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Using Paclobutrazol and Leaf-to-fruit-ratio as Tools for Improving Yield and Quality of Non-dwarfing High-density Peach Orchards

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Excessive fruit set and foliar shading are the major deterrents to the economic productivity of peach orchards raised on vigorous rootstocks. With the objective of obtaining an appropriate level of crop together with the best quality fruit from the high-density peach orchards, studies were conducted in the sub-Himalayan subtropics of Himachal Pradesh, India. In the Experimental orchard of the Department of Fruit Science, the premium Early Grande cultivar raised on non-dwarfing wild peach seedling rootstock was selected for the studies. The orchard soil was sandy loam soil with normal physico-chemical characteristics. The experiment was laid out in RBD factorial experimental design with paclobutrazol (PBZ) and leaf-to-fruit ratio (LFR) treatment factors; three levels of PBZ viz. P1-1500 ppm, P2-2500 ppm, P3-0 ppm and four levels of LFR i.e. L1-30:1, L2-40:1, L3-50:1 and L4 - normal leaf number were tried. The findings revealed that 2500 ppm PBZ together with 40:1 LFR treatment not only reduced the number of days from full bloom to maturity but also improved fruit

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thinning. The fruit retention was recorded better with 1500 ppm PBZ and 50:1 LFR; however, the yield was recorded highest with 2500 ppm PBZ and 40:1 LFR treatments. This treatment combination also resulted in better overall fruit quality in terms of fruit surface colour, total soluble solids, firmness, acidity, sugars etc. The control over vegetative growth was also observed better under this treatment combination.

Keywords: Low chill peach; Prunus persica; early grande; fruit drop; fruit quality; fruit surface redness; fruit sugars; vegetative growth.

1. INTRODUCTION

Peach [*Prunus persica* (L.) Batsch] is known worldwide for its wider adaptability; it originated in China about 4000 years ago, from here it spread to Persia then Europe and now has global distribution between the latitudes of 25° and 45° near and far from the equator [1,2]. It is grown commercially in the USA, Italy, France, Japan, Argentina, Australia, Mexico, Korea, West Germany, Portugal, New Zealand, Spain, Greece, South Africa, Turkey, Canada, Yugoslavia, Chile, India, Austria, and other countries. In India, it is mainly grown in the hills of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, and Uttar Pradesh, besides the hilly tracts of Punjab and the Nilgiri hills. It is also cultivated in the North-Eastern region, especially in the hills of Meghalaya, Arunachal Pradesh, Manipur, and Nagaland.

The peaches usually face the dual problem of large fruit set and excessive vegetative growth under the optimum growing conditions. The excessive fruit set sets competition amongst the developing fruits for assimilates and results in poor fruit size and low economic returns to the growers. On the other hand, under the high-density system of orcharding, the faster and more massive shoot growth of the closely spaced trees tend to exert a severe shading effect that in turn hampers the proper fruit colour and quality development. This problem is more serious in orchards that are raised on non-dwarfing rootstocks. Extensive research on this issue is, therefore, imperative; because the plantations on non-dwarfing rootstocks are quite common in many peach-growing countries.

From a horticultural point of view, the proportion of actively photosynthesizing leaves and growing fruit is very critical in peaches for maintaining a good source-sink relationship. The peach growers usually try to balance the proportion of the crop and vegetative growth by way of pruning and flower/fruit thinning. But, optimization of pruning and thinning practices is difficult as the level of flowering and subsequent fruit set is influenced by several other factors than pruning or thinning. Apart from this, if the pruning done goes a bit on the higher side it may results in poor crop due to excessive vegetative growth; and if it is on the lower side it tends to set heavy crop load which also leads to poor crop quality and yield. Likewise, the consequences of thinning are also variable as most of the trees show considerable loss to crop due to spring frost or fruit drop due to meteorological or edaphic factors. Moreover, the result of thinning agents used at flowering and fruit set stages is not consistent in most of the varieties. The usual practice of reducing fruit number is to apply growth retardants or auxins at higher concentrations, but, the use of these synthetic chemicals at the active cell division stage i.e. during full bloom or fruit set has been found to reduce the net yield of good quality. Therefore, it is essentially required to explore options that can be used for reducing fruit number at a stage when yield can be predicted with sufficient accuracy, and also the exogenous application of chemicals produces little effect on fruit development.

Paclobutrazol (PBZ) is a common organic compound that is used commonly as a plant growth retardant for regulating various aspects of plant growth. Its possible use as a fruit thinning agent was reported for the first time by Webster and Quinlan [3], when they observed significant fruit drop in certain plum cultivars. Keeping this characteristic of PBZ in mind it was hypothesized that its application during the fruit development stage can optimize the crop load as well as the vegetative growth of peach. And, further, the source-sink relation maintenance essentially through leaf-to-fruit ratio (LFR) may assure the accumulation of reserves and will result in better yield and fruit quality. The current studies were therefore conducted to regulate crop load through fruit thinning with foliar application of paclobutrazol at the beginning of the pit hardening stage and further optimizing the leaf-to-fruit ratio for improving yield and fruit quality of

Early Grande peach grown under a high-density system of planting; the individual and combined effects of PBZ and LFR treatments were planned to be observed and analyzed.

2. MATERIALS AND METHODS

2.1 Study Area and Pre-treatment Status of the Experimental Orchard

The studies were conducted at the experimental high-density peach orchard (2500 plants/ha, spaced at 2x2 m) of the Department of Fruit Science, Dr Y. S. Parmar University, College of Horticulture and Forestry, Neri, Hamirpur (HP) India. The orchard was situated at 31°41'50" N latitude and 72° 28' 02" E longitude, having an altitude of 650 m above mean sea level on the West-facing aspect in the subtropical sub-mountain region of Shiwalik Himalayas. This region experiences 1100 to 1200 mm of average annual rainfall. The soil type of the experimental orchard was sandy loam with a pH of 6.75, EC - 0.147 dsm^{-1}, organic carbon - 1.17%, N - 376.32 kg/ha, P - 19.7 kg/ha, and K - 446.75 kg/ha. During the year 2021, the uniformly growing 5-year-old plants of the Early Grande cultivar grafted on non-dwarfing wild peach seedling rootstock were selected for experimentation. The selected plants were kept at uniform orchard management practices including season pruning, fertilizer application, irrigation, pest and disease management etc. The initial observations on the vegetative growth status of the plant were taken in the form of trunk diameter which was recorded just before winter pruning. The status of the flowering and fruit set was also recorded at respective phenological states for later use. The pruning was done uniformly across the experimental trees by removing 25% of the shoot extension growth in all the shoots of the experimental trees. Also, the pre-treatment data on flowering and the per cent fruit set were taken as per the procedure described by Westwood [4].

2.2 Treatment Details

The experiment was conducted in a factorial randomized block design wherein the paclobutrazol (PBZ) foliar application comprised the first factor and the maintenance of specific leaf-to-fruit ratio (LFR) was the 2nd factor of the factorial experiment. Three levels of PBZ application viz. P1-1500 ppm, P2-2500 ppm and P3- 0 ppm (control) and four levels of leaf-to-fruit ratio (LFR) i.e. L1- 30:1, L2-40:1, L3-50:1 and L4-Natural LFR (control) were tried individually as well as in combination under the randomized block design (RBD) factorial experiment. The treatments were replicated thrice and one tree per replication comprised the unit of observation. The foliar application of PBZ treatments was done twice i.e. at 45 days after full bloom (beginning of pit hardening stage) and one week after that. The LFR treatments were applied immediately after the second PBZ foliar spray.

2.3 Observations Recorded

2.3.1 Fruit thinning

The data on the periodic drop of fruits after application of the treatments were collected at 10 days intervals and the periodic drop observed (number of fruits that dropped in a ten days interval) was categorized as the first drop, second drop and third drop. Per cent fruit drop was calculated *w.r.t.* initial level of fruit set.

'Periodic Drop (%) = (No. of fruits dropped ÷ No of Fruit set) x 100'

2.3.2 Final fruit number, days from full bloom to maturity (dffb) and yield

The total number of fruits per tree that were harvested through all the pickings was designated as the final fruit number. Days from full bloom to maturity (dffb) were taken as the count of the number of days the plants took from their date of full bloom to the completion of 75% of the harvest. The date of full bloom was taken as the day by which 75% of the flowers completed their anthesis. The yield was taken as the cumulative sum of the fruit weight (kg) harvested through different pickings.

2.3.3 Fruit colour and the relative redness (RR) of the fruit surface

The measurement of fruit colour was done on an RGB (Red, Green, and Blue) scale as per the procedure described by Joshi [5]. The quantification of RGB colours was done with help of the 'On-colour-Measure' mobile application which expressed the quantitative value of fruit colour in terms of RGB pixel value for the respective red, green and yellow colour proportion in the fruit surface and pulp colour. The Relative Redness (RR) of the fruit surface colour was computed using formulae: 'RR= R÷(R+G+B)'; where, RR- Relative Redness, R- Red colour pixel value, G- Green colour pixel value, and B- Blue colour pixel value.

2.3.4 Fruit physicochemical characteristics

The average values for the various physicochemical characteristics of the fruits were derived from the observations taken from the already tagged four branches per tree. Ten fruits per branch were removed randomly from the tagged branches for the fruit quality estimation. The fruit firmness was measured in terms of force (kg) using 'Turoni (tr)' penetrometer model FT-011. Fruit Size was taken as the average of the fruit length and diameter measured on both cheeks of the fruit. Fruit weight was taken as the average weight of ten fruits collected per tree from along the periphery of the tree. Various fruit biochemical estimations like total soluble solids, acidity, sugars, ascorbic acid etc. were done as per standard procedures of AOAC [6].

2.3.5 Vegetative growth parameters

The initial observations on the trunk diameter were recorded just after pruning. It was measured just above the graft union. The physical increment in the trunk diameter was recorded two months after harvest with respect to the measurement of the trunk diameter recorded during winters, at the time of pruning. The other vegetative growth parameters like the current season's shoot extension growth and shoot dry weight were also recorded two months after harvest. The current season's shoot extension growth was taken as the length (cm) of the growth which took place after flowering up to 2 months after harvest; it was recorded in 10 shoots selected randomly across the periphery of each experimental tree. For taking a measure of the dry weight of this extension growth, a 15 cm basal portion of the current growth was stroked off and dried in the hot air oven at 65-70^{o}C for 96 hours and was then weighed.

2.4 Statistical Analyses

The data collected for various parameters were computed, tabulated and analyzed by using the MS-Excel, and OPSTAT statistical packages. The analysis of variance (ANOVA) for two-factor Randomized Block Designs factorial experiment was done as per the procedure described by Gomez and Gomez [7]. The critical difference and standard errors were reported at the $P < 0.05$ level.

3. RESULTS

3.1 Fruit Thinning

The data about the effect of PBZ and LFR treatments, on the periodic fruit drop of Early Grande peach are presented in Fig. 1 (a, b & c). The perusal of data reveals that 2500ppm PBZ application resulted in the highest first and second fruit drop (26.3 & 16.1% respectively); the effect was not observed significant on 3rd fruit drop (a). The effect of LFR treatments was observed significant only for the first drop; the 40:1 LFR treatment caused the highest first drop (b). The critical difference in the means of different LFR treatments was insignificant but it was significantly different than the control i.e. L4. It implies that all the LFR treatments induced almost similar types of influence on fruit periodic fruit drops in Early Grande peach. The combined application of the PBZ and LFR treatments was found more effective and the highest first periodic drop was observed under the combination of 2500 ppm PBZ and 40:1 LFR treatments (c). It resulted in 29.6% first periodic drop which was higher than the individual effect of these treatments (26.3 % with 2500ppm PBZ and 20.2% with 40:1 LFR treatment); the initial drop only of 10% fruits was recorded under the control i.e. P3L4 treatment (c). The effect of this treatment combination (P2L2) was found to be at par with that of P2L1 treatment i.e. 2500 ppm PBZ and 30:1 LFR treatments.

3.2 Days from Full Bloom to Harvest

The foliar PBZ application at beginning of pit hardening resulted in a significant effect on the number of days the Early Grande peach took from full bloom to harvest of fruits (Table 1). The fruits under the treatment P2 i.e. 2500 ppm PBZ took only 78.1 days from full bloom to harvest which was about 2.5 days lesser than the control (P3). This effect of 2500 ppm PBZ application was statistically at par with that of 1500 ppm treatment (P1). The impact of LFR treatments or the combined effect of PBZ and LFR treatments was not found to be significant as far as the days from full bloom to harvest were concerned.

3.3 Fruit Number at Harvest

The treatment P2 i.e. 2500 ppm PBZ application resulted in the retention of 250.5 fruits per tree at harvest (Table 1). This count was significantly higher than that recorded (197.2 fruits) under control (P3) but it was at par with the number of fruits recorded under P1 i.e. 1500 ppm PBZ treatment. Likewise, the effect of LFR was also significant and the highest number of fruits per tree (246.7 fruits) was retained under the treatment L3 i.e. 50:1 LFR but statistically, it was at par with the number of fruits that were recorded under the 40:1 LFR treatment. The interaction effect of PBZ and LFR treatments was also significant and the highest number of fruits per tree were recorded under the treatment combination P1L3 i.e. PBZ 1500 ppm and LFR 50:1. Statistically, this number of fruits was not different from that recorded under the treatments P1L2, P2L1, P2L3, and P2L4.

3.4 Fruit Weight

The effect of PBZ treatments on fruit weight was found to be significant and P2 i.e. 2500 ppm PBZ application resulted in the highest fruit weight (110.7g) which was superior to all other treatments. The lowest fruit weight 79.2g was recorded under control (P3). The effect of LFR treatments was also significant and the highest fruit weight (99.7 g) was recorded with L3 i.e. LFR 50:1, but, statistically, it was at par with LFR 40:1 (L2) treatment which resulted in the average fruit weight of 98.0 g. The interaction effect of PBZ and LFR treatments was found to be positively significant and the treatment combination of P2L2 i.e. PBZ at 2500 ppm and LFR 40:1 produced the highest fruit weight of 113.4 g. Other treatment combinations like L3P1, L1P2, L3P2, and L4P2 also produced fruits of almost similar weight.

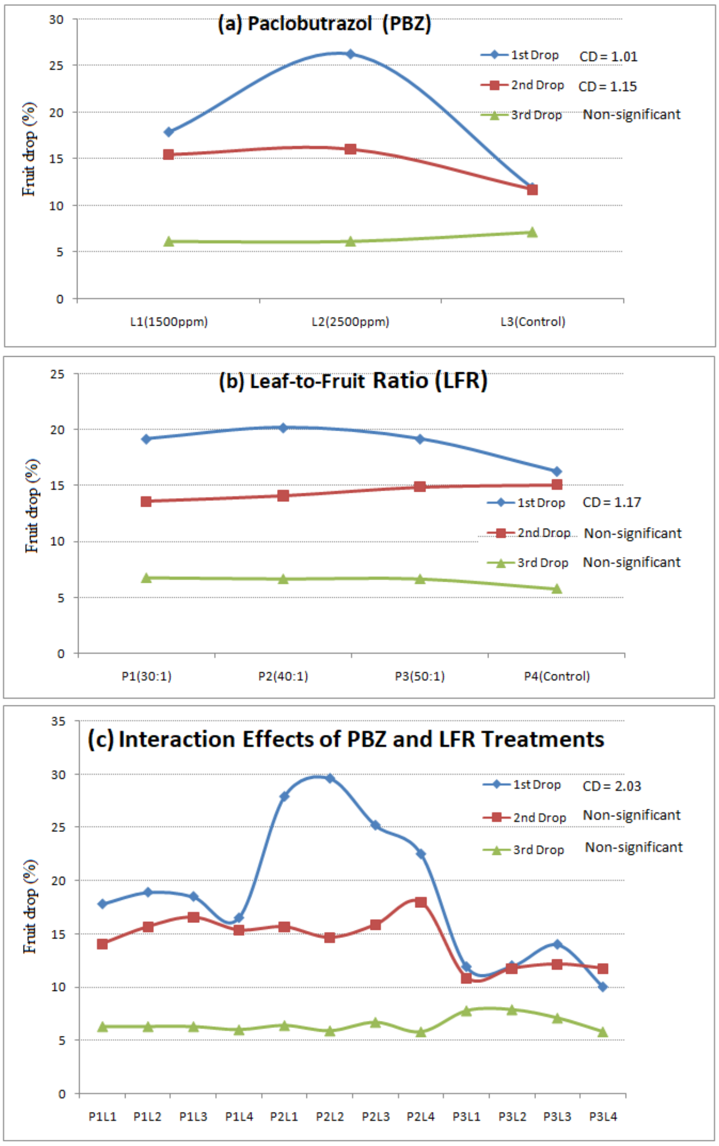

Fig. 1. Effect of paclobutrazol (PBZ), leaf-to-fruit ratio (LFR) and their interactions on the periodic fruit drop of peach cv. Early Grande

Table 1. Effect of paclobutrazol, leaf- to-fruit ratio treatments and their combination on the number days from full bloom to maturity, fruit number, fruit weight and yield of Early Grande peach

Treatments	Days from full bloom to harvest (No. of days)					Fruit Number					Fruit Weight (g)					Yield (kg)				
	L1	**L2**	**L3**	**L4**	**Mean**	**L1**	**L2**	**L3**	**L4**	**Mean**	**L1**	**L2**	**L3**	**L4**	**Mean**	**L1**	**L2**	**L3**	**L4**	**Mean**
P1	79.3	79.3	79.3	81.3	79.8	236.0	246.7	271.0	241.7	248.8	83.3	101.8	105.7	92.8	95.9	17.8	19.3	12	10	14.8
P2	78.0	76.7	79.3	78.7	78.1	245.7	233.0	262.7	260.7	250.5	111.1	113.4	110.1	108.1	110.7	26.5	28.1	20.8	13.1	22.2
P3	80.0	80.0	80.7	82.0	80.6	194.3	216.3	206.3	171.7	197.2	80.9	78.8	83.3	73.9	79.2	11.5	13.3	15.3	13.5	14
Mean	79.1	78.6	79.7	80.6		225.3	232.0	246.7	224.7		91.8	98.0	99.7	91.6		18.6	20.2	16	12.2	
	CD(0.05)	SE(d)	SE(m)			CD	SE(d)	SE(m)			CD	SE(d)	SE(m)			CD(0.05)	SE(d)	SE(m)		
P	1.50	0.72	0.51			13.3	6.38	4.51			4.4	2.1	1.5			2.47	1.18	0.83		
L	N/S	0.83	0.58			15.39	7.37	5.21			5.1	2.4	1.7			2.85	1.36	0.96		
PxL	N/S	1.44	1.02			26.66	12.7	9.03			8.9	4.3	3.0			4.94	2.36	1.67		

CD(0.05) – Critical Difference of means at 5 % level of significance
SE(d)- Standard Error of Standard Deviation
SE(m)- Standard Error of mean

Table 2. Effect of paclobutrazol, leaf-to-fruit ratio and their combination on total soluble solids (TSS) and titratable acidity (TA) of Early Grande peach

Treatments	TSS (^{o}B)					TA (%)				
	L1	**L2**	**L3**	**L4**	**Mean**	**L1**	**L2**	**L3**	**L4**	**Mean**
P1	8.64	9.34	9.59	10.0	9.41	1.35	1.21	1.10	1.2	1.21
P2	11.00	11.43	10.33	10.04	10.70	1.15	1.14	1.20	1.22	1.18
P3	8.26	9.25	8.58	6.88	8.24	1.47	1.34	1.27	1.56	1.41
Mean	9.30	10.00	9.50	9.00		1.32	1.23	1.19	1.33	
	CD(0.05)	SE(d)	SE(m)			CD(0.05)	SE(d)	SE(m)		
P	0.49	0.23	0.16			0.07	0.03	0.02		
L	0.56	0.27	0.19			0.08	0.04	0.03		
PxL	0.98	0.47	0.33			0.15	0.07	0.05		

CD(0.05) – Critical Difference of means at 5 % level of significance
SE(d)- Standard Error of Standard Deviation
SE(m)- Standard Error of mean

3.5 Yield

Fruit thinning with PBZ foliar spray at the beginning of pit hardening significantly improved the yield of Early Grande peach (Table 1); 2500 ppm PBZ application (P2) resulted in the highest yield of 22.2 kg per tree which was significantly higher than the other PBZ treatment and control. The LFR treatments also influenced yield significantly and the highest 20.2 kg per tree yield was recorded under L2 i.e. LFR 40:1 treatment; statistically, it was at par with L1 (LFR 30:1). The combined effect of PBZ and LFR treatments was also found to be significant and additive. The treatment combination of 2500 ppm PBZ and 40:1 LFR (P2L2) produced the highest yield of 28.1 kg per tree. The yield recorded under P2L1 i.e. 2500 ppm PBZ and 30:1 LFR was also found to be at par with the P2L2 treatment.

3.6 Fruit Surface and Pulp Colour

The data about the effect of PBZ, LFR treatments and their interactions on the fruit surface and pulp colour are presented in Fig. 2. It is evident from this figure that the highest fruit colour (both surface and pulp) was obtained with P2 i.e. 2500 ppm PBZ application, though the effect was not observed to be different from 1500 ppm treatment (P1) in the case of pulp colour, it was significantly better than the control. The effect of LFR treatments was not observed to be significant for surface colour but pulp colour was influenced by the LFR treatments. The highest pulp colour was obtained under the L2 *i.e.* 40:1 LFR treatment, at par with 30:1 LFR treatment. The combined application of PBZ and LFR treatments was found to influence the surface colour significantly but the pulp colour was not influenced significantly by the combined effect of PBZ and LFR treatments.

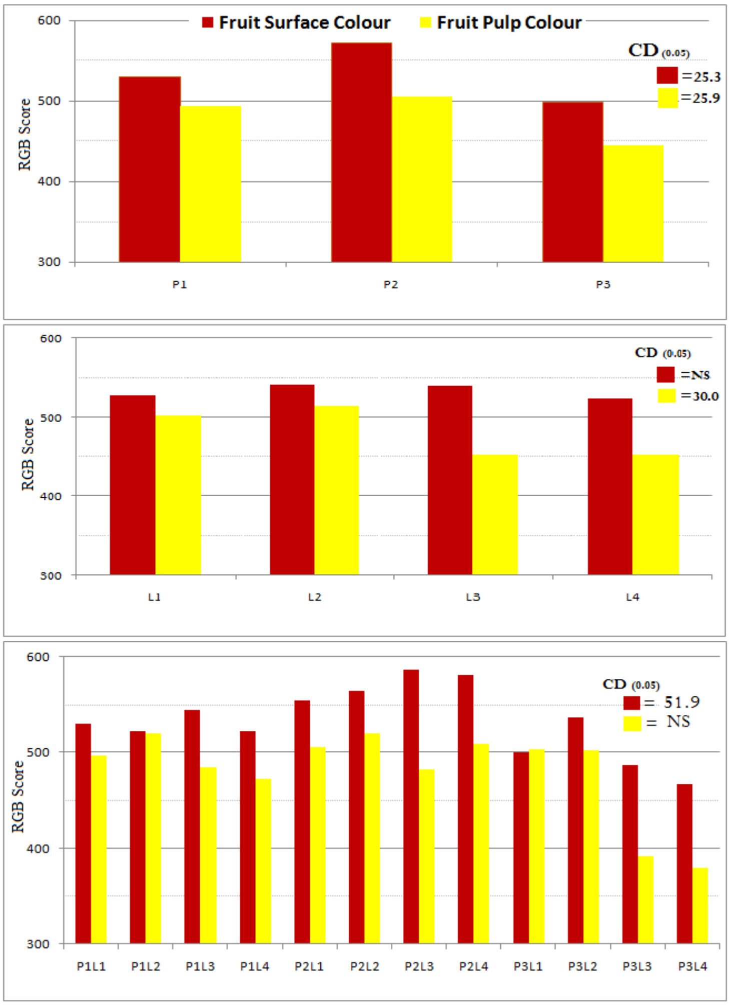

Fig. 2. Effect of paclobutrazol, leaf-to-fruit ratio treatments and their interactions on fruit colour of Early Grande peach

3.7 Relative Redness of Fruit Surface Colour

The PBZ treatments influenced the relative redness of the fruit surface significantly; P1 i.e. 1500 ppm PBZ produced 0.488 proportion of redness out unity which was quite higher than the relative proportion of fruit surface redness observed under control (Fig. 3). This effect was found to be at par with P2 i.e. 2500 ppm PBZ application. The LFR treatments also resulted in a significant influence on the relative redness of the fruit surface. The L1 treatment i.e. 30:1 LFR resulted in the highest redness of the fruits (0.491). Statistically, it was found at par with L2 i.e. 40:1 LFR treatment but, superior to control (L4) and 50:1 LFR (L3). The combined application of PBZ and LFR treatments resulted in more redness of the fruits' surface colour. The highest redness (0.549) was recorded under the treatment combination of P1L2 i.e. 1500 ppm PBZ and 40:1 LFR and it was at par with P2L1 and P2L2 i.e. 2500 ppm PBZ combined with either 30:1 or 40:1 LFR treatments.

3.8 TSS and Acidity

It is evident from the data presented in Table 2 that the treatment P2 i.e. 2500 ppm PBZ produced fruits with the highest TSS value of 10.7^{o}B and the control (P3) produced fruits with the lowest TSS of 8.24^{o}B. The LFR treatments also exerted a significant impact on the fruit TSS content. The 40:1 LFR produced fruits with the highest TSS value of 10.0^{o}B though it was at par with the 50:1 LFR treatment. The combined application of PBZ and LFR treatments resulted in the production of fruits with still more TSS than the individual effect of PBZ and LFR treatments. The treatment combination P2L2 i.e. 2500 ppm PBZ (P2L2) and 40:1 LFR produced fruits with the highest recorded TSS average of 11.43°B. The effect of this treatment combination was found almost similar to that of the P2L1 treatment.

The titrable acid content was recorded as lowest (1.18%) with P2 treatment, however, under LFR treatments the lowest acid (1.19%) content in the harvested fruits was recorded under the L3 i.e. 50:1 LFR treatment. The combination of PBZ and LFR also influenced the fruit acidity and the treatment combination P2L2 resulted in the lowest level (1.14%).

3.9 Fruit Sugars (Total, Reducing and Non-Reducing)

The data about the effect of PBZ and LFR treatments on the total, non-reducing, and reducing sugar content of the fruit juice are presented in Fig. 4. It is evident that only the PBZ treatments could influence the content of different types of sugars present in the fruit. And, the P2 i.e. PBZ @ 2500 ppm produced the highest amount of all the sugars estimated in the fruit juice. The effect of LFR treatments or the combined application of both PBZ and LFR was not found to be significant as far as the contents of different sugars in the fruit juice were concerned.

3.10 Fruit Firmness and Shelf Life

It is evident from the data presented in Table 3 that the PBZ application reduced the fruit firmness at resulted in the lowest recorded firmness of 3.3 kg under 2500 ppm PBZ treatment; whereas, the fruits produced on the trees kept under control were having the highest firmness of 3.83 kg at harvest. The effect of LFR treatments and their interaction with PBZ application was found to be non-significant, statistically. Further, the shelf life of the fruits was

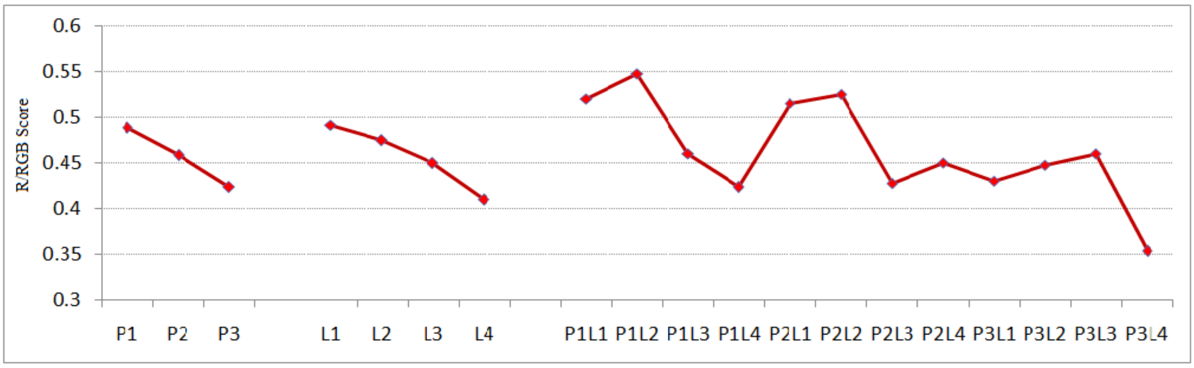

Fig. 3. Effect of paclobutrazol, leaf-to-fruit ratio treatments and their interactions on the redness of fruit surface colour of Early Grande peach

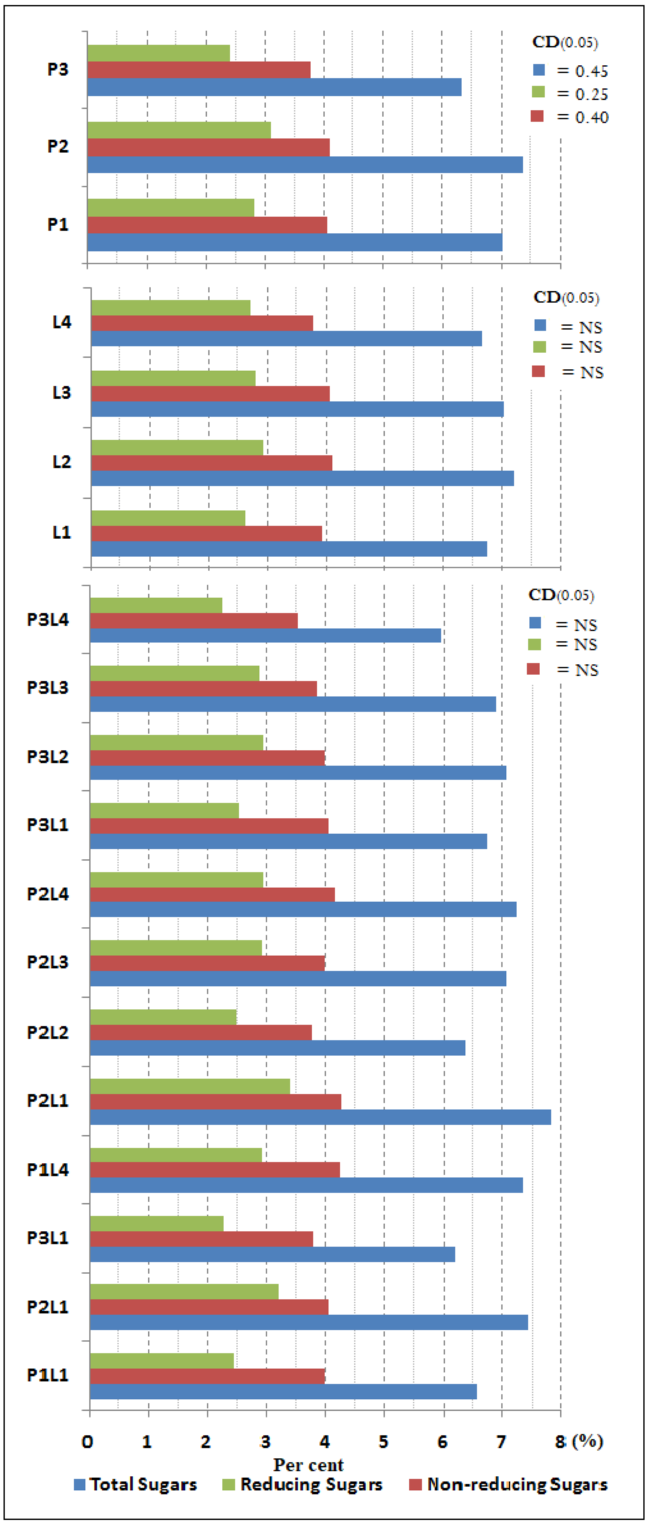

Fig. 4. Effect of paclobutrazol, leaf-to-fruit ratio treatments and their interactions of fruit sugars of Early Grande peach

also decreased by PBZ application and the lowest 5.3 days shelf life was recorded under P2 i.e. 2500 ppm PBZ application which was significantly lower than the shelf life recorded under the control (P3). The effect of LFR and its interaction with PBZ treatments was found to be non-significant.

Table 3. Effect of paclobutrazol, leaf-to-fruit ratio and their combination on fruit firmness and shelf-life of Early Grande peach

Treatments	Firmness (kg)					Shelf-life (No. of days)				
	L1	**L2**	**L3**	**L4**	**Mean**	**L1**	**L2**	**L3**	**L4**	**Mean**
P1	3.86	3.56	3.73	3.56	3.68	5.4	5.3	5.8	5.8	5.6
P2	3.13	3.06	3.43	3.60	3.31	5.1	5	5.5	5.6	5.3
P3	3.93	3.66	3.73	4.00	3.83	6.2	6.0	6.0	6.4	6.2
Mean	3.64	3.43	3.63	3.72		5.6	5.4	5.8	5.9	
	$CD_{(0.05)}$	SE(d)	SE(m)			CD	SE(d)	SE(m)		
P	0.22	0.10	0.07			0.33	0.16	0.11		
L	N/S	0.12	0.08			N/S	0.18	0.13		
PxL	N/S	0.21	0.15			N/S	0.31	0.22		

CD(0.05) – Critical Difference of means at 5 % level of significance
SE(d)- Standard Error of Standard Deviation
SE(m)- Standard Error of mean

Table 4. Effect of paclobutrazol, leaf-to-fruit ratio and their combination on increment of trunk diameter, shoot extension growth and shoot dry weight of Early Grande peach

Treatments	Increment in trunk diameter (%)					Shoot extension growth (cm)					Shoot dry wt. (g)				
	L1	**L2**	**L3**	**L4**	**Mean**	**L1**	**L2**	**L3**	**L4**	**Mean**	**L1**	**L2**	**L3**	**L4**	**Mean**
P1	1.7	1.7	2.5	2.2	2	28.3	27.6	28.6	29.6	28.5	1.0	0.9	1.07	1.07	1.01
P2	1.3	1.3	1.4	1.5	1.4	25.4	23.4	26.0	26.3	25.2	0.8	0.6	0.9	1.07	0.84
P3	3.1	3.2	2.7	6.0	3.8	35.3	31.1	30.3	50.7	36.8	1.1	1.47	1.43	1.5	1.37
Mean L	2.0	2.1	2.2	3.3		29.6	27.4	28.3	35.5		0.97	0.99	1.13	1.21	
	CD(0.05)	SE(d)	SE(m)			CD(0.05)	SE(d)	SE(m)			CD(0.05)	SE(d)	SE(m)		
P	0.59	0.28	0.2			4.59	2.19	1.55			0.37	0.18	0.12		
L	0.69	0.33	0.23			5.30	2.53	1.79			N/S	0.2	0.14		
PxL	1.19	0.57	0.4			9.18	4.39	3.11			N/S	0.35	0.25		

CD(0.05) – Critical Difference of means at 5 % level of significance
SE(d)- Standard Error of Standard Deviation
SE(m)- Standard Error of mean
Shoot extension growth

3.11 Vegetative Growth

3.11.1 Increment in trunk diameter

The perusal of data presented in Table 4 shows that PBZ application significantly restricted the increment in trunk diameter; a minimum increase (1.4%) was recorded with the highest dose of PBZ application i.e. 2500 ppm (P2) and the highest increase of 3.8% in trunk diameter was recorded under the control (P3). A lower per cent increase in the trunk diameter was also observed with LFR treatments than with the control. A minimum increase of 2% was recorded with L1 i.e. 30:1 LFR but it was not statisticallydifferent from the other LFR treatments though statistically, it was significantly lower than the control. The joint application of PBZ and LFR treatments further reduced the increment level of the trunk diameter and the combination of 2500 ppm PBZ with 40:1 LFR (P2L2) resulted in a minimum increment of 1.3% in trunk diameter.

The PBZ treatments resulted in lower levels of shoot extension growth (Table 4). Only 25.2 cm shoot extension growth was recorded under 2500 ppm PBZ treatment which was otherwise 36.8 cm under control (P3). The effect of LFR was also significant and a minimum increase in current season growth was 27.4 cm was recorded under the 40:1 LFR (L2). The interaction effect between LFR and PBZ treatments was also statistically significant. The combination of 2500ppm PBZ and 40:1 LFR resulted in the minimum increase of 23.4 cm shoot growth against the highest recorded 50.7 cm under P3L4 (control).

3.11.2 Shoot Dry weight

The dry weight of the current season growth was also influenced significantly by the PBZ treatments. Minimum dry weight of 0.84 g was recorded under 2500 ppm PBZ (P2) application, it was not statistically different from the 1500 ppm PBZ application but it was considerably lower than the control (P3) which produced a 1.37 g dry weight of the basal portion of the current season growth. The effect of LFR treatments or their combination with PBZ treatments was not found to be significant.

4. DISCUSSION

4.1 Fruit Thinning

The experimentation results presented in the above section (Fig. 1) have revealed that the foliar PBZ application at the beginning of the pit hardening stage has significantly induced fruit thinning in Early Grande peach by way of increasing the initial fruit drop. The effect was found higher with the higher dose of PBZ. This influence of PBZ application on fruit drop may be supported by the findings of Monge et al. [8], who reported that it is the interaction between the developing fruit and the PBZ which affects the absorption of different mineral elements and results in fruit thinning in peaches; a similar effect has been observed under the current studies for Early Grande peach wherein the 2500 ppm PBZ application resulted in effective fruit thinning.

The higher initial fruit drop observed under the LFR treatments than control (Fig. 1) may be attributed to the physiological shock that the fruits in the vicinity of leaves might have received upon removal of some of these leaves for maintenance of specific LFR. The findings of Corelli-Grappadelli and Coston [9] are also supportive in this regard; they reported that the developing fruits require leaves in the vicinity for meeting their requirement of carbohydrates for respiration and other fruit developmental processes.

The additive effect of PBZ and LFR treatments in inducing 1st or 2nd periodic fruit drop may be attributed both to the inhibitory effect of PBZ [8] and the sudden reduction in carbohydrates supply which was induced by the LFR treatments which might have resulted in higher fruit drop under the treatment combination of 2500 ppm PBZ and 40:1 LFR. Gernard et al. [10] attributed such type of influence to the preferential orientation of available assimilates toward the shoot growth rather than fruit growth in late-maturing peach cultivars. However, in medium or early-maturing peach cultivars fruit and vegetative growth occur concurrently, so the balance between assimilating fruits and leaves is reported to be important in peaches. Further, Mimoun et al. [11] while estimating the effect of LFR on peach leaf light-saturated photosynthesis concluded that there exists a significant effect of the LFR on leaf light-saturated photosynthesis, it happens to be highest at a specific LFR and gets reduced at higher LFR or lower LFR.

4.2 Days from Full Bloom to Fruit Harvest

In the present findings, the PBZ application @ 2500 ppm has been found to advance fruit maturity by 2.5 days (Table 1). It is now well-established that PBZ is widely used to advance the harvest maturity of many fruits crop [12]. It restricts the vegetative growth and a guide assimilates toward the developing fruit resulting in relatively early maturity of the fruits [13]. The effect of PBZ on fruit developmental processes is dose-dependent, Upreti et al. [14] reported that its application not only influences the gibberellins but also increases the contents of ABA and cytokinin viz. zeatin, zeatin riboside and dehydrogenation riboside concomitant with C: N ratio and leaf water potential which ultimately enhance the rate of fruit development.

4.3 Fruit Retention, Weight and Yield

The effect of PBZ on higher fruit retention (Table 1) may be attributed to the higher initial fruit drop induced by PBZ application (Fig. 1); the focussed supply of the assimilates to the fruits which remained there on the plants after the initial fruit drop might have helped in better fruit retention at harvest. Similar results were reported in McIntosh apples by Stan et al. [15] who reported that the foliar application of paclobutrazol reduced pre-harvest drop when applied within 5 weeks after full bloom. The highest final fruit retention specifically at 40:1 LFR may be supported by the findings of Gernard et al. [10] which can be used for explaining the balanced assimilates partitioning between developing fruit and vegetative parts.

The positive effect of PBZ on fruit weight may be attributed to the optimum number of fruits which remained after high initial thinning (Fig. 1) induced by the PBZ treatment. PBZ application not only increased the assimilate translocation toward the developing fruits but also reduced their translocation towards the vegetative sinks which are evident from the data presented in Table 4. Similar findings have been reported by Costa [16], Wu et al. [17] and Deshmukh [18].

Further, the appropriate number of leaves maintained through LFR treatment 40:1 not only restricted the excessive vegetative growth but also provided the target assimilate supply to the developing fruits. Thus, the combination of PBZ @ 2500 ppm LFR @ 40:1 resulted in the observance of the highest fruit weight. These findings are in close conformity with those of Urban and Lechudel [19] and Li et al. [20] who stated that reduction in leaf area to a certain extent leads to a rise in photosynthetic rates of remaining leaves which compensates the sink demands.

As yield is a function of fruit number and fruit weight; the higher values for these parameters recorded under the PBZ and LFR treatments thus resulted in higher per-plant yield (Table 1). Higher yields in peaches due to PBZ application and at a specific LFR have also been reported by Patel et al. [21]. As both these treatment factors exerted a positive influence on fruit number and fruit weight, their interactions thus produced an additive effect on fruit yield.

4.4 Fruit Colour

The significant improvement in fruit surface and pulp colour together with a higher proportion of surface redness due to PBZ application may be attributed to the suppression of gibberellins activity. These findings are in consonation with the findings of Saure [22] who reported that anthocyanin formation can be stimulated directly by decreasing the level of gibberellins or by increasing the level of inhibitors in developing fruits. Better red colour development in apples and cherries with PBZ application has also been reported by Wani [23], respectively. Further, the better colour development with the lower dose of PBZ is supported by the findings of Looney and Mckeller [24] who reported that in Lambert sweet cherry 1000 ppm produced lesser colour than 500 ppm treatment of paclobutrazol may be due to the attainment of anthocyanin synthesis maxima even with the lower dose of PBZ. Similar observations were recorded under the present experimentation also. 1500ppm resulted in better colour development though it was at par with the 2500 ppm PBZ application rate.

Similarly, the reduction in leaf number under LFR treatments resulted in better exposure of the fruits to sunlight and this might have improved the fruit surface redness and colour. The plantation under high density are known to induce shading through their dense canopies, therefore, improving light levels at the individual plant through Leaf-to-fruit ratio modifications might have accelerated the photo-sensory pathways of the fruit colour development. These findings are in harmony with those of Jone [25] who reported that fruit colour and commercial value can be improved by improving light at the canopy level. Better colour development in peaches with a specific proportion of leaves to fruit has also been reported by Zhang et al. [26].

4.5 Fruit Quality

Paclobutrazol application @ 2500 ppm produced a significant gain in almost all fruit quality parameters, like TSS, total sugars, and reducing and non-reducing sugars. On the other hand, the titratable acidity, firmness and shelf life of the fruits were found at the lowest at the higher dose of PBZ application. Such changes in fruit quality parameters might have happened due to modification in the source and sink relationship induced by the PBZ application [27]. The increase of TSS and sugars thus may be attributed to the reduced allocation of the assimilates to the vegetative growth (Table 4) and this might have resulted in more nutrient partitioning to the fruits.

The decrease in fruit acid content with PBZ application in a dose-dependent manner may be explained under the light of the fact that paclobutrazol while modifying the source-sink relation, may tend to reduce photo-assimilate demand of the growing shoot in favour of the growing sinks (fruits) and increased fruit soluble solids with a corresponding decrease in acidity. But, more appropriately it is speculated that the hastening of fruit developmental processes by PBZ application might be essentially coupled with the process of conversion of acid to sugars with the early onset of the fruit ripening process and this might have resulted in a lower level of fruit acidity at the higher dose of PBZ application.

The reduction in fruit firmness and shelf life of peaches under the present experimentation is also justified in the light of the fact that PBZ application has hastened the fruit maturity and reduced the number of days from full bloom to maturity (Table 1) and this might have resulted into early onset of ripening processes leading to the loosening of cohesive strength of the fruit cells. Deshmukh et al. [18] also reported similar findings of reduction in fruit firmness and subsequent decrease in the shelf life of peaches due to PBZ application.

The positive effect of LFR treatments was not noticed as significant as far as sugars, firmness or shelf life was concerned but the effect on total soluble solids (TSS), acidity, and ratio was significant. The LFR treatment 40:1 resulted in higher TSS and lower fruit acidity, almost similar to L3 i.e. 50:1 LFR treatment. Similar findings were reported by Urban and Lechudel [19] and Li et al. [20] who reported that maintaining a specific proportion of leaves increased total soluble solids and total sugars while decreasing the level of acidity due to enhancement photosynthetic efficiency of the remaining leaves after removal of extra leaves. The positive and additive effect of PBZ and LFR treatments on fruit quality parameters can be explained in the light of present findings that both these treatment factors restricted vegetative growth (Table 4) and this might have favoured assimilate production at greater photosynthetic efficiency thereby supporting the fruit sink in respiration, growth and storage in a preferential manner [28].

4.6 Vegetative Growth

The PBZ application has exerted a significant effect on tree size control (trunk diameter, shoot extension growth and shoot dry weight) under current experimentation and this may be attributed to the inhibitory effect of PBZ on vegetative growth. The PBZ is well known to inhibit gibberellins activity by modifying the isoprenoid pathway as a result of a block in the transformation of the gibberellin biosynthesis pathway from ent-kaurene to ent-kaurenoic acid [29]. The significant influence of LFR treatments on reducing shoot length increase might be due to the utilization of the assimilates more by the developing fruit rather than the vegetative part of the plant under the condition of decreased leaf number Mimoun et al. [11] also demonstrated a reduction in vegetative growth at reduced level leaf area in peaches. It implies that modification in the number of leaves per unit of fruit also restricted vegetative growth and it can be attributed to the ability of the developing fruit to act as a stronger sink and attract more assimilates than the vegetative parts [28].

The positive interaction effects of PBZ and LFR treatments on the reduction of increment in diameter trunk and length of shoot growth can also be supported by the above-discussed research stating strong control of these factors on vegetative growth which might have led to the additive effect on the control of trunk diameter and shoot growth, also.

5. CONCLUSION

The deleterious effects of excessive crop load and shading observed in the canopies of non-dwarfing peach high densities can be negated by inducing fruit thinning during the beginning of pit hardening (45 days after full bloom) with foliar application of paclobutrazol (PBZ) and by maintaining optimum leaf-to-fruit ratio. Though 1500 ppm PBZ foliar spray and 30:1 LFR were found effective for fruit colour and quality development; but, the treatment combination of 2500 ppm PBZ and 40:1 LFR was found best for overall yield, fruit colour, and quality and for checking excessive vegetative growth of Early Grande peach.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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