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Paclobutrazol and Summer Pruning Influences Fruit Quality of Red Delicious Apple

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ABSTRACT

Paclobutrazol and summer pruning can restrict vegetative growth and improve productivity and fruit quality in apple. The present experiment was carried out during two successive seasons on Red Delicious cultivar of apple. The study was carried out in a randomized block design with sixteen treatments and three replications. The trees were > 15 years old grown in experimental orchard of Division of Fruit Science, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, Jammu and Kashmir, spaced at 5.49 ×5.49 metre distance. The study was aimed to show the effect of different concentrations of paclobutrazol along with different levels of pruning on fruit quality. With increase in paclobutrazol concentration and pruning levels, an increase in TSS, TSS/acid ratio, anthocyanin, sugars, fruit calcium and improvement in fruit grade was observed with decrease in fruit acidity.

1. Introduction

Apple (*Malus domestica* Borkh) is a very important temperate fruit and its cultivation sites fall geographically between 25-52^{o} latitude. The apple productivity depends on canopy management, scion and rootstock behavior, fertilization, disease control measures and nutrigation. Among all, canopy management techniques play very vital role in production function. Paclobutrazol and summer pruning can restrict vegetative growth, improve productivity and fruit quality in apple. The plant growth regulator, [(2RS, 3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol- 1-yl)-pentan-3-ol](paclobutrazol;PP333), is a triazole derivative and has been shown to inhibit shoot growth on apple trees (Steffens et al. 1985). The ancymidol blocks the oxidative steps with high specificity leading from ent-kaurene to ent-kaurenoic acid in the pathway of GA' biosynthesis.

The same oxidative steps are thought to be inhibited by the active triazol derivatives (Graebe 1982). Paclobutrazol has been reported to inhibit GA biosynthesis in plants by inhibiting kaurene oxidase, a Cyt P-450 oxidase, thus blocking the oxidation of kaurene to kaurenoic acid (Dalziol and Lawrence 1984). The inhibitory activity of paclobutrazol can be reversed by GA (Steffens et al. 1985). Paclobutrazol was also shown to shift assimilate partitioning from leaves to roots, increase carbohydrates in all parts of apple seedlings, increase chlorophyll content, soluble protein and mineral element concentration in leaf tissue, increase root respiration and reduce water use (Wang and Steffens 1985). Summer pruning has been reported to reduce vegetative growth, improve canopy light penetration, re-exposes spur leaves and fruits of the interior canopy of apple trees, enhance fruit quality, concentrate fruit maturation and increase the number of flower buds (Rom and Ferree 1984). The relationship between vegetative and reproductive growth influences the amount and quality of fruits produced by an apple tree.

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The woody tissue of the tree competes with the fruits for the products of leaves and excessive vegetative growth is made at the expense of the fruits. Excessive tree vigour can reduce flower bud formation, fruit set and result in reduced fruit quality. Summer pruning has been regarded as less invigorating than dormant pruning (Utermark 1977). Pruning intensity, time and method have varying effects on apple quality at harvest and during storage (Wertheim 2005). The objective of this study was to test the effect of paclobutrazol and summer pruning on quality of apple (*Malus × domestica Borkh*).

2. Material and Methods

The main trial was established in the experimental orchard of Division of Fruit Science, SKUAST-K, Shalimar during the years 2011 and 2012. Forty-eight trees, matched for uniform growth and appearance, were selected from the site for the study. Paclobutrazol was used as a source. The quantity was calculated on the basis of active ingredient and spray material required was worked out on the basis of tree age and size. Three concentrations of paclobutrazol (250ppm, 500ppm and 750ppm) each with control were used and control plants were sprayed with water only. Two intensities of summer pruning were performed: summer pruning I (thinning out water sprouts and unwanted branches eight weeks after full bloom) and summer pruning II (heading back from upper, middle and lower canopy area to the extent of 25% only of current season's growth 12 weeks after full bloom). The experiment was laid in a completely Randomized Block Design. The total soluble solids content was determined from fresh strained, thoroughly stirred juice of fruits on each sampling date with the help of a digital hand refractometer and the readings were expressed as percent soluble solids (AOAC, 1980). The acidity was determined by diluting the known volume of apple juice and titrating the same against 1N sodium hydroxide solution using phenolphthalein as an indicator. It was expressed in terms of per cent malic acid. Total soluble solids / acid ratio was obtained by dividing the value of total soluble solids of fruit sample by the acidity value of the same sample. Total anthocyanin was extracted by using 95 per cent ethanol-1.5 N HCl (85:15) and estimations were made by calorimetric procedure as suggested by Ranganna (1986). The concentration of the reducing sugars was determined by Fehlings solution method of Lane and Eynon (1923) using methylene blue as an indicator. Total sugar content was estimated after acid hydrolysis (AOAC, 1990). The amount of non-reducing sugars was estimated by subtracting the value obtained for reducing sugars from total sugars and multiplying the same by a factor of 0.95. Fruit calcium content on the date of harvesting of fruits was determined with flame photometry (Jackson 1975) and the results were expressed in parts per million (ppm) on dry weight basis. At the time of harvesting, the fruits were graded on the basis of size, colour and following grades were allotted: A -Super large: Size of fruit 70 mm and above with colour development >65%, B -Super medium: Size of fruit 60-69 mm with colour development 65% and C –Super small: Size of fruit <60 mm with colour development <65%. Two years data was recorded, pooled and analyzed using data analyzing statistical software. The final data is being presented in the table for interpretation of the results.

3. Results and Discussion

3.1 Total soluble solids (TSS) and sugars

Highest total soluble solids (14.43^{o}B and14.51^{o}B) were recorded in treatment T_{15} which was significantly superior to all other treatments. The trees receiving no treatment (T_0) recorded lowest total soluble solids (11.85^{o}B and 11.86^{o}B) which was significantly lower than all other treatments during 2011 and 2012. Pooled data recorded highest total soluble solids (14.47 ^{o}B) in treatment T_{15} (Table 1) which was significantly different from rest of the treatments whereas, lowest total soluble solids (11.85^{o}B) were observed in T_0. The total sugar content was significantly increased by all the treatments of paclobutrazol and summer pruning during both the years of study. Pooled data recorded maximum total sugar content (10.80%) under the treatment T_{15} and minimum total sugar content was noticed in T_0 (8.59%). The highest reducing sugars (8.38%) was noticed under treatment T_{15} which was statistically similar to treatment T_{14} (8.29%) but significantly superior to all other treatments and lowest reducing sugars was observed under control (6.40%) in pooled data (Table 2). The non reducing sugars were significantly influenced by all the treatments of paclobutrazol and summer pruning during both the years of study. Pooled data (Table 2) recorded maximum non reducing sugars (2.42%) in treatment T_{15} which was significantly higher and minimum non reducing sugar content of (2.19%) was recorded in T_0 which was significantly lower than all other treatments. Foliar application of paclobutrazol at 750 ppm + summer pruning I + summer pruning II significantly improved total soluble solids and sugars in fruits. This can be explained on the basis of increased sucrose, starch and sugar levels due to reduced vegetative growth and thus the absence of other potentially competitive actively growing sinks which resulted in more nutrient partitioning to fruits (Abdel Rahim et al. 2011). Our findings are in conformity with the findings of Wani et al. (2007) in Red Delicious apple and Rebolledo-Martinez et al. (2008) in mango. The increased rate of photosynthesis led by more light penetration into the interior tree canopy, increased the soluble solids in fruits harvested from pruned trees (Ibrahim et al.

Table 1. Effect of paclobutrazol and summer pruning on chemical characteristics of apple cv. Red Delicious

Treatments		TSS (°Brix)			Acidity (%)			TSS/acid ratio			Anthocyanin (mg/100g)		
		2011	**2012**	**Pooled**	**2011**	**2012**	**Pooled**	**2011**	**2012**	**Pooled**	**2011**	**2012**	**Pooled**
T_0	Control	11.85	11.86	11.85	0.39	0.40	0.39	30.38	29.65	30.01	6.19	6.23	6.21
T_1	250 ppm PP333	13.21	12.83	13.02	0.36	0.35	0.35	36.69	36.66	36.67	8.41	8.76	8.58
T_2	500 ppm PP333	13.28	12.60	12.94	0.35	0.34	0.34	37.94	37.06	37.50	8.47	8.87	8.67
T_3	750 ppm PP333	13.31	13.40	13.35	0.33	0.32	0.32	40.33	41.88	41.10	8.55	9.03	8.79
T_4	SP I	13.27	13.40	13.33	0.36	0.35	0.35	36.86	38.29	37.57	8.45	8.84	8.64
T_5	250 ppm PP333+ SP I	13.39	13.34	13.36	0.32	0.31	0.31	41.84	43.03	42.43	8.12	9.15	8.63
T_6	500 ppm PP333 + SP I	13.46	13.49	13.47	0.30	0.28	0.29	44.87	48.18	46.52	8.81	9.33	9.07
T_7	750 ppm PP333 + SP I	13.53	13.66	13.59	0.28	0.26	0.27	48.32	52.54	50.43	9.03	9.54	9.28
T_8	SP II	13.34	13.42	13.38	0.34	0.32	0.33	39.24	41.94	40.59	8.52	8.97	8.74
T_9	250 ppm PP333 + SP II	13.44	13.52	13.48	0.31	0.30	0.30	43.35	45.07	44.21	8.73	9.24	8.98
T_{10}	500 ppm PP333 + SP II	13.49	13.65	13.57	0.29	0.27	0.28	46.52	50.56	48.54	8.92	9.43	9.17
T_{11}	750 ppm PP333 + SP II	13.75	13.78	13.76	0.27	0.25	0.26	50.93	55.12	53.02	9.11	9.61	9.36
T_{12}	SP I + SP II	13.75	13.94	13.84	0.30	0.28	0.29	45.83	49.79	47.81	8.86	9.38	9.12
T_{13}	250 ppm PP333 + SP I + SP II	13.93	14.18	14.05	0.27	0.25	0.26	51.59	56.72	54.15	9.19	9.75	9.47
T_{14}	500 ppm PP333 + SP I + SP II	14.25	14.32	14.28	0.26	0.23	0.24	54.81	62.26	58.53	9.30	9.87	9.58
T_{15}	750 ppm PP333 + SP I + SP II	14.43	14.51	14.47	0.24	0.22	0.23	60.13	65.95	63.04	9.42	10.03	9.72
	CD ($p \leq 0.05$)	**0.17**	**0.13**	**0.15**	**0.02**	**0.01**	**0.01**	**2.23**	**2.21**	**2.22**	**0.10**	**0.06**	**0.08**

SP I = summer pruning I, SP II = summer pruning II

1983). The significant increase in non reducing sugars by summer pruning could be due to active translocation of sucrose from leaves to fruits (Daulta and Singh 1986). These results are supported by Rather (2006) in 'Red Delicious' apple and Mercier et al. (2008) in peach.

3.2 Acidity

It is inferred from the data (Table 1) that lowest acidity (0.24% and 0.22%) was observed in the treatment T_{15} whereas, highest acidity (0.39% and0.40%) was noticed in T_0 during 2011 and 2012 which was significantly higher than rest of the treatments. Pooled data also recorded lowest acidity (0.23%) under the treatment T_{15} whereas, highest acidity (0.39%) was noticed in T_0 which was significantly higher than all other treatments (Table 1). Different treatments of paclobutrazol and summer pruning had significant effect on TSS/acid ratio of fruits. Maximum TSS/acid ratio (60.13 and 65.95) was noticed in treatment T_{15} which was significantly higher than all other treatments whereas, minimum TSS/acid ratio of (30.38 and 29.65) was observed in T_0 during 2011and 2012. Pooled data also recorded maximum TSS/acid ratio of (63.04) in treatment T_{15} and minimum TSS/acid ratio of fruits (30.01) in T_0 (Table 1) which was significantly lower than all other treatments. These results find the support of Andres et al. (2008) who observed that the acidity content of fruits diminished as a result of the ripening process in mango by paclobutrazol application which resulted in lowest values for acidity. Similar reports were found by Wani (2004) in sweet cherry and Wani et al. (2007). Fruit acidity was reduced by summer pruning. This may be attributed to the reason that fruit maturation was accelerated in summer pruned trees which resulted in higher soluble solid content and lower titratable acidity in the peach (Hossain et al. 2006).

3.3 Anthocyanin

Paclobutrazol and summer pruning significantly improved the anthocyanin content of fruits during both the years of study. Highest anthocyanin content of (9.42 mg/100 gm and 10.03 mg/100 gm) was observed in treatment T_{15} which was significantly superior to all other treatments whereas, the lowest anthocyanin content of (6.19 mg/100 g and 6.23 mg/100 g) was recorded in T_0 which was significantly lower than all other treatments during 2011 and 2012. Pooled data recorded highest anthocyanin content (9.72 mg/100 g) in treatment T_{15} which was significantly followed by treatment T_{14} (9.58 mg/100 g) and treatment T_{13} (9.47 mg/100 g), respectively and the lowest anthocyanin content (6.21 mg/100 g) was observed in T_0 (Table 1). Continuous application of paclobutrazol significantly reduced vegetative growth characters of the trees, thereby exposing fruits to direct sunlight which may have significantly increased red colouration of the fruits. These results are in accordance with Stover and Fargione (2003) in apple and Wani (2004) in sweet cherry. Increased fruit colour by summer pruning is attributed to the reason that by conducting summer pruning, the canopy size can be controlled and light availability to fruit for red colour development can be improved without undesirable post pruning regrowth by summer pruning (Dusi et al. 2004). The results are in accordance with Yongkoo et al. (2000) in 'Yataka Figi' and Rather (2006) in Red Delicious apple.

3.4 Fruit calcium

Highest fruit calcium content (400 ppm and 490 ppm) was recorded in treatment T_{15} whereas, lowest fruit calcium content (230 ppm and 220 ppm) was observed in T_0 in 2011 and 2012. Pooled data recorded highest fruit calcium content (440 ppm) in treatment T_{15} which was significantly higher than all other treatments whereas, lowest fruit calcium content (220 ppm) was observed in T_0 (Table 1). This is due to the reason that the number of shoots were reduced, transforming trees into a more desirable, spur type growth habit and as the vegetative sink was reduced, transport of nutrients including calcium towards fruits was enhanced (Greene 1991). These results are in accordance with Luo et al. (1989) who found increased calcium, phosphorus and potassium in apple fruits treated with paclobutrazol. Fruit calcium is increased for 2 to 3 years due to carry over effect. Our findings are in conformity with the findings of Wani (2004) in sweet cherry and Wani et al. (2007) in 'Red Delicious' apple. Summer pruning significantly enhanced fruit calcium which resulted in decrease in incidence of calcium related disorders like bitter pit, cork spot thereby, extending the shelf life of fruits. This may be due to the fact that summer pruning has the potential to reduce the competition between shoot growth and fruit for available calcium which increased calcium levels in fruits. Singh (1992) in peach also reported the same findings.

Effect of paclobutrazol and summer pruning on quality parameters

Grades

Paclobutrazol and summer pruning had significant influence on fruit grades (Table 3). During the year 2011, treatment T_3 to treatment T_{15} recorded fruits of grade A (with >70 mm fruit breadth) whereas, fruits of grade B (with 60-69 mm fruit breadth) were noticed in treatment T_1 and treatment T_2 and fruits of grade C (with < 60 mm fruit breadth) were observed

Table 2. Effect of paclobutrazol and summer pruning on chemical characteristics of apple cv. Red Delicious

Treatments		Total sugars (%)			Reducing sugars (%)			Non-reducing sugars (%)			Fruit calcium (ppm)		
		2011	**2012**	**Pooled**	**2011**	**2012**	**Pooled**	**2011**	**2012**	**Pooled**	**2011**	**2012**	**Pooled**
T_0	Control	8.60	8.59	8.59	6.41	6.39	6.40	2.19	2.20	2.19	230	220	220
T_1	250 ppm PP333	9.42	9.67	9.54	7.32	7.51	7.41	2.10	2.16	2.13	250	260	250
T_2	500 ppm PP333	9.48	9.82	9.65	7.40	7.72	7.56	2.08	2.10	2.09	260	280	270
T_3	750 ppm PP333	9.57	9.94	9.75	7.48	7.81	7.64	2.09	2.13	2.11	280	290	280
T_4	SP I	9.46	9.73	9.59	7.37	7.68	7.52	2.09	2.05	2.07	240	260	250
T_5	250 ppm PP333+ SP I	9.65	10.07	9.86	7.59	7.89	7.74	2.06	2.18	2.12	290	300	290
T_6	500 ppm PP333 + SP I	9.81	10.36	10.08	7.76	7.97	7.86	2.05	2.39	2.22	310	350	330
T_7	750 ppm PP333 + SP I	10.14	10.43	10.28	7.98	8.09	8.03	2.16	2.34	2.25	330	410	370
T_8	SP II	9.55	9.91	9.73	7.46	7.76	7.61	2.09	2.15	2.12	270	280	270
T_9	250 ppm PP333 + SP II	9.72	10.21	9.96	7.68	7.93	7.80	2.04	2.28	2.16	300	330	310
T_{10}	500 ppm PP333 + SP II	10.06	10.39	10.22	7.91	8.02	7.96	2.15	2.37	2.26	320	380	350
T_{11}	750 ppm PP333 + SP II	10.19	10.47	10.33	8.04	8.14	8.09	2.15	2.33	2.24	340	430	380
T_{12}	SP I + SP II	10.03	10.41	10.22	7.87	7.98	7.92	2.16	2.43	2.29	310	330	320
T_{13}	250 ppm PP333 + SP I + SP II	10.28	10.52	10.4	8.09	8.27	8.18	2.19	2.25	2.22	360	440	400
T_{14}	500 ppm PP333 + SP I + SP II	10.51	10.71	10.61	8.26	8.32	8.29	2.25	2.39	2.32	380	470	420
T_{15}	750 ppm PP333 + SP I + SP II	10.72	10.88	10.80	8.37	8.39	8.38	2.35	2.49	2.42	400	490	440
	CD ($p \leq 0.05$)	**0.10**	**0.13**	**0.12**	**0.07**	**0.10**	**0.09**	**0.02**	**0.03**	**0.02**	**10.30**	**20.0**	**16.70**

SP I = summer pruning I, SP II = summer pruning II

Table 3. Effect of paclobutrazol and summer pruning on quality parameters of apple cv. Red Delicious

Treatments		Grades	
		2011	**2012**
T_0	Control	8.60	8.59
T_1	250 ppm PP333	9.42	9.67
T_2	500 ppm PP333	9.48	9.82
T_3	750 ppm PP333	9.57	9.94
T_4	SP I	9.46	9.73
T_5	250 ppm PP333+ SP I	9.65	10.07
T_6	500 ppm PP333 + SP I	9.81	10.36
T_7	750 ppm PP333 + SP I	10.14	10.43
T_8	SP II	9.55	9.91
T_9	250 ppm PP333 + SP II	9.72	10.21
T_{10}	500 ppm PP333 + SP II	10.06	10.39
T_{11}	750 ppm PP333 + SP II	10.19	10.47
T_{12}	SP I + SP II	10.03	10.41
T_{13}	250 ppm PP333 + SP I + SP II	10.28	10.52
T_{14}	500 ppm PP333 + SP I + SP II	10.51	10.71
T_{15}	750 ppm PP333 + SP I + SP II	10.72	10.88
	CD ($p \leq 0.05$)	**0.10**	**0.13**

SP I = summer pruning I, SP II = summer pruning II summer pruning in T_0, respectively. During 2012, fruits of grade A were recorded in treatment T_2 to treatment T_{15} whereas, fruits of grade B were noticed in treatment T_1 and fruits of grade C were observed in T_0, respectively. This increase in fruit size was due to the reason that application of paclobutrazol reduced vegetative growth (sinks) which in turn, increased the partitioning of nutrients and dry matter towards fruits and thereby, increased the fruit size and weight (Wolstenholme et al. 1990). Similar results were obtained by Pant and Ratan (2004) in apple. Pruning decreased the fruit load and as the number of fruits were less, the available food material reached the individual fruit in sufficient quantity which thereby, increased the fruit size. These findings are in conformity with the findings of Siham et al. (2005) and Bussi et al. (2005) in peach.

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