

Interaction of Paclobutrazol, Boron and Zinc on Vegetative Growth, Yield and Fruit Quality of Strawberry (*Fragaria* × *Ananassa* Duch. Cv. Selva)

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ABSTRACT

Proper nutrient at the right time increases fruit quality, and yield of strawberry plants. An experiment was conducted with the aim of reducing vegetative growth and increasing yield and fruit quality of Selva strawberry cultivar using paclobutrazol (0, 100 mg l⁻¹), boric acid (0, 150, 300 mg l⁻¹) and zinc sulfate (0, 100, 200 mg l⁻¹). Rooted runners of strawberry grown in the greenhouse under hydroponic condition were used. The criteria measured were leaf number, leaf area, length and diameter of petiole, fresh and dry shoot root ratio, yield, total soluble solid, acidity and vitamin C. Results indicated that vegetative growth was reduced with PP333. Zinc (ZnSO₄) had positive effect on criteria measured. However, combined PP333×B decreased total soluble solid in fruits. Highest vitamin C was obtained at concentration of (0-300 mg l⁻¹ PP333- B). Foliar application of ZnSO₄ prior to flowering was recommend to increase fruit quality and yield of strawberry.

Key Words: Paclobutrazol, total soluble solid, yield, vitamin C, boric acid, vegetative growth

INTRODUCTION

Strawberries are ideal model for nutrient interaction studies in perennial crops. Since, they are relatively precocious in producing their first crop within months of planting, and also, they can easily be excavated and divided into vegetative and reproductive components, allowing for detailed evaluation of observed growth or responses (May and Pritts, 1993).

Balanced nutrient at proper time is one of the means to reach a commercial fruit production, and improved yield and fruit quality. Foliar program at key stages can have a marked positive effect on fruit yield and quality (Barker and Pilbeam, 2006).

The two chief methods of fertilization are adding fertilizer directly to the soil or foliar spraying. Both have been proved to be effective for crops. Soil applications are generally used for applying to field crops, but foliar sprays are more common on perennial crops such as fruit trees. Foliar application rates are usually about 50% lower than soil application rates (Barker and Pilbeam, 2006).

Among nutrient elements, zinc and boron have important role on pollination, fruit set and total yield (Motesharezade et al., 2001). Zinc is known to have an important role either as a metal component of enzymes or as a functional, structural or regulatory factor of a large number of enzymes (Bowler et al., 1994). Zinc induces pollen tube growth through its role on tryptophan as an auxin precursor biosynthesis (Chaplin and Westwood, 1980). Growth of the receptacle is controlled primarily by auxin, which is synthesized in achenes (Archbold and Dennid, 1984), therefore ZnSO₄ is applied to increase fruit number, size and quality. ZnSO₄ permits normal development of new leaves (Barker and Pilbeam, 2006). Dixi and Gamdagin (1978) claimed that a foliar spray application of ZnSO₄ on March and April increased size, TSS and juice of oranges. Zinc has also shown to have an important role in photosynthesis and related enzymes, resulting in increasing sugar and decreasing acidity (Abedy, 2001).

Another nutrient which also has an important role in fruit quality is boron. Boron has an affect on cell wall structure and also has a major effect on cell elongation (pollen tube) and root growth (Barker and Pilbeam, 2006). Boron (H₃BO₃) is considered to be a nutrient that increases the phloem carbohydrate movement (Marschner, 1995) which may increase fruit soluble solid content. Soil drench or foliar application of boron has increased yield and fruit quality, in raspberry (Wojcik, 2005b). Wojcik, 1999 reported that boron decreased acidity in fruit of prune. Foliar application of B increased yield and fruit quality of grape (Donna, 1986). Josten and Kutschera (1999) reported that the presence of boron resulted in the development of numerous roots in the lower part of the hypocotyl in sunflower (*Helianthus annuus* L.) cuttings.

Paclobutrazol (PP333), is a triazol that inhibits gibberellin biosynthesis (Hedden and Graebe, 1985) changes assimilate partitioning; with more assimilate toward buds and fruits (Davis, 1988). Paclobutrazol not only controls growth, but also influences cropping and fruit characteristics (Green and Murray, 1983). PP333 increased achenes per fruit of strawberry but decreased yield (McArthur and Eaton, 2003).

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PP333 has been tested on various fruit tree species and has shown positive response (Huang et al., 1989). Shaltout et al., (1988) reported that PP333 decreased TSS but increased acidity in strawberry fruit. It has decreased leaf area of strawberry (Nishizawa, 1993). The reduction in leaf area was attributed to reduction in absorbing available material (Deyong and Doyle, 1984).

The interaction of PP333, H₃BO₃ and ZnSO₄ on vegetative growth, yield and fruit quality of strawberry however has not been yet reported and, the object of this research was to evaluate the main effects and interactions of PP333, ZnSO₄ and H₃BO₃ on vegetative growth, yield and fruit quality in 'Selva' strawberry.

MATERIALS AND METHODS

Plant material and growth conditions

The experiment was conducted during 2007 and 2008 on strawberry plants at a hydroponic greenhouse located in Sadra, Shiraz, Iran (latitude 29°32'N, longitude 52°35'E). Strawberry plants (*Fragaria × ananassa* Duch. cv. Selva) were grown under natural light conditions. The temperature conditions were 26 ± 4°C and 15 ± 4°C, during days and nights respectively; with mean relative humidity of 60 ± 15%. Runner plants were rooted in plastic pots (12 cm diameter) filled with leca (Leca stone is a clean and attractive soil free media for hydroponics) and perlite. They were irrigated three times a day. Rooted plants were transplanted into 3 liter pots. The pots were filled with leca, perlite and peatmoss (1: 3: 1 v/v/v). The plants were fertilized with the following complete nutrient solution containing: N, P₂O₅, K₂O, Ca, Mg, S, Fe, Mn, Mo and Cu. Electrical conductivity (EC) was kept within the range of 0.5- 0.8 ds m⁻¹, while the pH of the solution was maintained at 5.5 and 6.2.

Treatments

Paclobutrazol at the rate of 100 mg l⁻¹, zinc at the rate of 100 and 200 mg l⁻¹ as ZnSO₄·7H₂O and boron at the rate of 150 and 300 mg l⁻¹ as boric acid were applied as foliar. The surface of pot was covered with aluminium foil to prevent the adding of PP333, H₃BO₃ and ZnSO₄ solution into root medium. Untreated plants were left as a control and sprayed with distilled water.

Measurements

Total leaf areas of each plant were recorded with portable leaf area meter (ΔT Devices, England). Number of leaves was also recorded both before treatments and at the end of experiment. Petiole length was measured using a ruler. The change in petiole diameter was determined for each plant using vernier caliper. Plants were harvested and divided into leaf, crown and root components. Roots were separated from the medium by washing them onto sieves and then manually separating roots from any remaining organic debris. Fresh weights of all components were recorded. To attain a constant weight for biomass estimation (dry weight), plant components were oven dried at 70°C.

Total fruit weight of each plant was separately measured and considered as yield. To evaluate fruit quality, total soluble solid (TSS), titratable acidity (TA) and ascorbic acid (vitamin C) were measured. TSS of fruits was determined using a refractometer. Titratable acidity and ascorbic acid of fruits was determined according to the method described by Ting and Russeff (1981).

Statistical analysis

The experiment was a factorial in completely randomized design with 18 treatments and 4 replications. Data were analyzed using MSTATC and means were compared using Duncans' multiple range test (P ≤ 0.05).

RESULTS AND DISCUSSION

Fig. 1, shows PP333 significantly decreased leaf area. This growth regulator affects assimilate partitioning, with low assimilate to shoots resulted in reduction leaf growth, also blocks gibberlin biosynthesis, decreasing leaf area. Nishizawa (1993) who reported a significant decrease in leaf area of strawberry after paclobutrazol treatment. Highest and lowest leaf area was observed in concentration of 300 and 150 mg l⁻¹, H₃BO₃ respectively (Fig. 1). Petiole length was also reduced by PP333 though it was not significant, however H₃BO₃ and ZnSO₄ did not have effect on length and diameter of petiole. Paroussi et al., (2002) have shown that gibberellic acid increased petiole length and leaf area of strawberry cultivar 'C skip'. PP333 by blocking GA3 biosynthesis in plant may have caused the decrease in petiole length.

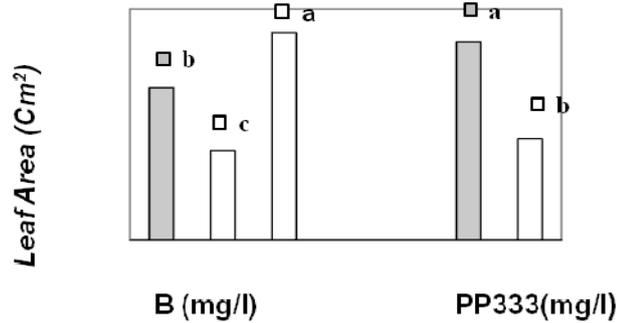


Figure 1. Effect of PP333 and H₃BO₃ on leaf area of strawberry

According to Fig. 2, PP333, H₃BO₃ and ZnSO₄ alone significantly increased mean leaf number. Furthermore positive significant correlations were observed between leaf number, H₃BO₃ and ZnSO₄ content. Meena (2010) reported the increase in vegetative growth of tomato which could be attributed to physiological role of boron and its involvement in the metabolism of protein, synthesis of pectin, maintaining the correct water relation within the plant, re synthesis of adenosine triphosphate (ATP) and translocation of sugar at development of the flowering and fruiting stages. Maximum leaf number was observed within highest concentrations of (100- 200 mg l⁻¹) PP333- ZnSO₄ and (100- 300 mg l⁻¹) PP333× H₃BO₃, either alone (Fig. 2) or in combination (Data not shown).

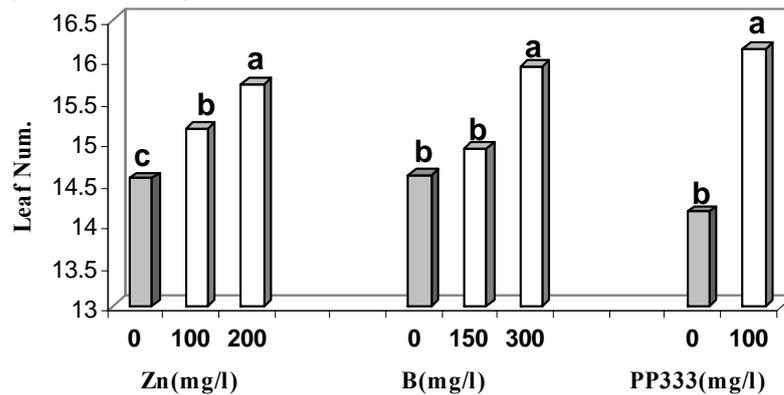


Figure 2. Effect of PP333, ZnSO₄ and H₃BO₃ on leaf number of strawberry.

Nazarpur (2005) and Chehrazi (1996) reported that PP333 and ZnSO₄ increased leaf number of strawberry cultivar Camarosa and Armore, respectively. Fig. 3 shows that fresh shoot / root ratio was decreased as a result of PP333, ZnSO₄ and B. Atkinson (1986) reported PP333 reduced this ratio in strawberry plants. This plant regulator affects translocation of assimilates towards the root (Symons et al., 1990). It has been established that adventitious roots develop on stem cuttings of bean only when boron is supplied (Ali and Jarvis, 1988).

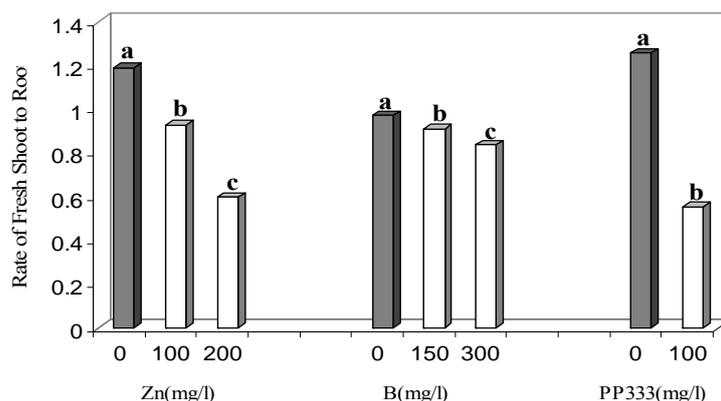


Figure 3. Effect of PP333, ZnSO₄ and H₃BO₃ on fresh shoot / root weight ratio

PP333 by itself brought about a significant yield decreased. Foliar application of PP333 before bloom, has decreased yield of strawberry, because of reduced growth of leaves (Braun and Garth, 1986), however ZnSO₄ when combined with PP333 brought about a yield increase. The highest yield was obtained from ZnSO₄ at 100 mg l⁻¹ without PP333, while PP333 at 100 mg l⁻¹ plus ZnSO₄ at 200 mg l⁻¹ produced the high yield (Table 1).

Table 1. Interaction of (PP333× ZnSO₄) on yield and acidity

PP333(mg/l)	ZnSO ₄ (mg/l)		
	0	100	200
Yield			
0	274.3 b	286.3 a	252.5 c
100	131.6 e	127.1 e	162.4 d
Acidity (mg/ 100 ml)			
0	0.8075 m	0.9097 c	0.8353 d
100	0.8499 c	0.8331 e	0.8960 b

In the present study PP333 and H₃BO₃ alone significantly decreased TSS in fruit compared to those of the untreated plants (Fig. 4). Huang et al., (1989) reported PP333 reduced TSS in fruit of watermelon. Fig. 4 shows that ZnSO₄ alone significantly increased TSS. Application of zinc sulfate can increase TSS in fruit of guava (Dobroluybsikii et al., 1981, 1982). Since zinc has an important role in photosynthesis and enzymes responsible for plant metabolism, therefore the increased TSS could be attributed to ZnSO₄. The highest TSS content in fruits was obtained from different concentration of ZnSO₄ without H₃BO₃ application (Table 2). Fig. 5 shows that total acid (TA) in fruit was not influenced by PP333 that confirmed the results of Rizzolo et al., 1993. According to Fig. 5 TA of fruit was significantly higher (0.8806 mg/100ml) at concentration of 150 mg l⁻¹ H₃BO₃ when compared with the other treatment and control, furthermore the lowest TA in fruit (0.8213 mg/100ml) was observed at (300 mg l⁻¹) boric acid. Wojcik (2005a; 1999) reported foliar application of H₃BO₃ significantly increased TA in fruit of blackcurrant but decreased it in plum fruit, respectively. Zinc alone (Fig. 5) and combined with PP333 (Table 1), significantly increased TA of fruit compared to control. The highest TA was obtained from interaction of PP333× ZnSO₄× H₃BO₃ (100×200×150 mg l⁻¹) (Data not shown).

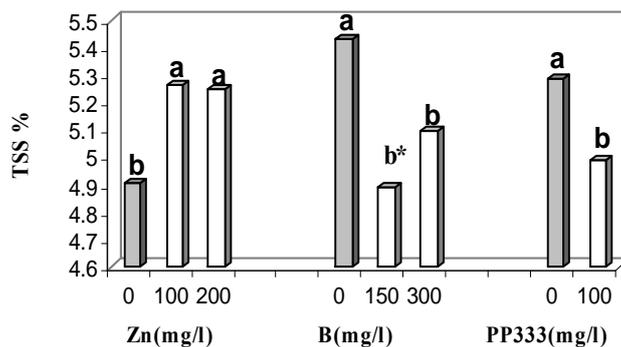


Figure 4. Effect of PP333, ZnSO₄ and H₃BO₃ on TSS of strawberry fruits
Same letters indicate no significant difference between treatment (P≤0.05 Duncan).

Table 2. Interaction of (H₃BO₃ × ZnSO₄) on TSS%

ZnSO ₄ (mg/l)	H ₃ BO ₃ (mg/l)		
	0	150	300
	TSS %		
0	5.042 b*	4.875 b	4.792 b
100	5.667 a	4.875 b	5.250 ab
200	5.583 a	4.917 b	5.250 ab

*Means followed by the same letter (small letters for means and capital letters for means of rows and columns) are not significantly different according to Duncan's multiple range test at P≤0.05.

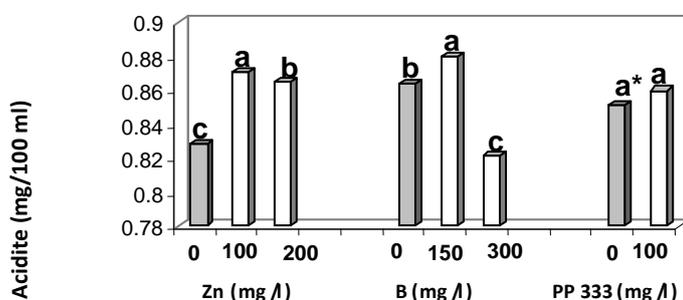


Figure 5. Effect of PP333, ZnSO₄ and B on acidity in strawberry fruits

* Same letters indicate no significant difference between treatment (P≤0.05 Duncan).

PP333 and H₃BO₃ alone, significantly decreased vitamin C content (Fig. 6). Francois (1984) reported that H₃BO₃ treatment significantly reduced the fruit quality of tomato. Fig. 6 shows a positive significant correlation between vitamin C and ZnSO₄ content. Maximum vitamin C belonged to the concentration of (200 mg l⁻¹) ZnSO₄ that significantly increased vitamin C from 111.9 mg/100g in control to 123.3 mg/100g. Rath et al., (1980) reported, foliar application of zinc sulfate (0.8 %) increased vitamin C. According to Fig. 7, significant differences were observed among treatments as far as vitamin C, is concerned and highest vitamin C was observed in maximum concentrations of ZnSO₄ and H₃BO₃ (300-200 mg l⁻¹ ZnSO₄ × H₃BO₃).

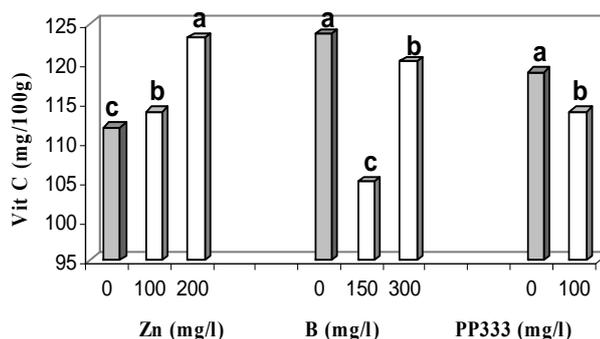


Figure 6. Effect of PP333, ZnSO₄ and H₃BO₃ on Vit. C of strawberry fruits

* Same letters indicate no significant difference between treatment ($P \leq 0.05$ Duncan).

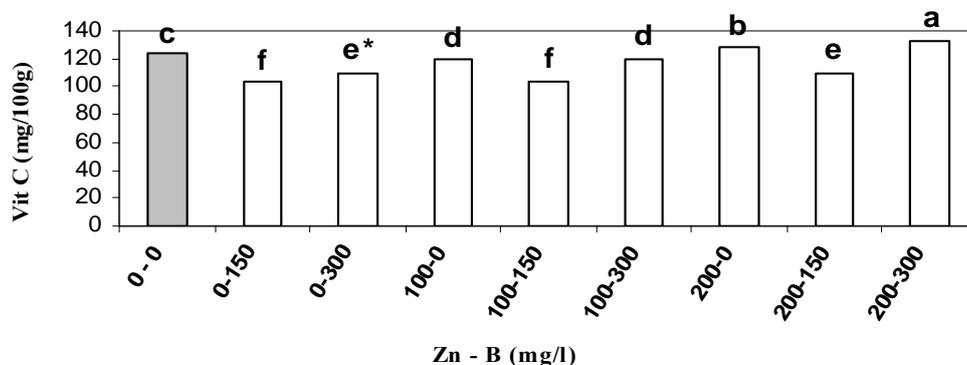


Figure 7. Interaction of ZnSO₄ × H₃BO₃ on Vit. C. of strawberry fruits

* Same letters indicate no significant difference between treatment ($P \leq 0.05$ Duncan).

In zinc sulfate (200 mg l⁻¹) treatment, with increasing paclobutrazol concentration, vitamin C significantly decreased. Vit. C was the highest (128.2 mg/ 100g) in (0-300 mg l⁻¹ PP333 × H₃BO₃) treatment and the lowest (102.2 mg/100g) in (0-150 mg l⁻¹ PP333- B) treatment. Interaction of PP333 × ZnSO₄ × H₃BO₃ (0-200-300 mg l⁻¹) significantly increased Vit. C from 123.2 mg/100g in control plants to 135.8 mg/100g (Data not shown) (Table 3).

Table 3. Mean squares of characters measured

Treatment	df	Leaf Area	Leaf Number	Petiole length	petiole diameter	Fresh shoot/root weight ratio	Yield	TSS	Vit. C	TA
PP333	1	332.029 **	71.003 **	3.45 ns	0.221 ns	8.93**	662.546*	1.185 **	327.574 **	0.001 ns
Zn	2	56.715 **	7.885 **	0.054 **	0.076 **	2.114**	54.170*	0.753 **	658.667 **	0.01 **
B	2	169.441 **	11.281 **	0.294 **	0.266 ns	0.11**	37.635 ns	1.344 **	1798.514 **	0.017 **
PP333 × Zn	2	291.054 **	0.066 **	0.115 **	0.062 **	1.895**	84.590*	0.189 ns	226.074 **	0.025 **
PP333 × B	2	33.569 *	58.774 **	0.029 **	0.068 **	0.154**	6.349*	0.314 ns	517.81 **	0.125 **
B × Zn	4	82.168 **	10.385 **	1.407 **	0.108 **	0.312**	32.947 ns	0.181 ns	173.222 **	0.061 **
PP333×Zn×B	4	207.31 **	38.618 **	0.108 **	0.232 ns	0.358**	21.239 ns	0.453 *	811.519 **	0.018 **

PP333: Paclobutrazol Zn:ZnSO₄ B: H3BO3

ns: are not significantly different at P≤0.05.

*, ** are significantly different at P≤0.05 and P≤0.01, respectively.

CONCLUSION

From the above results, it can be concluded that PP333 application reduced vegetative growth in tested plants. However ZnSO₄ brought about an increased yield and fruit quality. When ZnSO₄ was combined with H₃BO₃ or PP333, yield was decreased, but fruit quality remained high. PP333 and H₃BO₃ either alone or combined decreased yield, and fruit quality of the experimental of plants.

According to results of present study, in order to reach high yield and high fruit quality, strawberry plants could spray with ZnSO₄ before flowering. Whereas the controlling of vegetative growth is followed, grower can apply all of 3 treatments including PP333, ZnSO₄ and H₃BO₃.

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