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EFFECTS OF CHEMICAL THINNING WITH ARMOTHIN® ON FRUIT SET, YIELD AND QUALITY OF JAPANESE PLUM (*Prunus salicina* Lindl.) CV. 'FORTUNE'

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ABSTRACT

The effects of the application of the chemical thinner Armothin® on fruit set, yield and quality of Japanese plum (*Prunus salicina* Lindl.) cv. 'Fortune' were studied during two seasons in Central Chile (34.56°S, 71.5°W). Trees were sprayed with Armothin® at 0.5%, 1% and 2% concentrations. All thinning treatments reduced the fruit set and fruitlet number (fruitlets/50 cm of branch). Armothin® at 2% conc. was the most aggressive treatment, drastically reducing the fruit set from 85.9% and 82.9% of the control and crop load to unprofitable levels during both seasons. Chemical thinning treatments at the two lowest concentrations (0.5 and 1%) did not significantly alter the crop load compared with the unsprayed control during both study seasons. Thinning costs were reduced (Armothin® 0.5%, 25.0% and 21.5% of the control treatment and Armothin® 1%, 24.6% and 24.1% of the control, during the first and second season, respectively). In general, chemical thinning increased the fruit size and total soluble solids content (TSS). Taking into account the effects on thinning, crop load, fruit quality and thinning costs, Armothin® 1% and Armothin® 0.5% are the most advantageous treatments in the case of this study.

Key words: thinning agents, crop load regulation, plum, fruit quality, yield, bearing potential

INTRODUCTION

In Japanese plum (*Prunus salicina* Lindl.) as well as in many other *Prunus*, final fruit size depends to a great extent on the total number of fruits per tree [Tripon et al. 2014]. Crop load must be balanced with tree size and leaf area for maximizing the fruit size, and achieving a consistent and sustained cropping [Webster and Spencer 2000]. Heavy bearing of plum trees adversely affects the size and quality of fruits resulting in poor returns to the growers. In addition to reduced fruit size at harvest, other problems may result as for example breakage of limbs under heavy crop load, increasing susceptibility to late winter frost, particularly in the temperate zones and the establishment of a biennial pattern of cropping [Meitei et al. 2013]. Thinning may improve the fruit quality as well as size, for reducing crop load usually increases sugars in plums [Drkenda and Bertschinger 2006]. According to Coneva and Cline [2006], bloom thinners also offer the advantage of diverting the photosynthates to fewer sinks and subsequently, increased fruit size.

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Fruit thinning is therefore an essential commercial practice for optimizing the fruit size, maximizing crop value, improving fruit color, shape, quality, promoting return bloom and to maintain tree growth and structure [Byers et al. 2003]. A reduction in fruitlets or flowers on the tree will result in an increase in quality of the remaining fruit [Costa and Vizzotto 2000] and the fruit size [Wertheim 1997, Dennis 2000]. For this reason, manual thinning is generally performed every year, but this practice involves high costs and is very labor-intensive. Hand thinning is the only most expensive management practice of growing plums, therefore an alternative to hand thinning needs to be found. Chemical thinning of fruit trees to reduce or eliminate hand thinning could be of great economic help to growers [Johnson et al. 2002]. The horticulturists all over the world have been trying to evolve some chemical treatments to thin out the excessive crop load so that the quality of the remaining fruits is improved [Meitei et al. 2013]. Different treatments could be applied to thin out the fruits economically and without deleterious effect in the tree or fruit quality. These treatments involve spraying flowers with chemicals that in some way prevent from their pollination and/or fertilization. However, such chemicals had been observed to be specific as regard to their efficacy in different agri-climatic conditions and also differential response of different cultivars [Sosna 2012, Meitei et al. 2013].

The aim of this study was to evaluate the effect of chemical thinning with Armothin® on fruit set, yield and quality of Japanese plum (*Prunus salicina* Lindl.) cv. 'Fortune' and to economically compare different thinning treatments.

MATERIAL AND METHODS

Study area. This study was carried out in a commercial Japanese plum tree orchard cv. 'Fortune' located in Central Chile (34.57° LS; 71.10° LW; 280 m.a.s.l.) during two growing seasons. Climate in the region is characterized as Mediterranean, with the rainy season occurring primarily during winter months, while the summer is quite dry. Mean annual precipitation is 700 mm and mean annual temperature is 15°C [Santibañez and Uribe 1993]. Field topography is flat and the study site was surrounded by other Japanese plum and apple tree orchards. The soil is classified as Limanque series (Inceptisol) [CIREN 1997], presenting a sandy loam (coarse texture). CEC (17.75 cmolc kg^{-1}), EC (0.24 dS m^{-1}), pH-H_2O (6.2), O.M (6.1%), the average bulk density is 1.55 g cm^{-3} for the first 0.8 m of depth.

Plant material. Plant material consisted of five-year-old Japanese plum trees cv 'Fortune' on 'Nemaguard' seedling rootstock (*Prunus persica* × *Prunus davidiana*), spaced 4.5 × 3 m in north to south row and trained to an open pot system with 3–5 main branches and 3–4 sub-branches each. All sample trees were of uniform size and without any visible symptoms of neither disease nor pest infestation at the time of trial initiation. Trees were under-tree irrigated with micro-sprinklers weekly from November to late March. Conventional farming practices (irrigation, fertilization, pest and weed control, and dormant pruning) were followed every year.

Thinning treatments. Thinning solutions were prepared by dissolving Armothin® a poly-fatty acid amine [N, N-bis2-(omega-hydropolyoxyethylene/polyoxypropylene) ethyl alkylamine] in tap water at concentrations of 0.5%, 1% and 2%. Chemical concentrations were chosen based on previously published data [Wieniarska et al. 2000, Lemus 1996]. Trees were sprayed with Armothin® as dilute sprays to runoff at 80% blooming stage, using an air blast sprayer (1550 l ha^{-1}). No surfactants or any additives were included in the sprays. Trees were judged for possible leaf damage one month after application in one hundred leaves per tree and damage was expressed in a 1–9 scale (where 1 means no damage and 9 means very severe damage).

Experimental design and statistical analysis. Trees were assigned to a completely randomized design with ten individual trees as replications. Untreated trees (10 replicates) were used as control treatment. Four main uniform branches at four cardinal points of each experimented tree were tagged to evaluate treatment effects. Data was processed and analyzed by means of one-way analysis of variance using the JMP program package (SAS software). Means were compared using the Tuckey's test at $p < 0.05$.

Fruit set. Crop load and fruit set percentage were compared between treatments. For subsequent determination of fruit set, flowers were counted before treatment on 13th and 15th August at the first and second seasons, respectively. Then persisting fruits were counted on 10th and 13th October (during the first and second season, respectively). Fruit set was expressed as percentage of flowers, which developed into fruits.

Number of fruits removed in manual crop load adjustment. Crop load was previously fixed at 300 to 350 fruits/tree for all treatments, according to Janick and Paull [2007]. Complementary hand thinning was performed (11th and 14th October during the first and second seasons, respectively) to reach the goal of 300 to 350 fruits/tree. Fruits were thinned by leaving a distance of 7 to 10 cm between fruits. Removed fruits were weighed and expressed as wt of fruits removed/tree (kg).

Fruits characteristics. Fruits from different treatments (10 per replicate) were harvested based on firmness (8 mm tip): 3.2–4.0 kg and minimum SSC values of 11°Brix. Fruits were weighed using an electronic pan balance. Fruit diameter was measured using a cranston gauge (model Cranston Machinery). Fruit firmness (kg cm^{-2}) was measured using a hand Effegi FT-327 penetrometer supplemented with an 8 mm plunger tip by removing a small exocarp segment on the two opposite sides to expose the average flesh firmness of each fruit. Soluble solids concentration (SSC) in fruit juice was measured using a ATAGO ATC-1 hand refractometer. Results were expressed in Brix degrees.

Economic analysis. Different Armothin® chemical thinning treatments were compared in terms of costs (working hours and price of the required inputs) with manual thinning for assessment of the economic viability of this thinning strategy.

RESULT AND DISCUSSION

Effects of chemical thinning with Armothin® on fruit set and crop load

Armothin® tested concentrations were effective thinners when applied as dilute sprays to runoff during 80% blooming stage to the plum cultivar 'Fortune'. Significant differences in fruitlet number and fruit set were found during the first and second season (Tab. 1). All thinning treatments reduced fruit set and the number of fruitlets/50 cm of branch. Armothin® 2% was the strongest thinner, reducing fruit set from 85.9% and 82.9% of the control during the first and second seasons, respectively. In Japanese plum, a fruit set of about 5% is required to provide a full crop [Webster and Holland 1993]. In the case of Armothin® 2%, the thinning effect was too aggressive and fruit set achieved values of only 1.3% and 1.5% each year. This clearly affected also cropping (Tab. 3). According to this result, Armothin® 2% is not recommended for the aim of economic plum production. Our results are in accordance with those of Meland [2007], who reported that Armothin® 1% applied in European plum cultivars 'Opal' and 'Victoria' reduced the fruit set from 50 to 70% of the control trees and increased the fruit size and soluble solids content. Baroni et al. [1998] found that sprays applied at the end of bloom (80 to 100% open flowers) at concentrations ranging from 1.5 to 2% resulted in the best cropping in two peach cultivars. Our results did not agree with those, probably because the plum cultivar 'Fortune' is more sensitive for blossom thinning than peaches and needs a lower dosage.

Table 1. Effects of chemical thinning with Armothin® on fruit set and crop load (50 cm branch length)

Treatment	Number of flowers before thinning		Number of fruitlets after thinning		Percentage of fruit set	
	season 1	season 2	season 1	season 2	season 1	season 2
Unsprayed control	149.4 ±14.0 a	143.4 ±17.3 a	14.5 ±1.5 a	14.3 ±1.2 a	9.2 ±1.2 a	8.8 ±1.3 a
Armothin® 0.5%	127.5 ±13.0 a	137.6 ±13.9 a	8.2 ±2.8 b	9.1 ±2.6 b	6.5 ±1.4 b	6.8 ±1.3 b
Armothin® 1%	124.1 ±22.2 a	131.3 ±12.1 a	8.0 ±2.3 b	9.1 ±2.1 b	6.9 ±1.5 b	7.5 ±1.1 b
Armothin® 2%	114.2 ±25.2 a	124.5 ±15.1 a	1.4 ±1.3 c	2.7 ±1.8 c	1.3 ±1.3 c	1.5 ±1.4 c

Values in columns with different letters are significantly different at $P < 0.05$ by LSD in ANOVA

Table 2. Manual crop load adjustment requirements of the different treatments with Armothin®

Treatment	Wt of fruits removed/tree (kg)		Number of fruits/tree after manual crop load adjustment	
	season 1	season 2	season 1	season 2
Unsprayed control	5.7 ±2.0 a	6.1 ±2.1 a	316.6 ±19.5 a	322.0 ±26.3 a
Armothin® 0.5%	6.3 ±3.8 a	6.8 ±3.6 a	331.0 ±23.5 a	336.0 ±28.0 a
Armothin® 1%	6.2 ±2.2 a	6.6 ±2.4 a	345.2. ±29.8 a	344.0 ±6.8 a
Armothin® 2%	0.0 b	0.0 b	158,4 ±23.7 b	174.0 ±48.8 b

Values in columns with different letters are significantly different at P < 0.05 by LSD in ANOVA

Table 3. Effects of chemical thinning with Armothin® on fruit yield

Treatment	Fruit weight (g)		Total yield/tree (kg)		Yield (t/ha)	
	season 1	season 2	season 1	season 2	season 1	season 2
Unsprayed control	89.4 ±3.1 a	88.8 ±2.4 a	28.4 ±2.6 a	28.6 ±2.9 a	20.2±1.8 b	21.2 ±2.1 ab
Armothin® 0.5%	86.7 ±7.6 a	87.6 ±8.1 a	32.2 ±3.8 a	29.2 ±2.4 a	22.9 ±2.1 ab	21.6 ±1.2 ab
Armothin® 1%	127.5 ±15.0 a	94.8 ±16.7 a	37.5 ±7.5 a	36.4 ±6.3 a	26.7 ±2.3 a	26.9 ±4.6 b
Armothin® 2%	20.5 ±4.9 b	134.0 ±10.0 b	20.5 ±4.9 b	23.6 ±2.3 b	14.6 ±5.6 c	17.4 ±2.2 c

Values in columns with different letters are significantly different at P < 0.05 by LSD in ANOVA

Table 4. Effects of chemical thinning with Armothin® on fruit quality parameters

Treatment	Fruit diameter (mm)		TSS (%)		Fruit firmness (kg/cm^2)	
	season 1	season 2	season 1	season 2	season 1	season 2
Unsprayed control	54.8 ±1.6 b	54.9 ±2.5 b	12.9 ±0.3 c	12.2 ±0.4 a	6.6 ±0.7 a	6.8 ±0.4 a
Armothin® 0.5%	53.7 ±1.5 b	52.6 ±1.4 b	13.0 ±0.3 bc	13.5 ±0.6 b	5.4 ±0.6 ab	5.4 ±0.3 b
Armothin® 1%	55.9 ±4.5 b	54.2 ±2.4 b	13.5 ±0.4 b	13.4 ±0.4 b	5.3 ±0.3b	5.3 ±0.2 b
Armothin® 2%	61.5 ±2.8 a	61. ±1.7 a	16.6 ±0.4 a	13.5 ±0.3 b	5.6 ±0.8 ab	5.7 ± 0.7 b

Values in columns with different letters are significantly different at P < 0.05 by LSD in ANOVA

Table 5. Economic analysis of different treatments

Treatment	Chemical thinning				Manual thinning				Total costs	
	season 1		season 2		season 1		season 2		season 1	season 2
	(l)	USD	(l)	USD	(h)	USD	(h)	USD	USD	USD
Unsprayed control	0.0	0.0	0.0	0.0	84.3	1,214.0	86.5	1,245.6	1,214.0	1,245.6
Armothin® 0.5%	7.5	100.7	7.5	100.7	47.8	688.1	52.3	753.1	788.8	853.8
Armothin® 1%	15.0	197.8	15.0	197.8	40.6	584.8	42.6	613.1	782.6	810.9
Armothin® 2%	30.0	392.2	30.0	392.2	0.0	0.0	0.0	0.0	392.2	392.2

No significant differences in fruit set and number of fruitlets/50 cm were found between Armothin® 0.5% and Armothin® 1%, even though both treatments considerably reduced fruit set compared with the unsprayed control (78–80% of the control). No differences in return bloom during the second year were observed. Abundant flowering was observed on all trees, including the non-thinned trees. Similar results were achieved by Melan [2004] in the case of 'Victoria' plums and by Lemus [1996] with 'Friar' plums (fruit set was reduced to about half of control values).

No significant differences in flowering were found during season 1 before thinning and the number of flowers before thinning was also uniform during the second season. Armothin® produced minor damage on leaves only in the case of the highest concentration (Armothin® 2%). Leaf damage scored 1.2 and 1.4 the first and second season, respectively. Damage was expressed in a 1–9 scale (where 1 means no damage and 9 means very severe damage).

Manual crop load adjustment requirements. In most of the thinning treatments, further hand crop load adjustments was required to adjust crop load to the desired 300–350 fruits/tree (Tab. 2). This was the expected number of fruits per tree to achieve annual yields of high quality fruits for the conditions of 'Fortune' plums. No hand thinning was performed in the case of Armothin® 2% because of its deficit percentage of fruit set (<5% required in this cultivar) and very low number of remaining fruits/tree after chemical thinning. No significant differences in fruit weight of removed fruits were found between control and Armothin® 0.5% and Armothin® 1.0%. Fruit distribution throughout the tree was in general very uniform (no fruit clumping in the tops of the trees) and there was no necessity of special hand thinning to break up these clusters.

Effects on fruit yield and quality. Chemical thinning treatments at the two lowest concentrations (0.5 and 1%) did not significantly alter the crop load compared with the unsprayed control during both seasons (Tab. 3). Yields were significantly reduced in the case of the highest concentration of Armothin® (2%). In the case of this treatment, the yield was extremely low during both seasons, reducing the total yield per tree from 72.3% and 82.1% of the control during the first and second season, respectively. Similar effects of thinning treatments on fruit weight were reported after the use of Armothin® by Wieniarska et al. [2000] and Meland [2004]. In a study by Johnson et al. [2002], a considerable effect of thinning was obtained in plums after the application of Armothin® 3% concentration.

Fruit diameter was not affected by chemical thinning treatments at the two lowest concentrations, 0.5% and 1% (Tab. 4). Larger fruit diameter for Armothin® 2% may be explained due to the lower crop load (Tab. 3). As mentioned by Wertheim [1997] and Dennis [2000], a reduction in fruitlets number or flowers on the tree will result in fruit size increase and higher TSS contents for the remaining fruits. Since larger fruits are substantially more valuable, the loss in yield is often compensated by these larger fruits. However in the present study, a noticeable increase of larger fruit diameters was not noticed. Therefore, the yield decrease resulted in a substantial profit loss. For plum cultivar 'Fortune', the preferred fresh fruit markets diameters are fruits >50 mm. These diameters were achieved by the control, Armothin® 0.5% and Armothin® 1%, thus the significant increase in diameter achieved by Armothin® 2% seems not to be crucial for the economic profit, especially if it is obtained at the expenses of a very low crop load. TSS (%) and fruit firmness (kg cm^{-2}) were increased by treatments. The increase in TSS values might have attributed to increased conversion of carbon assimilates and organic acids to sugars [Rajput and Bhatia 2017]. Similar results were reported by Melan [2017] in European plums treated with Armothin® 1% and in cherry cv. 'Rising Star' after the application of the chemical thinner ATS [Osborne and Robinson 2008].

Economic analysis of different treatments. Different Armothin® chemical thinning treatments were compared with manual thinning in terms of required working hours (h) and volume of inputs (l) to assess its economic viability (Tab. 5). Manual thinning proved to be a very labor-consuming treatment and, therefore, expensive. During the first season, 84.3 working hours were required and during the second – 86.5 hours. Only by relying on manual thinning, growers would have to spend large sums of money (1,214.0 USD and 1,245.6 USD), the first and second seasons, respectively, therefore considerably reducing the profit margin.

The profit margin can be increased if the higher costs of hand thinning could be reduced prior to chemical thinning. Significant savings in hand thinning costs were achieved with the use of chemical thinning. In the case of Armothin® 0.5%, thinning costs represented 65.0% and 68.5% of the control in the first and second season, respectively. In the case of Armothin® 1%, these costs represented 64.4% and 65.1% and for Armothin® 2%, only 32.3% 31.4% of the costs of the control. In most of the thinning treatments, further crop load adjustments by hand, post-bloom, were required to adjust crop load to the desired 300–350 fruits/tree (Tab. 2). No manual thinning was performed in the case of Armothin® 2% because of low percentage of fruit set (<5% required in this cultivar) and very low number of remaining fruits/tree after chemical thinning (Tab. 3). According to our results, Armothin® 2% is not recommended for chemical thinning due its aggressive effect on reducing fruit set and crop load to unprofitable levels.

CONCLUSIONS

Based on the results of our trial, it is proved that all Armothin® tested concentrations were effective thinners of the plum cultivar 'Fortune', when applied during 80% blooming stage. Armothin® 2% was the strongest thinner, reducing fruit set 85.9% and 82.9% during the first and second seasons, respectively. The thinning effect was too aggressive and fruit set achieved values of only 1.3% and 1.5% each year, making this concentration not recommended for economic plum production. Chemical thinning treatments at the two lowest concentrations (0.5 and 1%) did not significantly alter the crop load compared with the unsprayed control during both years. In general, chemical thinning increased the fruit size and TSS content. Manual thinning proved to be a very labor-consuming treatment and, therefore, expensive. Significant savings in hand thinning costs were achieved with the use of chemical thinning. In the case of Armothin® 0.5%, thinning costs represented 65.0% and 68.5% of the control in the first and second seasons, respectively. In the case of Armothin® 1%, these costs were reduced to 64.4% and 65.1% during the first and second season, respectively.

Taking into account thinning effects, crop load, fruit quality and associated thinning costs, Armothin® 1% and Armothin® 0.5% are recommended as thinning treatments for European plum cv. 'Fortune'.

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