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Manage of crop load to improve fruit quality in plums

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Abstract- The crop load of European plums must be adjusted to achieve high quality with adequate size and skin color in order to attend market requirements. The present study had the objective to investigate the effects of chemical and mechanical thinning, applied isolated and in combination of both, at different phenological stages of Katinka plum growing in Southern Germany. The following thinners were tested: mechanical thinning, chemical thinning with Ammoniumthiosulfate - ATS, Ethephon, Prohexadione-Calcium and Gibberellin. Mechanical thinning treatment isolated or associated with ATS. Significantly increased fruit drop and reduced the yield. It also, increased fruit size and fruit weight when compared to the control plants. Also Ethephon increased fruit drop and fruit size when compared to the control plants. Among to other chemical treatments, no positive effects were observed for fruit thinning when compared to the control plants.
Index terms: *Prunus domestica*, Mechanical thinning, Chemical thinning, Fruit drop.

Manejo da carga de frutos visando a incrementar a qualidade dos frutos em ameixeiras

Resumo – A carga de colheita de frutas de ameixa Europeia deve ser ajustada para atingir alta qualidade em calibre e em coloração para atender às exigências do mercado. O presente estudo teve por objetivo investigar os efeitos de diferentes métodos de desbaste de frutos, utilizando vários raleantes químicos, isolados ou associados com raleio mecânico, em diferentes estádios fenológicos de ameixeira Katinka no sul da Alemanha. Os seguintes raleantes foram testados: raleio mecânico, desbaste químico com Amoniotiossulfato – ATS, Ethephon, Prohexadione de Cálcio e Giberelina. Os tratamentos de raleio mecânico, isolado ou associado com ATS, aumentaram significativamente a queda de frutos e reduziram o rendimento por planta. Também aumentaram o tamanho e o peso dos frutos em relação às plantas-testemunha. Entre os tratamentos químicos, o Ethephon apresentou resultados positivos para queda de frutos e aumento do tamanho do fruto em comparação com as plantas-testemunha. Entre os demais tratamentos químicos, não foram observados efeitos positivos no raleio de frutos em comparação à testemunha.
Termos para indexação: *Prunus domestica*, raleio mecânico, raleio químico, vingamento de fruto.

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Introduction

Fruit trees, very frequently bear excess of flowers, affecting the fruit size along the season and usually reducing the crop load on the next season. Many fruit species require a reduction of fruit load to reach a vegetative and reproductive balance. Normally this objective is attained through fruit thinning methods. This operation is performed yearly, mainly in stone-fruit and pome-fruit species (COSTA; BLANKE, 2013).

For apple trees, only around 7% of the flowers are sufficient for a commercially profitable harvest (UNTIEDT; BLANKE, 2001) while approximately 20-25% of flowers are needed in peach trees (COSTA and VIZZOTO, 2000). The commercial criterion for fruit of Japanese plum is a regular distribution of fruit at 15-20 cm apart on the branches (GONZÁLEZ-ROSSIA et al., 2006).

Fruit thinning usually is necessary to achieve high fruit quality with adequate size and color for class one marketing. It is essential for overcoming alternate fruit bearing. In order to ensure satisfactory annual yields and to improve sugar content and pulp firmness as important parameter for good storability (SEEHUBER et al., 2011).

Nevertheless, the adoption of hand-thinning by farmers will progressively diminish due to shortage and cost of land labor (AHRENS et al., 2014).

Hand fruit thinning is one of the most laborious-intensive, costly practices for peach growers, often costing as much as US$ 2,470 per hectare in Pennsylvania (MILLER et al., 2011) and US$ 3,705 per hectare in California (BAUGHER et al., 2009). In Canada, hand thinning can require between 100-150 hours.ha^{-1}. Depending on tree vigor, age, size, and fruit set, resulting in an estimated cost of about US$ 1,235 ha^{-1} per year (TAHERI et al., 2012).

Chemical thinning has long been established, but the choice of registered chemical products drastically diminishes in many countries. The efficacy of the few remaining products such as: Lime Sulphur, Ammoniumthiosulfate (ATS), Ethephon (Ethrel), and Benzyladenine (BA) are dependent on air temperature, cultivar, flowering dynamics and tree age (BANGERTH, 2000; SEEHUBER et al., 2013; PAVANELLO; AYUB, 2014).

Among these products, ATS is the only remaining chemical allowed in Germany, registered as a foliar fertilizer, but not for fruit thinning. Carbaryl should not be used more in almost every country and Naphthyl acid (NAA/NAAm) has been banned in many European countries, including Germany (DAMEROW; BLANKE, 2009; SEEHUBER et al., 2013). Even though pome fruits are easier to thin, stone fruits fail to react to chemical thinning with lime sulphur and NAA (SEEHUBER et al., 2011).

According to Zhang and Whiting (2011), an alternative approach for thinning to improve source-sink balance and fruit quality, is manipulating source-sink activity with exogenous plant growth regulators such as Prohexadione-Ca and Gibberellins.

Gibberellins, such as GA_3, GA_4 and GA_7 has been applied in apples, peaches, nectarines and plums for fruit thinning and fruit quality (EROGUL and SEN, 2015). Gibberellins are thought to move from the fruit to the nearby nodes, where they inhibit the initiation of new floral primordial. A process usually initiated about 6-8 weeks after fruit set (WEBSTER and SPENCER, 2000).

Prohexadione-calcium (calcium 3-oxido-4-propionyl-5-oxo-cyclohexene carboxylate - ProCa), an inhibitor of Gibberellins biosynthesis, showed potential for manipulating flower density and reducing seasonal vegetative extension growth in sweet cherry and apple (ELFVING et al., 2003).

The inactivation of exogenously applied GA_3 and GA_4 by 2β-hydroxylation can be inhibited by simultaneous treatment with ProCa, resulting in increased GA-like activity (NAKAYAMA et al., 1990). The hypothesis is that application of ProCa plus GA_3 or GA_4 increase the concentration of $GA_{4/7}$ and GA_3 in fruit mesocarp tissue, which promotes cell enlargement, a critical component for final fruit size in sweet cherry (OLMSTEAD et al., 2007).

According to Guak et al. (2001), the leaf applying of $GA_{4/7}$ one day later to prohexadione-calcium-treated plants restored elongation growth to a level even exceeding the control, without any lag phase in fruit growth.

Mechanical thinning of blossoms could be a solution for reducing the chemical impact on the environment (GREENE; COSTA, 2013; WEBER, 2013). This is a new environmentally friendly technology and an alternative to the standard chemical thinning of blossoms and is suitable for both integrated as well as organic fruit cultivation (SOLOMAKHIN; BLANKE, 2010).

According to Baugher et al. (2009), mechanical thinners diminish peach crop load up to 36% and may decrease complementary hand thinning time by 20% to 42%. The net economic impact (economic savings) of mechanical thinning versus hand thinning ranged from US$ 175 to 1,966 per hectare, respectively.

Numerous mechanical approaches have been attempted, including limb and trunk shakers, rotating arms in the canopy and manually hitting limbs. There were varying degrees of success, but no method has been commercially adopted on a wide scale up to now. The new technology recently made available, named as 'Darwin machine', appears to show real promise for more widespread commercial use (BAUGHER et al., 2010; MILLER et al., 2011; SCHUPP et al., 2011). Its designing is described on Materials and Methods.

The 'Darwin machine' is consisted of a tractor-mounted frame with a 2.0m tall vertical spindle in the center of the frame. Attached to the spindle there are 24 bars with 9 strings on each one, securing total of 216 plastic injection strings measuring 60cm long. The speed of the clockwise rotating spindle is adjusted with a hydraulic motor and the height and angle of the frame is adjustable to conform to the vertical inclination of the tree canopy, and the intensity of thinning is adjustable by tractor speed and rotation speed of the spindle (JOHNSON et al., 2010).

Miller et al. (2011) reported a removal of 30% to 46% of flowers by a mechanical string thinner in peach trees. Furthermore, it reduced crop load and time required for hand thinning after mechanical thinning compared with hand thinning alone. Weber (2013) verified a reduction of 50% the time used for hand-thinning-labor when using the association of chemical (ATS or Ethephon) and mechanical thinning.

The main objective of this study was to evaluate the response for fruit quality of different methods of fruit thinning, both chemical and mechanical, alone and in combination of both, using various chemical thinning agents at different phenological stages of Katinka plum growing in Southern Germany.

Materials and methods

Field Conditions

The experiment was carried out in an experimental orchard in the Competence Centre For Fruit Growing, at Lake Constance (KOB) in Bavendorf, South Germany. The four-year-old 'Katinka' plum trees (*Prunus domestica* L.), were grafted on rootstock Wangenheim/Wavit, spaced 4.0m x 2.1m and trained as spindle system.

Treatments

The following thinners were tested: mechanical fruit thinning with the Darwin-200 machine (Fruit Tec®, Germany); Chemical fruit thinning with Ammoniumthiosulfate - ATS (15% Nitrogen (Total - N) plus 67% Ammonium NH_4 and 22% Sulfur) - from Agro-N-Fluid Plus, Proagro®, Germany; Ethephon (Flordimex® 420, Spiess-Urania, Germany); Prohexadione-Calcium (10% ProCa) from Regalis®, BASF, Germany; and Gibberellin (1% $GA_{4/7}$) from Novagib®, Fine Agrochemicals, UK. All were sprayed with 1000 litres of water per hectare. The experimental was established as a completely randomized block design with sixteen treatments and three or four plots per treatment and one tree per replication.

The treatments applied were as follow:

1. Unthinned control (Untreated) - UTC;
2. Mechanical thinning - MTsoft;
3. Mechanical thinning followed by chemical thinning with one spraying with ATS 1.0% ai in full bloom – Mtsoft + ATS 1% - FB;
4. Mechanical thinning followed by chemical thinning with one spraying with ATS 2.0% ai in full bloom – Mtsoft + ATS 2% - FB;
5. Mechanical thinning followed by chemical thinning with one spraying with ATS 1.5% ai in early fruit stage (1.0 cm length) – Mtsoft + ATS 1.5% - 1.75cm fruit;
6. Mechanical thinning followed by chemical thinning with one spraying with ATS 1.5% ai at middle fruit stage (1.5 – 2.0 cm length) – Mtsoft + ATS 1.5% - 1.5 – 2.0 cm fruit;
7. ATS 1.0% ai sprayed in the full bloom;
8. ATS 2.0% ai sprayed in the full bloom;
9. ATS 3.0% ai sprayed in the full bloom;
10. ATS 1.5% ai sprayed at early fruit stage (±1.0 cm length);
11. ATS 1.5% ai sprayed at middle fruit stage (±1.5 – 2.0 cm length);
12. ProCa 150 $mg.L^{-1}$ + $GA_{4/7}$15 $mg.L^{-1}$ sprayed thirty days after full bloom;
13. ProCa 250 $mg.L^{-1}$ + $GA_{4/7}$ 25 $mg.L^{-1}$ sprayed thirty days after full bloom;
14. Ethephon 100 $\mu L.L^{-1}$, sprayed thirty days after full bloom;
15. ProCa 150 $mg.L^{-1}$ + $GA_{4/7}$15 $mg.L^{-1}$, sprayed forty days after full bloom;
16. ProCa 250 $mg.L^{-1}$ + $GA_{4/7}$ 25 $mg.L^{-1}$, sprayed forty days after full bloom;

The mechanical thinning was performed with a tractor at a speed 6 $km.h^{-1}$ and 200 rpm, with fifty percent strings (meaning soft, ZOTH (2011)) applied at full bloom (BBCH Scale 65 and MEIER, 2009) on April 2nd, 2014. The chemical products were sprayed with a manual machine.

Evaluations

Fruit set (%): two branches were selected per tree and 200 flowers were counted for each one. After June the number of fruits drop on each branch was counted and with these data the percentage of fruit set was estimated.

1) **Fruit weight:** At the commercial harvest (July 21st, 2014), all the fruits of selected branches were collected counted and weighed.
2) **Yield (kg ha^{-1}):** The total production of each plant was weighed to establish the yield per tree. With the yield per tree and the number of trees per hectare, it was calculated the yield per hectare.

3) **Fruit quality:** samples of twelve fruits randomly harvested from each tree were used to estimate the average fruit weight, diameter and fruit firmness. Firmness was measured using a nondestructive device FirmTech II (BioWorks, Wamego, KS, USA).
4) **Production per Trunk Cross Sectional Area (TCSA):** The trunk tree diameter was measured at twenty centimeters above graft union and the number and weight of fruits per trunk cross sectional area was calculated.
5) **Yearly vegetative growth:** Strength of growth was measured using a visual rating scale: (1 = very weak; 3 = weak; 5 = medium; 7 = strong; 9 = very strong) and estimated during fruit development (BBCH Scale 91, MEIER, 2009).

Results were statistically processed using analysis of variance, *t* test and Bonferroni test at a 95% probability level of significance, using IBM® SPSS® Statistics 21 statistical software (IBM, Armonk, USA).

Results

Mechanical thinning treatments, associated or not with chemical thinning treatments with ATS, significantly decreased fruit set compared to the control (Figure 1), independently of the concentration and the time of ATS applied. No efficiency on fruit thinning was observed for most of the chemical treatments when applied isolated. However, Ethephon 200 μL.L^{-1} applied at full bloom presented intermediate values for fruit set, with no significant differences compared to mechanical thinning. Independently of the ATS treatment associated, the mechanical thinning was the most effective treatment, with mean reduction of fruit set near to 20%.

Mechanical thinning significantly decreased the number of fruits per tree at harvest, reducing on 80% the total fruits per tree as compared to the control (Figure 2). Almost all mechanical thinning treatments associated with chemical thinning also presented the same effect, except for the use of ATS 1.5% applied later (fruits with 1.75 cm). Among the chemical treatments applied isolated, only the Pro-CA + $Ga_{4/7}$ 150/15 ppm, 45 DAFB significantly decreased the number of fruits per tree, with a reduction of 65% of total fruits per tree, as compared to control.

Mechanical thinning treatments, associated or not with ATS to chemical treatments and the Ethephon 200 μL.L^{-1}, significantly increased fruit size compared with the control (Figure 3). There were no significant differences among them, with an increasing on fruit diameter up to 20%, as compared to the control. Among the chemical treatments applied isolated, only Ethephon 200 μL.L^{-1} showed similar effect on fruit size as compared to the mechanical treatment. Fruit size is an important requirement of the market for commercialization of plums. In general, the minimum diameter in the international market is 30mm.

Mechanical thinning was also effective for increasing fruit weight, either associated or not with ATS chemical thinning, as compared with the control treatment (Figure 4). For these treatments, the average increment was up to 72%. But no positive effects on fruit weight were observed for the chemical thinner treatments ATS, Pro-CA/GA (independently of the concentration and the time of application), and for Ethephon 200 μL.L^{-1}.

Mechanical thinning treatments were the only ones that significantly decreased the yield of ‘Katinka’ plum trees compared to the control (Figure 5). Moreover, no differences were found between mechanical thinning and the majority of the treatments with chemical thinning agents. Even though the yield of trees under mechanical thinning was almost one-third as compared to the control, the fruit weight from the mechanical thinning was significantly higher than on the control trees (Figure 5).

For the variable fruit firmness, thinning with mechanical treatments showed a tendency for lower firmness (Figure 6). This should be a consequence of the lower yield and, subsequently, bigger fruits observed on trees under mechanical thinning. For apples, Denardi and Camilo, (1996) observed a good negative correlation between fruit size and fruit firmness on apples harvested on the same variety cultivated in the same climatic conditions at Southern Brazil.

Mechanically thinned plants, associated or not with ATS chemical treatments showed significantly more branches than the other treatments, except for ATS 3% and Ethephon 200 μL.L^{-1} (Figure 7). In the other words, mechanical thinning, certainty, stimulated branching as an effect of reducing the crop load.

Discussion

According to Sauerteig and Cline (2013), the percentage of removed flowers increased linearly proportionally to the mechanical thinning intensity applied in peach trees. It removes from 42% to 75% of the flowers, according to the thinning intensity. In a trial with chemical thinning of ‘Victoria’ plum trees, Meland (2007) reported reduction in crop load and improvement of fruit quality with the applications of ATS 1.5%, or Ethephon 250 μL.L^{-1} at full bloom or NAA 10 mg.L^{-1} + Ethephon at four weeks after bloom. Similar results were observed in ‘Opal’ plum trees with the application of ATS 1% or Lime Sulphur 5% at full bloom.

Furthermore, Taheri et al. (2012), in a trial with Ethephon and AVG applied at 30 DAFB on ‘Redhaven’ peach trees, observed linear decrease in fruit set the increase of Ethephon concentration (from 0 to 400 μL.L^{-1}). This treatment significantly reduced fruit set as compared to the control and the AVG treatment.

As a support to the results of this study, Seehuber et al. (2011) reported a reduction of the number of fruits, with a concomitant increasing of fruit growth in 'Ortenauer' plum trees submitted to mechanical thinning. Sauerteig and Cline (2013), using a Darwin (Fruit Tec®) machine for mechanical thinning of peaches cv. All-star also verified a linear reduction in the number of fruit harvested per tree and an increasing of fruit size with the increase of rotor speeds of the machine.

In Japanese plums (*Prunus salicina*), some authors also verified increase in fruit size by the application of Ethephon 30 DAFB (PAVANELLO; AYUB, 2012); (PAVANELLO; AYUB, 2014). Compared to the other authors who achieved good results in plums, peaches and cherries, no effects were observed for chemical thinning treatments. Although Ethephon promoted reduced fruit set and increased fruit size compared with the control plants.

Meland (2007) reported an increase in fruit weight of plums cv. Victoria by application of the chemical thinner agents Armothin® (Ethyl alkylamine) 1%, ATS 1.5%, NAA 10 mg.L^{-1} + Ethephon 75 µL.L^{-1} and Ethephon 250 µL.L^{-1}. Worthy of note, the combination of ProCa + $GA_{4/7}$ sprayed 30 days after anthesis, improved fruit weight by about 15% in sweet cherry (ZHANG; WHITING, 2011). However, Taheri et al. (2012) reported reductions in yield for "Redhaven" peach trees treated with Ethephon proportional to the increase of the treatment applied. For their study, the treatments with Ethephon 150 µL.L^{-1} significantly reduced the yield per tree, as compared to the control and AVG treatments. The increase concentration of Ethephon was linearly associated with reduced yield per tree.

Decreasing crop load by reducing the number of fruits per plant will be benefit, for increasing fruit size and weight, inducing a better balance and distribution of assimilate between vegetation and fruit production. As a result, carbohydrate sources will be better distributed on trees for developing fruit and canopy, preventing alternate bearing. For the present study, in spite of the plants used being of young age, consequently with lower cropping capacity, the yield obtained under mechanical thinning was satisfactory.

The treatment with MTsoft + ATS 1% FB, compared to the other treatments associated with mechanical thinning, had a tendency to give a higher rate of fruit set. It also induced higher number of fruit per tree and had a tendency for a greater fruit weight and yield per tree, showing that low concentration of ATS may have fertilization effects instead of thinning effects.

The treatment with Ethephon reduced fruit set. However, for the other variable studied as fruit size, number of fruit per tree, and mainly fruit weight, this treatment had no positive effects.

Taheri et al. (2012), determined that firmness was significantly influenced which resulted in softer fruit. In contrast, Zhang and Whiting (2011), working with sweet cherry treated with the combination of ProCa + $GA_{4/7}$, sprayed 30 days after anthesis, observed improved fruit firmness, increasing it to 280 g/mm as compared to the control with 245 g/mm.

All the mechanically thinned plants showed more branches than the others treatments (Figure 7). In these treatments the lower numbers of fruits per tree suggest a better nutrients and carbohydrates distribution between vegetative components and fruits. This induced the growing of new branches, contributing for a better fruit production on next season. Furthermore, broken branches were observed in plants with excessive fruit set.

In contrast, Zhang and Whiting (2011), working with sweet cherry treated with a combination ProCa + $GA_{4/7}$, sprayed 30 days after anthesis, observed reduced vegetative vigor and the extension of current season shoots was less than half the length of untreated shoots after terminal buds set.

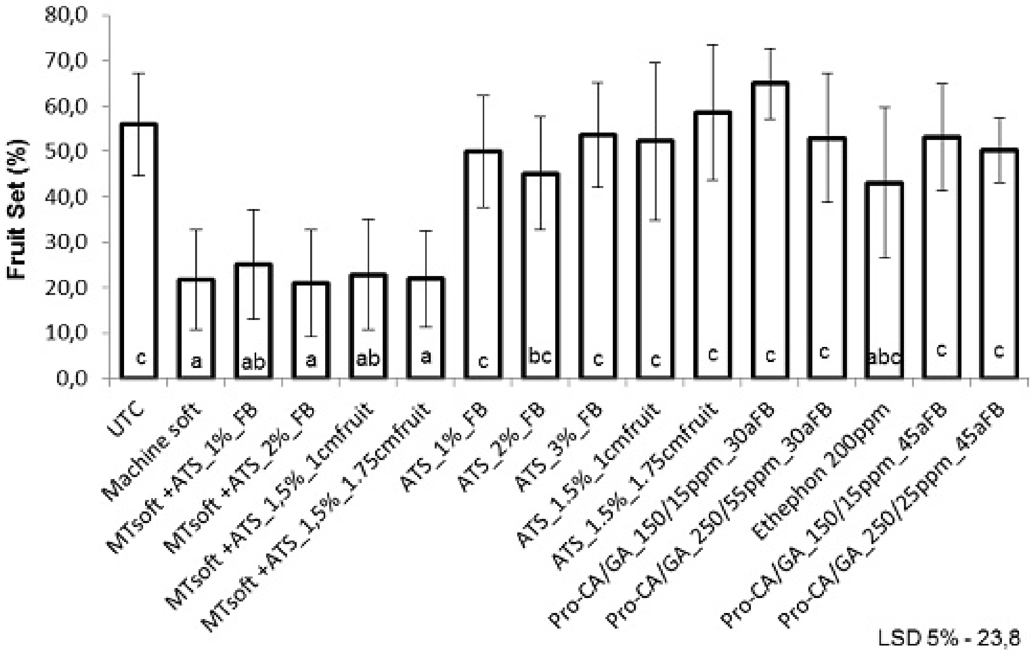


Figure 1. Effects of different combinations of mechanical and chemical thinners on fruit set of Katinka plum - Bavendorf – Germany - 2014.

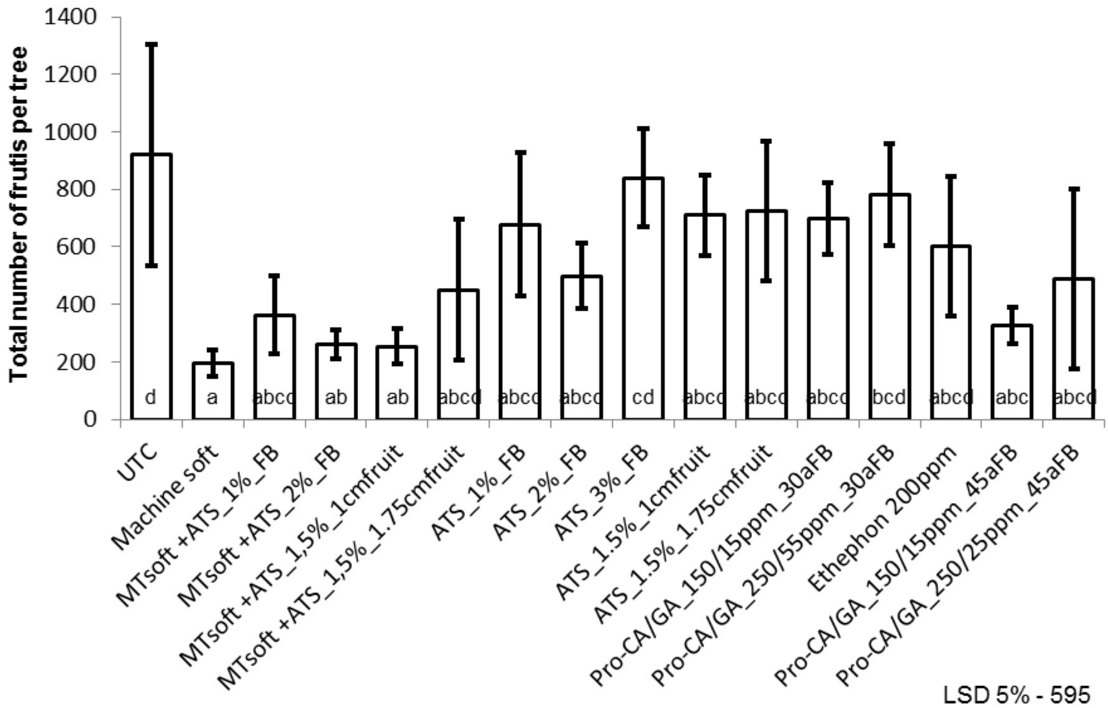


Figure 2. Effects of different combinations of mechanical and chemical thinner on total number of fruits per tree of Katinka plum – Bavendorf – Germany – 2014.

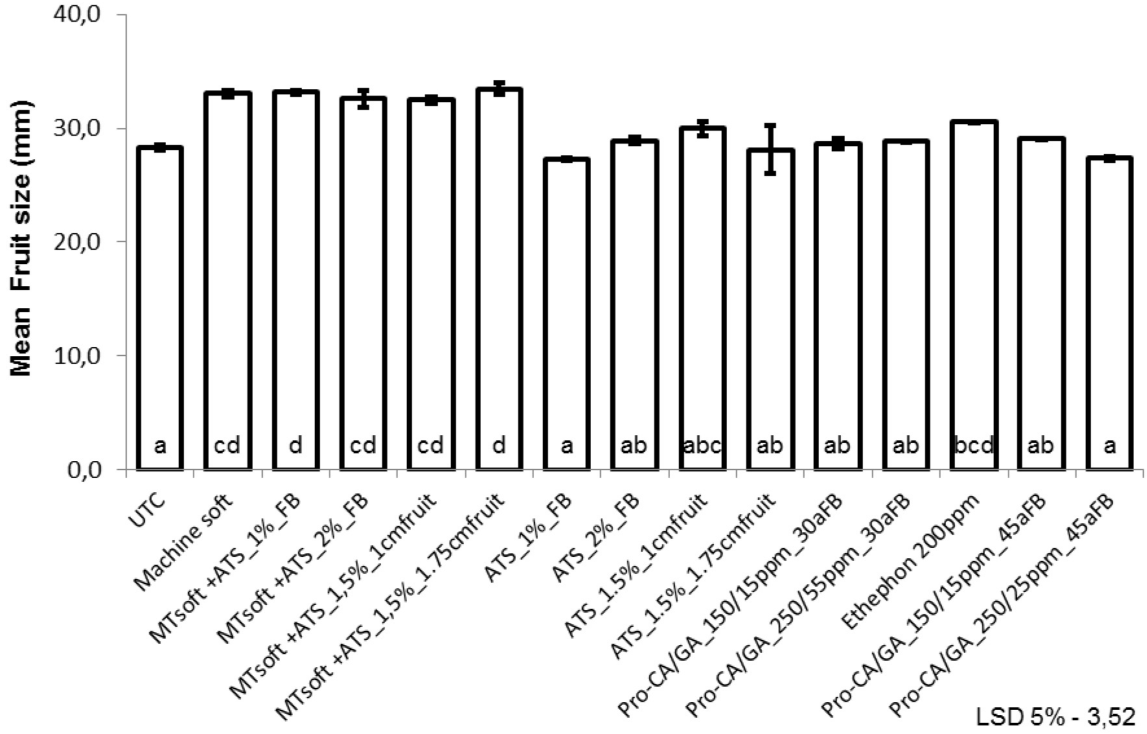
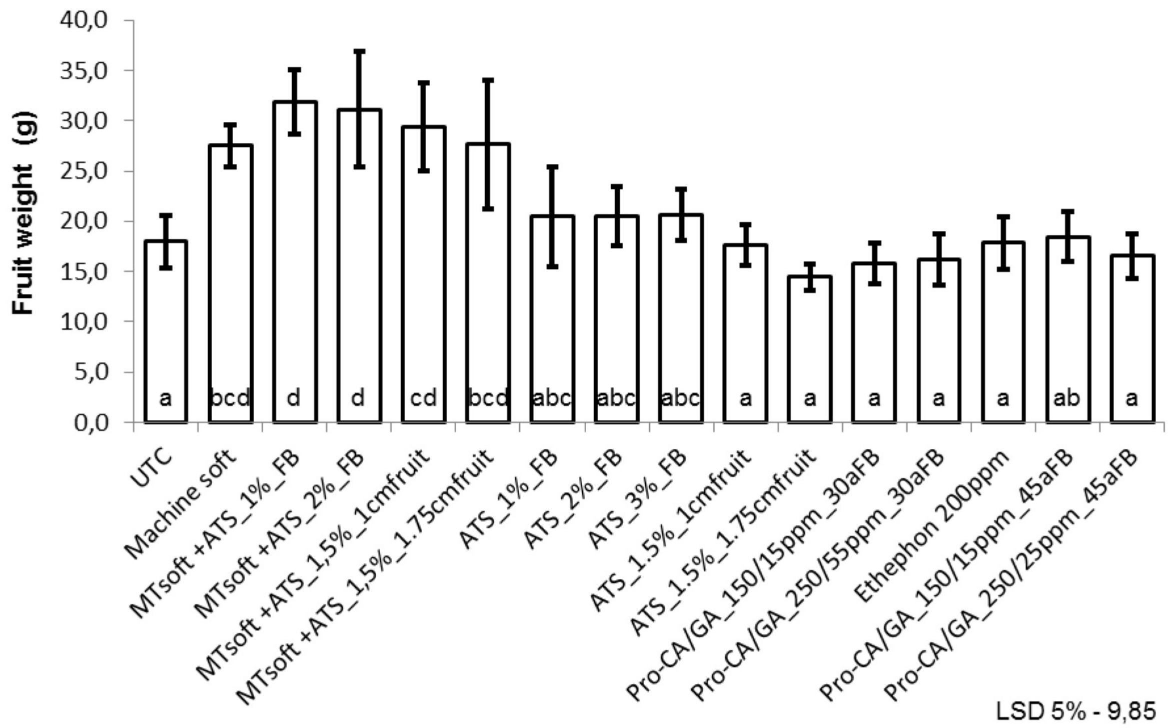
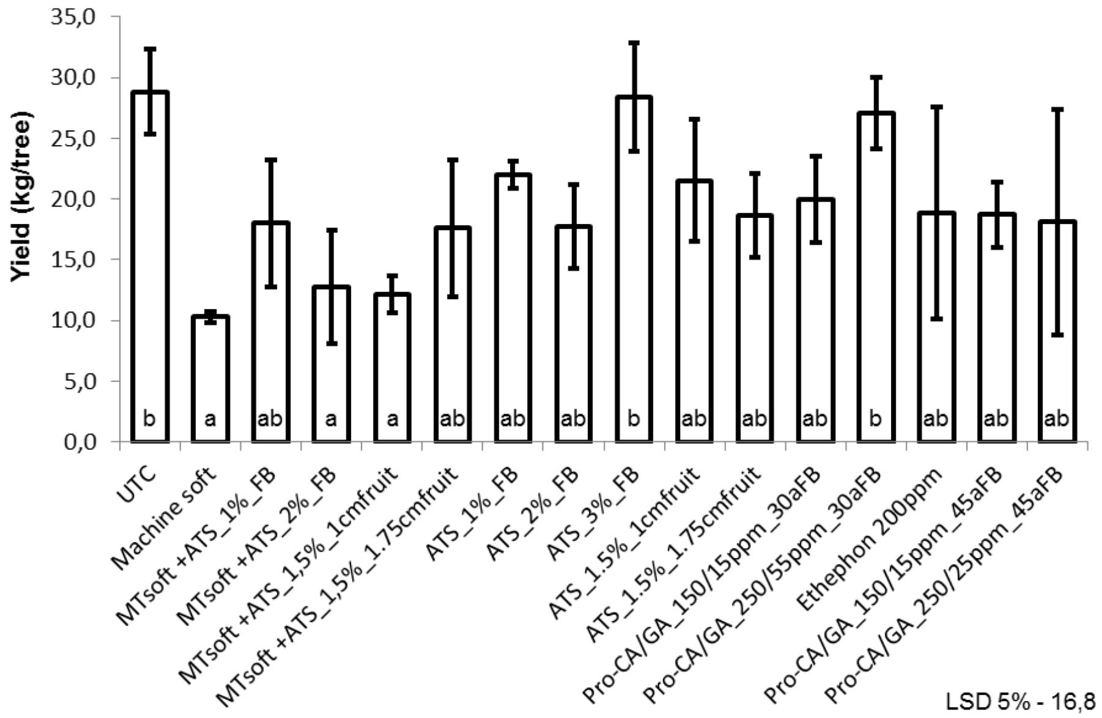


Figure 3. Effects of different combinations of mechanical and chemical thinners on fruit size of Katinka



plum - Bavendorf – Germany - 2014.

Figure 4. Effects of different combinations of mechanical and chemical thinners on fruit weight of Katinka



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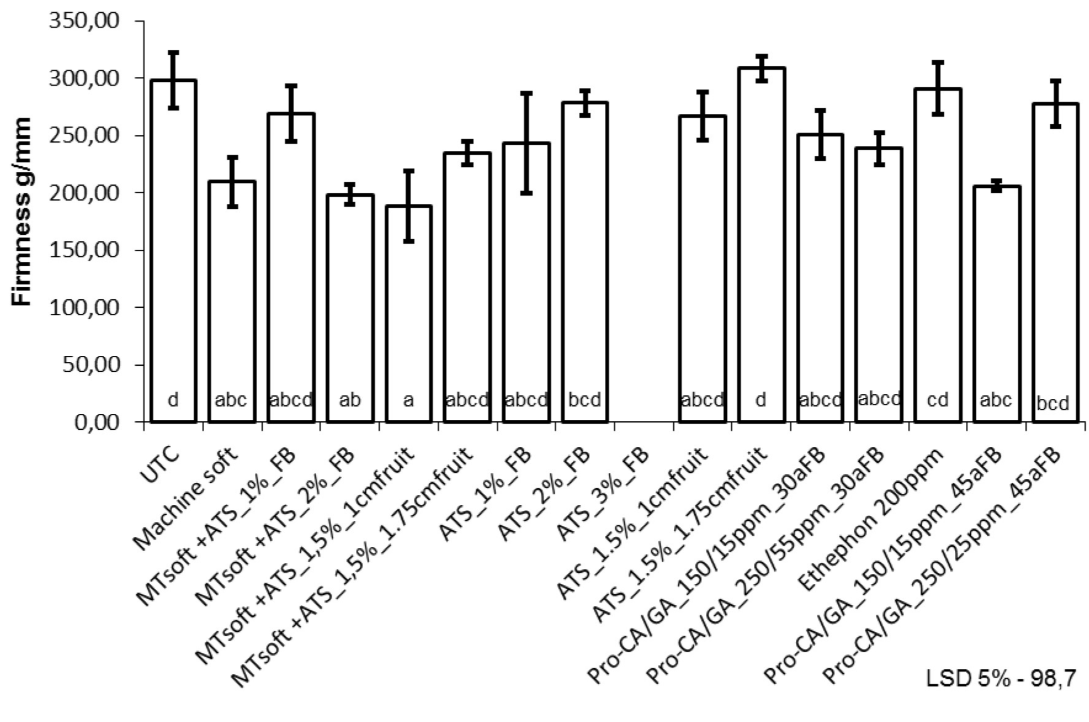

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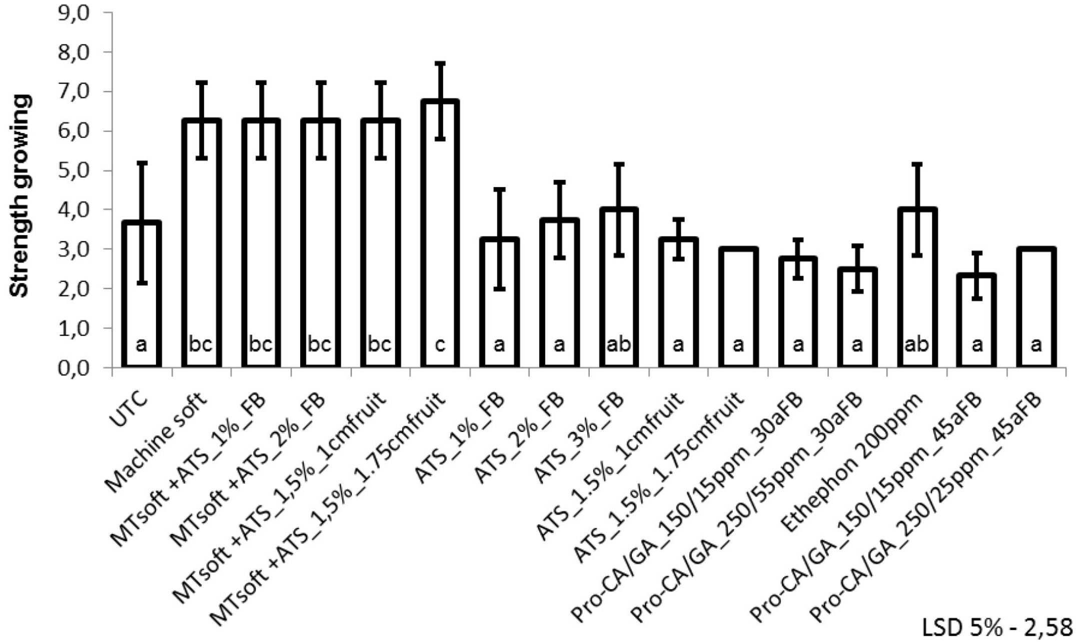

Figure 5. Effects of different combinations of mechanical and chemical thinners on Yield of Katinka plum – Bavendorf – Germany - 2014.

Conclusion

The main conclusions should be draw out from this study:

Mechanical thinning - MT with the Darwin Machine is efficient for thinning Katinka plum.

The MT treatment reduces the fruit set, the number of fruits per tree and yield, but increases fruit size and fruit weight, promotes higher vegetative growth and avoids biannual bearing on Katinka plum.

Expect for Ethephon 250 $\mu L.L^{-1}$, the chemical treatments used have no sufficient fruit thinning effect for Katinka plum.

Ethephon at 250 $\mu L.L^{-1}$ reduces fruit set and increased fruit size of Katinka plum.

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