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Management of alternate bearing and flower induction in litchi cv. China

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ABSTRACT

To counteract the alternate bearing in some litchi cultivars, an experiment was conducted on annual guided branch girdling for four consecutive fruit bearing years using a commercial plantation of litchi cv. China litchi at Ranchi, India. Trees were girdled by removing a bark strip (2, 4 and 6 mm width) circularly around the selected 25% and 50% primary branches. During OFF- years, the flowering was increased by 8.62 (2017) and 4.37 (2019) times whereas; it was 3.49 (2015) and 1.68 (2018) times higher during ON-years with the L2G2 treatment (4 mm width girdling of 50% primary branches). Treatment L2G2 also showed the highest cumulative yield with 201.19 kg/tree from four years, while the control showed the lowest cumulative yield with 96.98 kg/tree. After four years, the pooled fruit yield data showed that the highest average yield was recorded in L2G2 treatment (50.30 kg/ tree), and it was lowest in the control (24.24 kg/ tree). The pooled data also showed that the highest average alternate bearing index (*I*) value (0.73) was observed in the control treatment whereas it was lowest (0.32) in L2G1 (2 mm width girdling of 50% primary branches) followed by L2G2 (0.35) treatment. The Long-Term Yield Index (LTYI) ranged from 31.01% in control to 122.25% in L2G2 treatment. Therefore, 4 mm width girdling of 50% primary branches, reduces alternate bearing behaviour of litchi cv. China. In our experiment, cumulative yield was increased by 2.07 times (under L2G2) as compared to un-girdled trees during the four years of the trial.

Key words: *Litchi chinensis* Sonn., alternate bearing, yield, girdling, long-term yield index,

INTRODUCTION

The yield of many fruit trees is erratic due to the occurrence of varying degrees of alternate and irregular bearings. Alternate bearing has an impact on a few fruit trees that consists of the changes in the yield level with a high yield ("ON" year) and a low yield ("OFF" year) in the following year. This pattern repeats year after year. There are several reports about alternate bearing in fruit plants including litchi (Monselise and Goldschmidt, 12). Alternate bearing results from genetic characteristics, growth conditions, endogenous hormonal level, crop load and impact of other particular annual variables related to carbohydrate storage and mobilization (Barnett and Mielke, 3; Wood, 18). The area under litchi in India is approximately 95000 ha, producing 727000 tonnes annually (Anonymous, 1). Litchi has a narrow genetic base in India (Bajpai *et al*., 2) and the number of commercial cultivars is limited to only 8-10. In fruit crops, alternate bearing also varies with varieties. Litchi cv. 'China' has a strong tendency to alternate but is an above-average yielder with shorter canopy, less prone to cracking and consistently good quality fruits during the "ON" year. These attributes could probably be a reason for its use in commercial plantings in India. The intra plant variation in flushing and shoot growth pattern was also found to influence the overall floriferousness of the litchi plants (Das *et al*., 5). In contrast being late maturing litchi varieties, 'China' litchi had little time for carbohydrate storage to support the growing flowers and fruiting in next season (Malhotra *et al.*,11). This trait, when combined with a heavy fruit set, would leave 'China' trees with depleted carbohydrate reserves at the end of the season, and lead to poor fruit set in the following year. A useful method for the quantification of alternate bearing is through the measurement of the alternate bearing index (ABI), which is expressed as *I* (Pearce and Doberˇsek-Urbanc, 14). Across a diverse range of fruit species and cultivars, *I* ranged on a scale of 0 to 1 (0 = no alternate bearing; 1 = total alternate bearing). The alternate bearing of this magnitude disrupts marketing by precipitating strong fluctuations in net return to the growers and processors.

The most effective strategies for reducing alternation are through raising the amount of carbohydrate available for the next season, fruit thinning, branch girdling, and increasing exposure to sunlight by pruning and ensuring sufficient supply of soil, water and nutrients (Conner and Worley, 4). Girdling, appeared to be the best option for

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controlling the alternate bearing of litchi (Li and Xiao, 10), wherein photosynthates are not transported to other sections below the girdle and photosynthates are accumulated just above the girdle region that increases the C:N ratio and support the flowering (Kumar *et al*., 8). Girdling has the drawback of inhibiting assimilate transfer to the roots. Litchi is an important woody mycorrhizal fruit tree. However, girdling adversely affects carbohydrate transport from shoot to the root, which restricts litchi's mycorrhizal root development and root absorption (Shu *et al*., 16). As a consequence, the girdling of all primary shoots in litchi can affect plant health. Hence, now-a-days it is not advisable to girdle all primary branches. Sruamsiri *et al*. (17) indicated that the girdling of 50 per cent of the branches favoured a more frequent flowering in litchi. There is inadequate information on how this girdling affects the alternate bearing index, the alternate bearing intensity and the long-term yield index (LTYI) in cv. 'China'. Therefore, the prime objective of this work was to test the effect of different girdling treatments on flowering, fruiting, quality and alternate bearing parameters in litchi cv. 'China'.

MATERIALS AND METHODS

Experimental litchi orchard located near Ranchi city, Jharkhand, India (23°16′ N latitude, 85° 50′ E longitude) at an altitude of 651m. The field was located entirely within a single soil type, sandy-loam, with a pH range of 4.5-5.5. The region represents a hot-dry, sub-humid climate. The long-term maximum average temperature was 29.5°C and the long-term average minimum temperature was 18.0°C. Rainfall shows an annual average of 1,316 mm.

There was apparent hailstorm during October 2015, which resulted in no flowering during January 2016. Although 2017 was expected to be an ON year of fruiting, the flower intensity recorded during the year indicated an OFF year. Looking at the intensity of damage to the plants by the hailstorm during October, 2015, the low flower intensity during 2017 can be attributed to the inability of the trees to recoup out of the stress induced by the hailstorm even after one year. The lower assimilate content in the plant during 2016 as a result of heavy fruiting in 2015 combined with complete defoliation of the plants for a prolonged duration during 2016 due to hailstorm leading to poor accumulation of assimilates might have contributed towards the low flowering intensity during 2017. The study was conducted during the production cycles of 2015 (ON year), 2017 (OFF year), 2018 (ON year) and 2019 (OFF year) in 32-year-old 'China' variety planted at 10 m x 10 m (100 trees ha^{-1}). Plants were maintained under the rainfed conditions and with pruning of litchi terminal branches at 40 cm after harvesting (2nd week of June). Girdling treatment was applied to 25% (L1) and 50% (L2) primary branches by removing 2 mm (G1), 4 mm (G2) and 6 mm (G3) width bark. Litchi trees with four primary branches were chosen for the study to maintain uniformity, and the girdling was done 10 cm above the origin of the primary branches.

Sufficient care was taken to select the branches with uniform diameter for imposing the girdling treatments. The diameter of all the primary branches under the study ranged from 75 to 80 cm. In order to impose the treatment on '25% of primary branches', one primary branch out of the four primary branches was girdled per tree. Similarly for the treatment on '50% of primary branches' two number of primary branches out of four were girdled. A treatment without any girdling served as control (L0G0). Thus, the experiment consisted of seven treatments such as L1G1 (Girdling of 25% primary branches + 2 mm girdling), L1G2 (Girdling of 25% primary branches + 4 mm girdling), L1G3 (Girdling of 25% primary branches + 6 mm girdling), L2G1 (Girdling of 50% primary branches + 2 mm girdling), L2G2 (Girdling of 50% primary branches + 4 mm girdling), L2G3 (Girdling of 50% primary branches + 6 mm girdling) and control (without girdling) arranged in three replications. Each replicate consists of two trees. The girdling operation performed every year during 1st week of September. A bark strip (2, 4 and 6 mm width) was removed in a circular fashion around the selected 25% and 50% primary branches. In the first year, the girdling on the primary branch was performed close to the base and then stepped up to 5 cm each year.

The observation on per cent flowering shoot was recorded in the month of first week of March from tagged shoots (50 numbers per tree) selected randomly from each direction of the plant during in first week of November. The final fruit yield of ON and OFF year was calculated for each treatment over four successive bearing cycles and the data collected was used for the calculation of the alternate bearing index (ABI). The fluctuation in yield was expressed in terms of the alternate bearing index (I) (Table 1)

To calculate the alternate bearing intensity and long-term yield index, the formula reported by Noperi-Mosqueda *et al*. (13) was used:

Mean fruit, peel and seed weight were determined using the analytical balance (Mettler Toledo, PB403-S) based on 50 fruit samples taken randomly from each replication. Aril (%) was calculated using the formulae: pulp weight/fruit weight × 100. Fruit length and width were measured with a digital vernier caliper (RSK™, 150 mm, 0.01

Table 1. The details of the formula used in the study.

S. No.	Parameter	Formula	Details of abbreviations	Reference
1.	Alternate bearing index (*I*)	*I* = 1 / (n–1) ´ {|(a2 – a1)| / (a2 + a1) + |(a3 – a2)| / (a3+ a2) … + |(a(n) – a(n–1))| / (a(n) + a(n–1))}	n = number of years, and a1, a2, …, a(n–1), an =yields of corresponding years	(Pearce and Dober˘sek-Urbanc, 14)
2.	Alternate bearing intensity	Alternate bearing intensity = [standard deviation of yield (years analyzed) / average yield (years analyzed)] * 100		Noperi-Mosqueda *et al.* (13)
3.	Long-term yield index	Long-term yield index = (average yield of the years analyzed / alternate bearing intensity) * 100		Noperi-Mosqueda *et al.* (13)

mm reading capacity). TSS (°Brix) was recorded using a digital refractometer (ATAGO PAL-1, Japan, Range 0-53°Brix). Titratable acidity was estimated using 0.1 N sodium hydroxide solution (Ranganna, 15). Total sugars was determined as per the method of Lane and Eynon (9).

The experiment was laid out in randomized block design with three replicates and two trees per replication. Mean separation was conducted using Duncan's test with a 5 % significance level using SPSS version 20.

RESULTS AND DISCUSSION

Girdling treatments had a significant effect on per cent flowering shoots in China litchi during ON and OFF-years. A 4 mm width girdling of 50% primary branches (L2G2) had significantly higher per cent flowering shoots than other treatments during all the four years of experimentation. Treatment L2G2 had 39.72, 29.39, 68.17 and 29.36% flowering shoots during the respective years (Table 2). During OFF-years the percent increase in flowering was 725.56% (2017) and 336.90% (2019), whereas it was 248.73% (2015) and 67.58% (2018) during ON-years. In the study of Li and Xiao (10), the girdling treatment increased the flowering as compared to the untreated 'Nuomici' litchi trees, and proved to be an important basis for good cropping. The additional presence of carbohydrate in leaves and shoots has been reported to be associated with increased flowering due to reduced carbohydrate flow to the roots (Xianjun *et al.*, 19).

Litchi fruit yield during various fruiting seasons varied with the different girdling treatments. Mean yields in the two ON years (2015 and 2018) were greater than mean yields during OFF years (2017 and 2019). Severe reduction in yield from the ON to the OFF years indicates a deficit in tree's carbohydrate reserves during the OFF years because of heavy fruiting during the ON year. Furthermore increase in yield in the subsequent ON year indicated sufficient reserves of carbohydrate in the OFF year because of low yield during the OFF year. Four mm wide girdling in 50 per cent primary branches (L2G2) on annual yield per tree have shown the mitigation of alternate bearing in China litchi trees (Table 3). Trees that had received L2G2 treatment had higher yields than control trees over the course of the four years. Under L2G2 treatment, a full four-years yield assessment showed the highest yield in the 2015

Table 2. Effect of girdling on flowering (%) from four subsequent bearing cycles (2015-2019).

Symbol	Treatment	2015 (ON year)	2017 (OFF year)	2018 (ON year)	2019 (OFF year)
L1G1	25% PB + 2 mm G	27.22±2.72^{c}	6.86±0.90^{de}	40.58±2.42^{de}	8.31±0.49^{e}
L2G1	50% PB + 2 mm G	25.56±1.64^{c}	22.11±1.55^{b}	46.33±3.08^{c}	23.75±1.58^{b}
L1G2	25% PB + 4 mm G	18.33±2.04^{d}	10.42±2.50^{c}	51.26±2.01^{b}	10.88±0.43^{d}
L2G2	50% PB + 4 mm G	39.72±3.64^{a}	29.39±3.46^{a}	68.17±2.97^{a}	29.36±1.28^{a}
L1G3	25% PB + 6 mm G	32.78±1.83^{b}	10.14±3.84^{cd}	40.42±2.52^{e}	10.34±0.65^{d}
L2G3	50% PB + 6 mm G	33.61±2.68^{b}	21.67±4.33^{b}	45.01±2.64^{cd}	20.35±1.19^{c}
L0G0	Control	11.39±0.76^{e}	3.56±1.26^{e}	40.68±2.49^{de}	6.72±0.41^{e}

In a column, means with the same small superscript letters are not significantly different according to Duncan's test at a significance level of 5%. Results showed Mean±SD. PB: Primary branch, G: Girdling

Table 3. Effect of girdling on annual fruit yield (kg/tree) from four subsequent bearing cycles (2015-2019).

Symbol	2015 (ON year)	2017 (OFF year)	2018 (ON year)	2019 (OFF year)
L1G1	45.52±6.58[bc]	7.89±2.17[d]	43.67±2.60[c]	15.40±2.93[d]
L2G1	48.74±6.54[bc]	25.43±2.21[b]	46.29±3.08[c]	22.31±1.94[c]
L1G2	52.46±4.10[b]	11.98±1.64[c]	55.94±2.19[b]	17.51±2.40[d]
L2G2	65.23±9.61[a]	33.80±2.87[a]	70.40±3.06[a]	31.77±4.52[a]
L1G3	40.82±7.21[c]	11.66±0.89[cd]	44.98±2.81[c]	16.89±4.37[d]
L2G3	53.53±8.16[b]	24.92±3.03[b]	58.76±3.45[b]	25.40±2.25[b]
L0G0	38.35±2.59[c]	4.09±0.51[e]	42.27±2.59[c]	12.27±1.55[e]

and 2018 (65.23 and 70.4 kg/tree, respectively) and the lowest in the 2017 and 2019 (33.80 and 31.77 kg/tree, respectively). The comparison between the best treatment (L2G2) and control showed that the highest increase in yields was observed during the OFF-year period, *i.e.* in the 2017 (726.41%) and 2019 (158.92%) and the lowest increase in yields in ON-years, *i.e.* in 2015 (70.09%) and 2018 (66.55%). The girdling showed a direct impact on yield due to carbohydrate accumulation (Xianjun *et al*., 19). Thus, the girdling of 50% primary branches with 4 mm width allows rising accumulation of carbohydrate in branches without diminishing the fruit yield. This could be due to the fact that girdling facilitates the assimilation of carbohydrate and phytohormones. Therefore, in our study, girdling (50% primary branches with 4 mm width) tended to increase the bearing as well as yield per tree. Huang *et al*. (6) also found the similar effect of girdling on the yield of litchi cvs. 'Nuomici' and 'Guiwei'. The L2G2 treatment also showed the highest cumulative yield with 201.19 kg/tree from four years, while it was only the 96.98 kg/tree in control. The pooled fruit yield data of four years showed the highest average yield in L2G2 treatment (50.30 kg/ tree), and the lowest in control (24.24 kg/ tree) (Fig. 1).

The *I* value under various girdling treatments was evaluated between ON- and OFF-year yields.

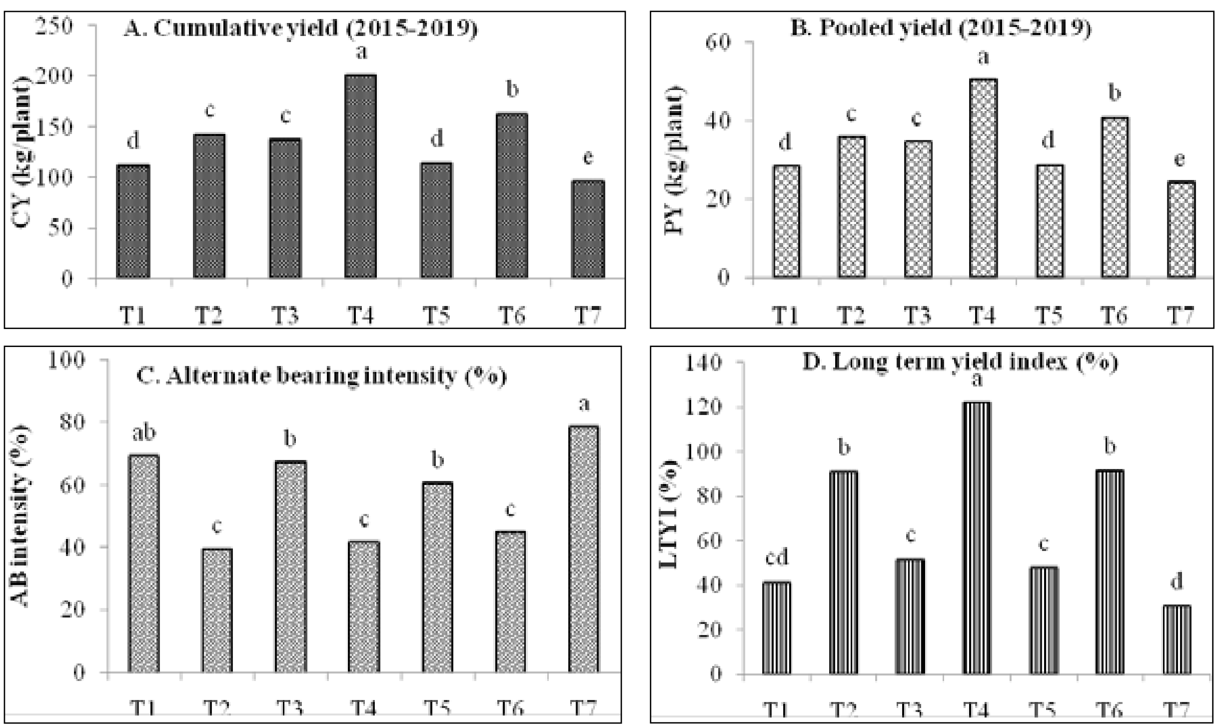

Fig. 1. Cumulative China litchi yield per tree in kg/plant (A), pooled yield in kg/plant (B), alternate bearing intensity (%) (C) and long term yield index (%) (D) of litchi var. 'China'. T1 (L1G1), T2 (L2G1), T3 (L1G2), T4 (L2G2), T5 (L1G3), T6 (L2G3) and T7 (L0G0).

The *I* value decreased from 0.81 under control to 0.31 and 0.32 (p<0.05) under treatment L2G1 and L2G2, respectively, when compared to first ON-year and second OFF-year yields, respectively. This pattern has been consistent in year-on-year yields from the second OFF to the third ON-year, and yields from the third ON-year to the fourth OFF-year. The pooled data showed that the highest average *I* value was observed in the control treatment (0.73), and the lowest in L2G1 (0.32) followed by L2G2 (0.35) treatment (Table 4). All girdling treatments reduced the severity of the alternative bearing in litchi cv. China. From 2015 through 2019, girdled trees had more annual yield than control (un-girdled). Because of these differences in annual yields, the alternate-bearing index also differed among treatments (P < 0.05). Therefore, if the alternate bearing index would be close to 1, differences in crop production between 2 years are very high. The treatment L2G2 (50% PB + 4 mm G) and L2G1 (50% PB + 2 mm G) had *I* values of only 0.35 and 0.32, respectively. The yield wise treatment L2G2 gave higher yield than L2G1 but L2G1 had lower *I* value due to less fluctuation in yield. Thus using '*I* value' to quantify the extent to which a tree bears alternately was found to be inadequate in the present study. The alternate bearing index (*I*) is sensitive to the tree's total fruit production (Huff, 7).

Table 4. Effect of girdling on alternate bearing index (I) of China litchi.

Symbol	2015-17	2017-18	2018-19	Pooled (2015-19)
L1G1	0.70±0.09^{ab}	0.69±0.08^{b}	0.48±0.09^{b}	0.62^{b}
L2G1	0.31±0.03^{d}	0.29±0.07^{e}	0.35±0.07^{d}	0.32^{d}
L1G2	0.63±0.05^{bc}	0.65±0.04^{bc}	0.52±0.05^{ab}	0.60^{bc}
L2G2	0.32±0.04^{d}	0.35±0.05^{de}	0.38±0.04^{d}	0.35^{d}
L1G3	0.57±0.05^{c}	0.60±0.04^{c}	0.46±0.12^{bc}	0.53^{c}
L2G3	0.37±0.11^{d}	0.41±0.08^{d}	0.40±0.01^{cd}	0.39^{d}
L0G0	0.81±0.02^{a}	0.82±0.02^{a}	0.55±0.04^{a}	0.73^{a}

To address this issue, Noperi-Mosqueda *et al*. (13) proposed two more parameters *i.e.* alternate bearing intensity and long-term yield index. In this study, the average alternative bearings intensity ranged from 78.36% in control trees to 39.40% in L2G1 (T2) treatment (Fig. 1). In this study, the average of alternate bearing intensity was lower in L2G1, L2G2 and L2G3 than control. The Long-Term Yield Index (LTYI) has also been determined, which was significantly influenced by various girdling treatments. In the present study, the LTYI ranged from 31.01% in control to 122.25% in L2G2 (T4) treatment (Fig. 1). LTYI is defined as the increasing percentage in productivity over time. It is important to highlight that girdling also has influenced both the production and the alternate bearing intensity, which are directly related to the LTYI.

The result of various girdling treatments revealed that T_5 (25 per cent PB + 6 mm G) had the maximum pooled fruit weight (19.74 g). Among L2G1, L1G2, L2G2 and control treatment, there was no significant difference in fruit weight. Huang *et al*. (6) also observed that there was no significant difference in average fruit weight between spiral girdled and control plants of Guiwei litchi variety. The treatment L1G3 also exhibited the highest pooled fruit volume (18.52cc) during the study period (2015-2019). There was no significant difference between various treatments for pooled fruit length. The pooled fruit width in L2G3 treatment was significantly higher (32.02 mm) than other treatments, but did not differ significantly with L1G3 (Table 5). The various girdling treatments demonstrated no significant difference with control over the aril percentage, acidity (%) and sugar (%) within four years of study. Only TSS varied due to different girdling treatments and in treatment $T_{5,}$ it was highest (20.31 °Brix) followed by treatments L2G1 and L1G2. There was no significant difference in TSS between L1G1, L2G2 and the control treatment (Table 6).

In a column, means with the same small superscript letters are not significantly different

Table 5. Effect of girdling on fruit characteristics (2015-2019).

Symbol	Fruit weight (g)	Fruit volume (cc)	Fruit length (mm)	Fruit width (mm)
L1G1	19.24±0.15^{a}	18.11±0.32^{abc}	36.83±0.21^{a}	31.45±0.20^{bcd}
L2G1	18.30±0.46^{b}	17.11±0.68^{d}	36.25±0.07^{a}	31.51±0.38^{bc}
L1G2	18.54±0.40^{b}	17.37±0.32^{cd}	36.30±0.51^{a}	31.33±0.08^{bcd}
L2G2	18.29±0.47^{b}	17.23±0.48^{d}	36.98±0.77^{a}	31.12±0.44^{cd}
L1G3	19.74±0.41^{a}	18.52±0.46^{a}	37.31±0.85^{a}	31.71±0.44^{ab}
L2G3	19.73±0.37^{a}	18.31±0.31^{ab}	36.74±0.52^{a}	32.02±0.51^{a}
L0G0	18.54±0.65^{b}	17.60±0.59^{bcd}	37.60±1.13^{a}	31.02±0.34^{d}

Table 6. Effect of girdling on fruit quality characteristics (2015-2019).

Symbol	Aril (%)	TSS (°Brix)	Acidity (%)	Sugar (%)
L1G1	64.15±0.49[a]	19.21±0.18[c]	0.25±0.01[a]	13.00±0.53[a]
L2G1	63.80±2.11[a]	20.03±0.40[ab]	0.24±0.01[a]	13.21±0.23[a]
L1G2	65.64±2.46[a]	19.64±0.45[abc]	0.25±0.01[a]	12.83±0.38[a]
L2G2	64.51±0.37[a]	19.05±0.50[c]	0.24±0.01[a]	12.80±0.11[a]
L1G3	64.59±2.85[a]	20.31±0.18[a]	0.25±0.02[a]	13.57±0.91[a]
L2G3	66.15±0.91[a]	19.40±0.49[bc]	0.24±0.00[a]	12.75±0.43[a]
L0G0	63.28±0.32[a]	19.21±0.49[c]	0.25±0.01[a]	13.00±0.18[a]

according to Duncan's test at a significance level of 5%. Results showed Mean±SD.

In conclusion, 4 mm width girdling of 50% primary branches, reduces alternate bearing behaviour in 'China' litchi. In our experiment, cumulative yield was increased by 2.07 times with regard to un-girdled trees during the four years of the trial. The assessment of alternate bearing through ABI (*I*) is misleading because *I* is sensitive to fluctuation in yield during ON and OFF years and it is not representing the tree's total fruit production in long term. LTYI is more reliable for assessment of alternate bearing along with yield fluctuations under different treatments.

AUTHORS' CONTRIBUTION

Conceptualization of research (BD, PP and AKS); Designing of experiment (MKD, BD and SG); Field/lab experiments and data collection (MKD and SG); data interpretation (MKD and BD); Preparation of the manuscript (MKD and BD).

DECLARATION

The authors declare that they have no conflict of interest.

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