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Thidiazuron (TDZ) increases fruit set and yield of 'Hosui' and 'Packham's Triumph' pear trees

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ABSTRACT

The low fruit set is one of the main factors leading to poor yield of pear orchards in Brazil. The exogenous application of thidiazuron (TDZ) and aminoethoxyvinilglycine (AVG) has shown promising results in some pear cultivars and other temperate fruit trees. The objective of this study was to evaluate the effect of TDZ and AVG on fruit set, yield, and fruit quality of 'Hosui' and 'Packham's Triumph' pears. The study was performed in a commercial orchard located in São Joaquim, SC. Plant material consisted of 'Hosui' and 'Packham's Triumph' pear trees grafted on *Pyrus calleryana*. Treatments consisted on different rates of TDZ (0 mg L^{-1}, 20 mg L^{-1}, 40 mg L^{-1} and 60 mg L^{-1}) sprayed at full bloom for both cultivars. An additional treatment of AVG 60 mg L^{-1} was sprayed one week after full bloom in 'Hosui'. The fruit set, number of fruit per tree, yield, fruit weight, seed number, and fruit quality attributes were assessed. Fruit set and yield of both cultivars are consistently increased by TDZ, within the rates of 20 to 60 mg L^{-1}. Besides, its application increased fruit size of 'Hosui' and did not negatively affect fruit quality attributes of both cultivars.

Key words: *Pyrus* sp., fruit drop, plant growth regulators, cytokinin, fruit quality.

INTRODUCTION

The low fruit set (Hawerroth et al. 2011), along with the lack of knowledge about the best scion-rootstock combinations, excessive vegetative growth and scarce formation of flower buds (Pasa et al. 2012), is one of the main factors leading to the low production of pears in Brazil. Fruitlet retention in pears is dependent on effective pollination and fertilization, which are affected mainly by the presence of compatible pollen and pollination vectors, climatic conditions during flowering, and hormonal balance (Webster 2002).

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Climatic conditions play an important role on the fruit set process, mainly temperatures and precipitation during flowering. Excessive rain and wind may impair the activity of pollen vectors and once the pollen is deposited on the stigma temperatures should be warm (15°C - 25°C). Temperature affects pollen germination, pollen tube growth rate and the longevity of the ovules, resulting in a variation in the effective pollination period of 1 to 9 days (Sanzol and Herrero 2001). However, even when all these conditions are suitable, pear trees frequently fail to produce adequate yields.

Plant growth regulators are also involved in fruit set of fruit trees (Jackson 2003). Several studies have reported positive effects of gibberellins (Hawerroth et al. 2011, Vercammen and Gomand 2008, Deckers and Schoofs 2002) and TDZ (Amarante et al. 2002, Petri et al. 2001, Bianchi et al. 2000) on fruit set of apple and pear trees when applied at full bloom. Significant increase in fruit set induced by TDZ 10 and 20 mg L^{-1} sprayed at full bloom was observed in 'Packham's Triumph' (Petri et al. 2001) and 'Shinseiki' (Hawerroth et al. 2011) pears, respectively. The higher fruit set induced by these substances is usually due to a higher rate of parthenocarpy (Vercammen and Gomand 2008, Petri et al. 2001), which in some cases may lead to misshapen fruits (Bianchi et al. 2000), mainly in response to high rates of TDZ (Greene 1995). Besides, the application of gibberellins may reduce flower bud formation and return bloom (Deckers and Schoofs 2002).

Ethylene is also involved on the senescence and abscission of flowers and young fruits. Then, the early application of ethylene inhibitors, such as AVG (Aminoethoxyvinylglycine) might also be an option to increase pear fruit set. Einhorn et al. (2013) observed increased fruit set and yield of 'Comice' and 'D'Anjou' in response to 60 and 80 mg L^{-1} of AVG, sprayed two weeks after full bloom, as well as Sánchez et al. (2011) in 'Abate Fetel' and 'Packham's Triumph' sprayed with 250 mg L^{-1}.

The objective of this study was, therefore, to evaluate the effect of TDZ and AVG on fruit set, yield, and fruit quality of 'Hosui' and 'Packham's Triumph' pears.

MATERIALS AND METHODS

The study was performed in a commercial orchard in São Joaquim, Santa Catarina State, Brazil (28º17'39''S, 49º55'56''W, at 1,400 m of altitude), in the 2015/2016 growing season. The climate of the region is mesothermal humid (Cfb) according to Köppen-Geiger classification, i.e., temperate climate constantly humid, without dry season, and cool summer. Average accumulation of temperatures below 7.2ºC is 900 hours. The soil of the experimental field is a Cambissolo Húmico (Inceptisol), according to the Brazilian soil classification system (Santos et al. 2013). Plant material consisted of 18 year-old 'Hosui' and 'Packham's Triumph' pear trees grafted on *Pyrus calleryana*, trained in a central leader system. The cultivars complement each other as pollinators. Trees were spaced at 5 m between rows and 2 m within the row, totalizing 1,000 trees per hectare. Climatic conditions before and following the application of treatments are shown in figure 1.

Treatments consisted on different rates of TDZ (0 mg L^{-1}, 20 mg L^{-1}, 40 mg L^{-1} and 60 mg L^{-1}) for both cultivars. An additional treatment of AVG 60 mg L^{-1} was tested only in 'Hosui'. The source of TDZ and AVG were Dropp® (50% a.i.) and Retain® (15% a.i.), respectively. All solutions were supplemented with 0.05% of a nonionic silicone surfactant (Break-Thru®). TDZ treatments were sprayed at full bloom (70% of flowers opened) and AVG 1 one week after full bloom (WAFB). Full bloom of 'Hosui' occurred in 09/07/2015 and of 'Packham's Triumph' in 09/10/2015. Treatments were sprayed to runoff with a motorized hand-gun backpack sprayer (Stihl SR 450) with a flow rate of 2.64 L min^{-1}. Spraying volume was approximately 1000 L ha^{-1}. The application water pH was ~6.95. Trees were sprayed during the morning, with temperature ranging from 15 to 18°C, relative humidity of 85 to 95% and wind speed not exceeding 7 km h^{-1}.

Trees were arranged in a randomized complete block design with four replicates of three trees each. At full bloom, all flower clusters per tree were counted and blocking was performed according to bloom density. Only the central tree was used for evaluation, leaving one at each end as border. After the last natural fruit drop period occurred (~40 DAFB) the total number of fruit per tree was recorded to calculate fruit set. Fruit set was expressed as number of fruit per flower cluster. Trees were harvested at commercial maturity in 01/26/2016 ('Hosui') and 02/12/2016 ('Packham's Triumph'). The total number of fruit per tree was counted and weighed (kg). From these data, the yield per tree (kg) and average fruit weight (g) were calculated. At harvest, samples of 15 fruit per replicate (tree) were taken for fruit quality analysis (fruit firmness and soluble solids). Fruit firmness (N) was measured with a digital firmness tester, model "Fruit Texture Analyzer" (Güss Manufacturing, Strand, South Africa), using an 8 mm diameter probe. Sections of skin, 2 cm in diameter, were removed at the widest point of the fruit on opposite sides prior to the determination of fruit firmness. After fruit firmness measurements, the fruit of the sample were juiced and placed into a digital refractometer (PR-32, Atago Co., Tokyo, Japan) to determine TSS, expressed as ºBrix. The number of viable seeds per fruit was assessed by cutting the fruit in two halves and manually removing and counting the seeds of each fruit individually.

Statistical analyses were performed using the R software (R Core Team 2014). Data were analyzed for statistical significance by means of F test. Polynomial regression and Scott-Knott's test were performed to compare treatments when analysis of variance showed significant differences among means.

RESULTS

Considering the cultivar 'Hosui' and according to mean comparison test, the greatest fruit set was observed with TDZ 40 and 60 mg L^{-1}. Trees sprayed with TDZ 60 mg L^{-1} showed greater number of fruits per tree and yield than the other treatments, followed by TDZ 40 mg L^{-1}, which differed of control and AVG but not of TDZ 20 mg L^{-1}, for the number of fruits. Fruit weight was significantly increased by all TDZ rates relative to control, but not differing of AVG (Table I).

Regarding the effect of TDZ rates, fruit set, number of fruits per tree, and yield were significantly increased by TDZ in both cultivars, showing a positive linear rate effect. Fruit weight of 'Hosui' was linearly increased by TDZ (Table I). Flesh firmness and soluble solids were not affected in both cultivars, while number of seeds per fruit was significantly reduced as increasing TDZ rates in 'Hosui' (Table II)

DISCUSSION

We have tested the effect of increasing rates on TDZ on fruit set and yield of 'Hosui' and 'Packham's Triumph' pears. The results we have found show that TDZ significantly reduces fruit drop and increases fruitlet retention, ultimately resulting in greater yields. Petri et al. (2001) reported similar effects in 'Packham's Triumph' pears treated with TDZ 10 mg L^{-1}, as well as Hawerroth et al. (2011) in 'Shinseiki' pears in response to TDZ 20 mg L^{-1}. TDZ is also reported to increase fruit set and yield of other temperate fruit trees, like apples and kiwi (Petri et al. 2001). On the other hand, Greene (1995) found that TDZ 15 mg L^{-1} reduced fruit set of 'Empire' apples, working as a fruit thinner. The same author also observed that TDZ (10 and 50 mg L^{-1}) sprayed at full bloom, showed no effect

TABLE I
The effect of thidiazuron (TDZ) and aminoethoxyvinylglycine (AVG) on yield componentes of 'Hosui' and 'Packham's Triumph' pears.

Treatment	Fruit set[2]	Fruits (n° $tree^{-1}$)	Yield (kg $tree^{-1}$)	Fruit weight (g)
		'Hosui'		
Control	0.23 b[1]	49.5 c	6.8 c	138.8 b
AVG 60 mg L^{-1}	0.47 b	47.8 c	7.0 c	146.3 ab
TDZ 20 mg L^{-1}	0.42 b	60.3 b	9.1 c	150.5 a
TDZ 40 mg L^{-1}	0.70 a	71.0 b	10.7 b	151.7 a
TDZ 60 mg L^{-1}	0.71 a	95.5 a	14.5 a	151.9 a
p	0.035	<0.001	0.004	0.623
p (TDZ rate effect)				
Linear	0.002	<0.001	<0.001	<0.001
Quadratic	ns	ns	ns	ns
Cubic	ns	ns	ns	ns
		Packham's Triumph		
Control	0.42	29.8	5.9	196.8
TDZ 20 mg L^{-1}	0.99	59.0	11.3	190.9
TDZ 40 mg L^{-1}	1.01	59.8	11.6	194.6
TDZ 60 mg L^{-1}	1.07	65.0	12.5	193.7
p				
Linear	0.012	0.005	0.003	ns
Quadratic	ns	ns	ns	ns
Cubic	ns	ns	ns	ns

[1]Different letters within column indicate significant differences according to Scott-Knott's test (Probability (p) < 0.05). ns = not significant.
[2]Fruit set was expressed as the number of fruits per flower cluster.
Regression equations: 'Hosui'- $y = 0.0086x + 0.257$, $r^2 = 0.91$ (Fruit set); $y = 0.7438x + 46.75$, $r^2 = 0.95$ (Fruits); $y = 0.124x + 6.58$, $r^2 = 0.97$ (Yield). Packham's Triumph - $y = 0.0099x + 0.577$, $r^2 = 0.70$ (Fruit set); $y = 0.532x + 37.44$, $r^2 = 0.74$ (Fruits); $y = 0.1005x + 7.31$, $r^2 = 0.75$ (Yield).

TABLE II
The effect of thidiazuron (TDZ) and aminoethoxyvinylglycine (AVG) on fruit quality of 'Hosui' and 'Packham's Triumph' pears.

Treatment	Flesh firmness (N)	Soluble solids (°brix)	Seeds (n° $fruit^{-1}$)
	'Hosui'		
Control	26.9	12.7	0.57
AVG 60 mg L^{-1}	27.0	12.3	0.53
TDZ 20 mg L^{-1}	27.3	12.6	0.48
TDZ 40 mg L^{-1}	27.9	12.6	0.45
TDZ 60 mg L^{-1}	26.7	12.4	0.23
p	0.488	0.936	0.216
p (TDZ rate effect)			
Linear	ns	ns	0.008
Quadratic	ns	ns	ns
Cubic	ns	ns	ns
	Packham's Triumph		
Control	71.7	12.8	2.14
TDZ 20 mg L^{-1}	71.2	12.8	2.17
TDZ 40 mg L^{-1}	71.0	13.0	2.32
TDZ 60 mg L^{-1}	71.3	12.9	2.27
p			
Linear	ns	ns	ns
Quadratic	ns	ns	ns
Cubic	ns	ns	ns

Regression equation 'Hosui' (Seeds): $y = -0.0053x + 0.5867$; $r^2 = 0.87$. (Probability (p) < 0.05). ns = not significant.

either on fruit set or thinning of 'McIntosh' apples. These results suggest TDZ effect on fruit set is rate and cultivar-dependent, so it should be tested for each cultivar and species separately, as means to adjust the rates according the expected results, i.e., fruitlet retention or thinning. The way synthetic cytokinins like TDZ increase fruit set in not clear. One hypothesis is that TDZ promotes fruitlet retention by increasing sink strength of developing fruits. This hypothesis is based on recent findings showing that cytokinin acts inhibiting leaf senescence (Zwack and Rashotte 2013), by altering sink-source balance.

The results we have found with TDZ are particularly interesting because the application of this substance has the potential to partly overcome the negative effects of climatic conditions during flowering on fruit set. Shortly after full bloom of both cultivars, we observed a period of very unfavorable weather conditions. From Sep 11 to 14, minimum temperatures were lower than 5°C and maximum temperatures did not exceed 15°C. Indeed, in Sep 12 and 13 minimum temperatures dropped below 0°C (Figure 1). In order to have adequate pollination and fertilization temperatures should be warm (15°C - 25°C), because it affects pollen germination, pollen tube growth rate and the longevity of the ovules (Sanzol and Herrero 2001). Besides, following this period of low temperatures, we experienced a 2-day rain event of over 200 mm and strong winds (Figure 1), which is not favorable for fruitlet retention as well, because it impairs the activity of pollen vectors and mechanically drops fruits. Then, even in these conditions, TDZ treatments efficiently increased fruit set and yield of both cultivars.

Fruit weight of 'Hosui' was significantly increased by TDZ. This effect is commercially desirable since large Asian pears reach better prices than small ones. Several studies suggest that endogenous cytokinin levels play a major role on cell division and fruit growth (Shargal et al. 2006, Stern et al. 2003). TDZ is a phenylurea compound, which shows cytokinin-like activity (Greene 1995), then its positive effect on fruit growth should be expected. Indeed, exogenous application of TDZ increased fruit size of 'Spadona', 'Coscia' (Stern et al. 2003) and 'Shinseiki' (Hawerroth et al. 2011) pears, similarly as the results we have found with 'Hosui'. Increased fruit size in response to TDZ

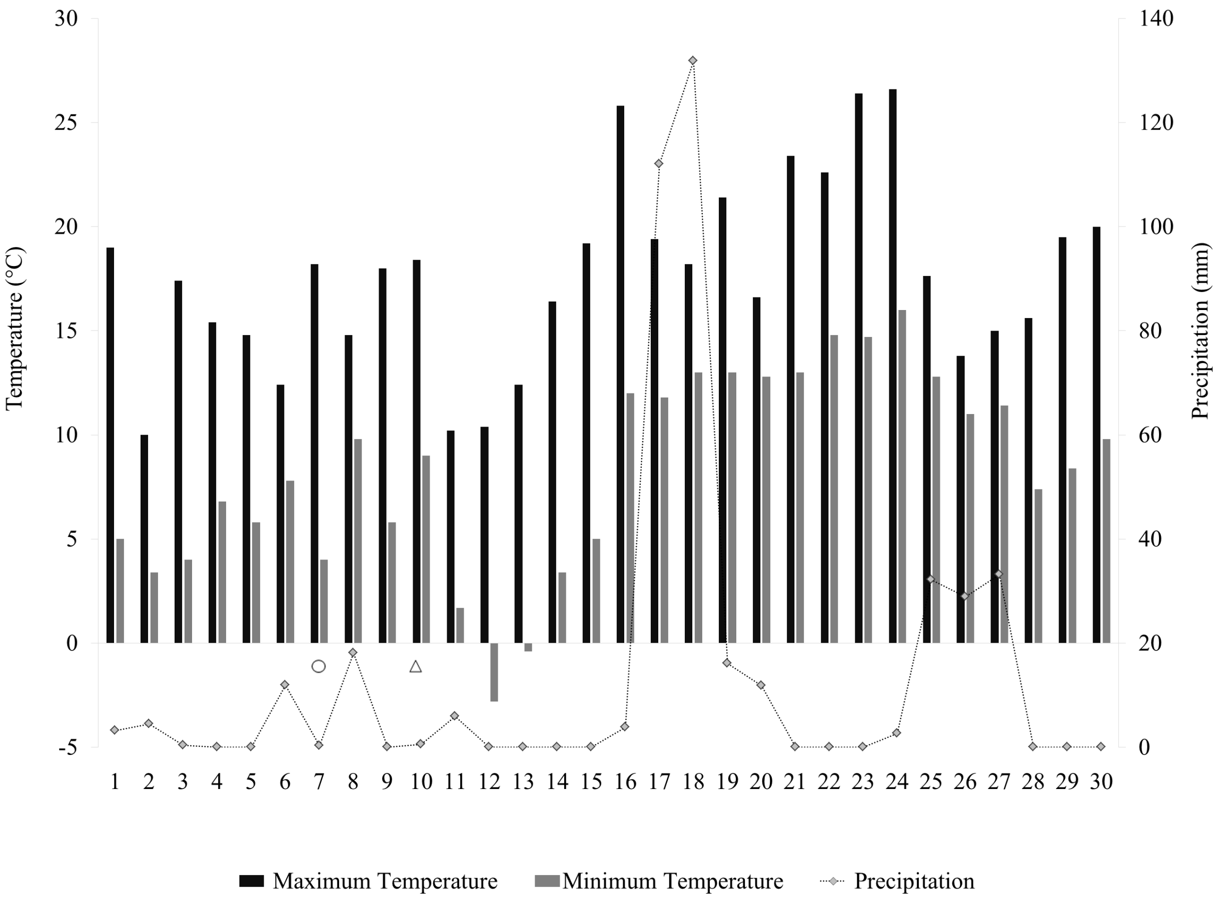

Figure 1 - Climatic conditions before and following the application of treatments in September 2015. Circle and triangle in the "x" axis denotes the time of TDZ application in 'Hosui' and 'Packham's Triumph', respectively. São Joaquim, SC. Source: INMET/BDMEP.

was also reported in 'McIntosh', 'Empire' (Greene 1995), and 'Gala' apples (Petri et al. 2001).

Fruit quality attributes (fruit firmness and soluble solids) at harvest of both cultivars were not influenced by TDZ. Similar results were reported in 'Shinseiki' pears treated with TDZ 20 mg L^{-1} (Hawerroth et al. 2011). On the other hand, the application of TDZ rates varying from 5 to 20 mg L^{-1} at full bloom reduced soluble solids of 'Gala' apples but increased of 'Fuji', with no effect on flesh firmness (Amarante et al. 2002). Similar effects were observed by Greene (1995), which did not observe effect of TDZ sprayed at full bloom on fruit firmness and soluble solids of 'McIntosh' and 'Empire' apples. Based on the results we have obtained and on the literature, seems that when TDZ is sprayed at bloom there is little effect on fruit quality attributes of both pears and apples.

Seed number was reduced linearly as increasing TDZ rate in 'Hosui', while no significant effects were observed in 'Packham's Triumph'. Reduction in seed number might be expected in response to TDZ, since this substance tends to increase the rate of parthenocarpic fruits, as observed in 'Packham's Triumph' pears (Petri et al. 2001). However, we only observed reduction in the number of seeds with the higher rate of TDZ (60 mg L^{-1}). No differences in the number of seeds per fruit were observed in 'Shinseiki' (Hawerroth et al. 2011) and 'Spadona' (Stern et al. 2003) pears, treated with TDZ 20 mg L^{-1}. We believe the TDZ effect on the reduction of number of seeds should be greater on situations of low pollen availability due to the absence of pollinators or asynchrony of flowering. This would explain why we observed a slight reduction in the number of seeds of 'Hosui' and not in 'Packham's Triumph', since the former starts flowering 2-3 days before the latter, then the first flowers do not have available pollen to be fertilized, while by the time 'Packham's Triumph' starts flowering there is already available pollen from 'Hosui' flowers. These cultivars complement each other in pollination.

CONCLUSIONS

Fruit set and yield of 'Hosui' and 'Packham's Triumph' pears are consistently and rate-dependently increased by TDZ sprayed at full bloom, within the rates of 20 to 60 mg L^{1}. Besides, its application increased fruit size of 'Hosui' and did not negatively affect fruit quality attributes of both cultivars. Collectively, our results show that the use of TDZ is a potential tool to overcome the fruit set issue in Brazilian orchards in order to help pear growers achieve greater yields and profits.

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