 ± 1.00	206.17	2,006.67 ± 5.23	4,232 ± 4.16	3,119.34	0.357
^PBZ	70 ± 0.98	142.00 ± 0.89	106.00	7.33 ± 0.11	208.33 ± 2.06	107.83	40.67 ± 0.10	4,341 ± 49.96	2,190.84	0.982
@Girdling	147.66 ± 3.30	46.00 ± 0.12	96.83	211.66 ± 4.95	111.67 ± 1.04	161.66	1,448.67 ± 20.36	3,259 ± 10.41	2,353.84	0.385
\$SSA (2000 ppm)	23.0 ± 0.57	86.66 ± 0.81	54.83	62.33 ± 0.26	263.33 ± 0.00	162.83	584.67 ± 10.34	4,055 ± 84.66	2,319.84	0.748
KH <sub>2</sub> PO <sub>4</sub> (0.5%)	389.33 ± 5.065	13.66 ± 0.19	201.49	7.66 ± 0.16	321.67 ± 0.00	164.66	70.00 ± 0.40	3,180 ± 3.24	1,625.00	0.957
Spd (0.01mM)	140.00 ± 0.438	52.00 ± 1.08	96.00	8.33 ± 0.036	352.00 ± 7.15	180.16	67.67 ± 0.60	4,120 ± 64.53	2,093.84	0.968
Control	132.66 ± 2.899	68.33 ± 0.99	100.49	3.33 ± 0.078	215.00 ± 2.57	109.16	35.00 ± 0.40	3,065 ± 23.78	1,550.00	0.977
CD (p=0.05)	7.73	6.27	-	5.48	9.241	-	28.44	165.52	-	-
SEM±	2.52	2.05	-	1.79	3.017	-	9.28	54.05	-	-

^, 2.5 g/m canopy diameter; @, 3 mm in 75% primary branches; \$, Salicylic acid; Spd, Spermidine; ABI, Alternate bearing index.

Table 6 Effect of different bearing regulating practices on physico-chemical attributes in litchi cv. China

Treatment	Fruit weight (g)	*Pulp content (%)	TSS (°B)			Titrate acidity (%)			TSS:acid ratio			Vitamin C (mg/100 g pulp)		
			2019	2020	Pooled average	2019	2020	Pooled average	2019	2020	Pooled average	2019	2020	Pooled average
KNO <sub>3</sub> (2%)	19.41 ± 0.03	64.29 (53.28)	21.53 ± 0.22	18.45 ± 0.29	19.99	0.33 ± 0.006	0.45 ± 0.00	0.39	66.76 ± 1.18	41.50 ± 0.10	54.13	28.15 ± 0.04	29.5 ± 0.59	28.83
Pro-Ca (0.5 g)	19.31 ± 0.25	64.16 (53.20)	17.47 ± 0.3	18.50 ± 0.26	17.99	0.29 ± 0.003	0.42 ± 0.012	0.35	61.44 ± 0.77	43.75 ± 0.11	52.60	22.07 ± 0.52	33.50 ± 0.40	27.79
^PBZ	18.44 ± 0.46	67.62 (55.29)	22.60 ± 0.38	18.15 ± 0.44	20.38	0.34 ± 0.006	0.55 ± 0.012	0.44	66.97 ± 0.94	33.27 ± 0.52	50.12	25.19 ± 0.22	33.00 ± 0.65	29.10
@Girdling	18.74 ± 0.24	65.10 (53.76)	18.53 ± 0.30	18.20 ± 0.34	18.37	0.38 ± 0.00	0.45 ± 0.00	0.42	49.46 ± 1.19	40.98 ± 0.47	45.22	22.59 ± 0.00	28.00 ± 0.44	25.30
§SSA (2000 ppm)	19.85 ± 0.45	64.13 (53.18)	21.47 ± 0.18	19.00 ± 0.01	20.24	0.39 ± 0.006	0.50 ± 0.00	0.45	54.73 ± 0.17	38.00 ± 0.22	46.37	29.26 ± 0.69	30.00 ± 0.08	29.63
KH <sub>2</sub> PO <sub>4</sub> (0.5%)	18.94 ± 0.05	64.41 (53.35)	20.20 ± 0.34	18.20 ± 0.19	19.20	0.39 ± 0.009	0.51 ± 0.006	0.45	51.80 ± 0.40	36.41 ± 0.32	44.10	24.82 ± 0.13	31.00 ± 0.56	27.91
Spd (0.01mM)	18.80 ± 0.22	63.61 (52.87)	21.37 ± 0.28	19.20 ± 0.02	20.29	0.40 ± 0.006	0.45 ± 0.009	0.42	53.12 ± 1.22	43.18 ± 0.85	48.15	22.59 ± 0.04	31.00 ± 0.52	26.80
Control	18.41 ± 0.21	66.97 (54.91)	18.07 ± 0.27	18.90 ± 0.01	18.48	0.35 ± 0.00	0.64 ± 0.009	0.50	52.07 ± 0.19	29.53 ± 0.46	40.80	24.07 ± 0.49	28.00 ± 0.06	26.03
CD (p=0.05)	0.89	0.43 (0.263)	0.86	NS	-	0.017	0.024	-	2.518	1.42	-	1.18	1.50	-
SEM±	0.29	0.14 (0.086)	0.28	0.25	-	0.006	0.008	-	0.822	0.46	-	0.38	0.49	-

\*Value in parenthesis indicates angular transformed values. ^, 2.5 g/m canopy diameter; @, 3 mm in 75% primary branches; §, Salicylic acid; Spd, Spermidine.

In conclusion, although in litchi cv. Shahi, the PBZ @3.0 g was best for reducing GA<sub>3</sub>, enhancing ABA and cytokinins that supports flower induction, but PBZ @2.0 g caused balanced reduction in GA<sub>3</sub> and IAA with elevated iPA and most effective treatment in terms of overall enhancement in fruit set/ yield, high TCA, leaf RWC, fruit's TSS and vitamin C content. In litchi cv. China, every year spray of KNO<sub>3</sub> (2.0%) during first week of October was the most effective tool for yield enhancement (and for combating shy bearing) with fewer winter flushes, and better fruit quality (high individual fruit weight, TSS, high TSS: acid ratio, pulp vitamin C content).

Higher dose (4.0 g/m canopy diameter) of PBZ could be proved better to bring regularity in bearing in litchi cv. China if applied in alternate years if preceding year is 'on' year. The foliar spray of ambition-multiplex-ambition (2 mL/L as alternate spray at 15 days interval starting from 5<sup>th</sup> April) will enhance yield (more than 70% over control trees) in litchi cv. Shahi.

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