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PERFORMANCE OF 'GALA' APPLE UNDER CHEMICAL THINNING OR PRECISION CROP LOAD MANAGEMENT

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Abstract

In Europe, the most common measure for crop load management is chemical thinning. Nevertheless, its effect is influenced by many variable factors, thus difficult to control and predict. Precision crop load management is a possible strategy to avoid use of chemical thinning and it provides consistent predictable crop loads. Objective of the research was to test the influence of fruitlet thinning timing on final yield performance when precision quantified crop load management is applied, compare it with chemical thinning, and assess its practical feasibility in current standard spindle orchards. Artificial spur extinction in balloon stage to set 6 flower clusters/cm^2 of branch cross sectional area was applied in several treatments which were further hand fruitlet thinned at three different stages: 5 mm, 10–12 mm, or 20 mm of fruitlet diameter. It was variously combined or compared with chemical fruitlet thinning treatments and control. The thinning effect, production parameters and return bloom were assessed. The results obtained in this study did not favour the precision quantified non-chemical crop load management because it is labour demanding and did not outperform standard chemical thinning approach in fruit quality and yield of the Gala variety.

Keywords: crop load, fruit tree, flower cluster, *Malus* sp., return bloom, yield, quality

INTRODUCTION

One of the key factors of profitable apple production is well handled crop load management. Chemical thinning is the most common measure in Central European conditions and based on the situation, the growers consider two main steps. The first is flower thinning and the second is fruitlet thinning with the goal to avoid or minimise following hand fruitlet thinning which is costly (Mathieu *et al.*, 2011). Flower chemical thinning is used if there are very high flower sets and good weather is forecast. Nevertheless, considering the frequent occurrence of late frosts even 3–4 weeks after full bloom, it is a risky and not popular decision. Fruitlet chemical thinning is considered for some practical reasons as the main regulation measure (Costa *et al.*, 2013; Costa and Botton, 2022). There is an available portfolio of more or less effective active ingrediences e.g. 1-naphthalene acetic acid, 6-benzyladenine, or metamitron (Verma *et al.*, 2023; Gonzalez *et al.*, 2024). There is quite wide window between 6 to 16 mm of fruitlet size when they can be commonly applied and application by sprayer is quick with a relatively low cost. Further, the application is done at a time when the occurrence of late frost is less common or is well predictable by forecast, fruitlet set is already visible and it is possible to evaluate its consistency and decide about thinning intensity (Costa and Botton, 2022). Therefore, the growers rely primarily on this second step. However, both chemical thinning steps are dependent on variable conditions and even though there are some developed models (Robinson *et al*., 2023; Hillmann *et al*., 2025) or available models as RimPro or Brevismart® which decrease the risk of low or high thinning effect, chemical thinning is still considered as a risky treatment. For the above-mentioned reasons, the alternative non-chemical precision crop load management was developed and studied (Lauri, 2008). Other reasons for implementation of precision crop load management were possibly increased yields and higher ratio of first class well marketable fruits (van Hooijdonk *et al*., 2014; van Hooijdonk *et al*., 2018; Bound, 2019). Precision crop load management is based on quantified thinning dependent on branch cross sectional area (Mathieu *et al*., 2011). In this way, a highly uniform and optimized crop load can be achieved, contributing to improved fruit quality and overall orchard performance. It is mainly seen as useful for highly priced club varieties. Nevertheless, the disadvantage of this approach is the high labour cost of artificial spur extinction or flower cluster thinning and hand fruitlet thinning (Mathieu *et al*., 2011; Costa *et al*., 2013; Bound, 2019). There are several questions remaining unanswered for its practical use. Will precise crop load management bring extra yields in standard pruned spindle trees? Will the stage of fruitlet thinning severely influence the final performance and return bloom and will the difference with standard chemically treated tress be significant? Is the precision crop load management suitable for standard Gala variety considering high labour cost and problematic labour availability? The objective of the experiment was to answer these questions.

MATERIALS AND METHODS

Site and Plant Material

The experiments were conducted in apple (*Malus domestica* Borkh.) orchard of variety Gala/M9 located in company Agrosad Velké Bílovice spol. s r.o. in South Moravia, Czech Republic (48.8387069N, 16.9165089E). It was a standard mature drip irrigated production orchard planted on fertile soil with a spacing 3.5 × 0.7 m (4,081 trees/ha) established in 2019. Trees were trained as a slender spindle and pruned by click pruning with a height 3.2 m after winter pruning. Approximately 5 side branches per 1 m of crown height were left after pruning. Complete cultivation except crop load management was carried out according to standard integrated production rules. Mowed grass in inter-rows and weed free row strips were maintained. New trees with uniform thinning management in the previous year were used in both years to have as uniform as possible flower set. The trees were further chosen or adjusted to have the initial flower set between 150–300 and 120–280 flower clusters per tree in 2024 and 2025, respectively.

Treatments

Several thinning treatments were applied in 2024 and 2025, and summary of applied treatments is in Tab. I. Three replications (blocks) of two trees were used for each treatment (6 trees per treatment) every year. If applied in treatment, flower cluster thinning (FC) was done at the balloon stage (BBCH 59). Flower clusters were thinned based on branch cross sectional area (BCSA) to set 6 flower clusters/fruits per 1 cm^2 BCSA. At some treatments, chemical thinning (CH) at 8–10 mm fruitlet size stage was applied. In both years the following tank mix was used: Globaryll 100 (100 g 6-benzyladenine) 1.5 L/ha, Fixor (100 g 1-naphthalene acetic acid) 150 mL/ha, Silwet Star 0.3 L/ha, water 1 000 L/ha. Backpack mistblower (Oleo-Mac MB800) was used for application. Depending on applied treatment, hand fruitlet thinning was done at three different stages: 5 mm, 10–12 mm, or 20 mm king fruitlet size. Only king fruit was left in each fruitlet cluster when fruitlet thinning was done.

In 2024, the day tempeatures during flowering reached 15–20 °C and it was mostly sunny with few light showers before opening of the flowers. Cooling of the weather came after flowering, when the fruitlets were between 5–10 mm of size, however, it was not freezing. In 2025, the day temperatures

I: *Overview of applied crop load regulation treatments*

Abbreviation	Flower cluster thinning (FC)	Chemical fruitlet thinning (CH)	Hand fruitlet thinning on king fruit (HF)
FC	yes	-	-
FC HF 5	yes	-	at 5 mm
FC HF 12	yes	-	at 12 mm
FC HF 20	yes	-	at 20 mm
FC CH HF 20	yes	yes	at 20 mm
C	-	-	-
C CH	-	yes	-
C CH HF 20	-	yes	at 20 mm

during the flowering reached 16–25 °C and it was mostly cloudy and windy (max. 8–10 m/s). There was no cooling of the weather after flowering.

Assessment

Following parameters were measured in both years on each tree: initial number of flower clusters, and where applied, the number of flower clusters after thinning and the number of hand thinned fruitlets. During the manual fruitlet thining, the date and the labour time for two workers per one tree was recorded. At the harvest time, the number and weight of fruits in four size categories (less than 60 mm, 60–70 mm, 70–80 mm, and greater than 80 mm), and the visual assessment of colouration in % of red colour fruit coverage was recorded. The return bloom of 2024 treated trees was assessed by counting flower clusters in spring 2025.

From the data, the thinning effect in number of harvested fruits per 100 flower clusters and the fruit yield in tons per hectare was calculated. The ratio between 2025 developed flower clusters (return bloom) and 2024 number of harvested fruits was used to express the effect of thinning treatments on the flower cluster formation and potential yield in the year after thining.

Statistical Analysis

The effect of treatments on thinning effect, the fruit yield, the weight of fruits in four sizes and the ratio between 2025 developed flower clusters and 2024 number of harvested fruits was statistically analysed using Statistica 14 software (TIBCO, USA). First the distribution analysis was performed where all the data showed normal distribution. For each year separately, the effects of treatments were analysed using analysis of variance (ANOVA) and if significant effect ($P < 0.05$) was observed, the differences between the treatments were further analysed by post-hoc analysis with Tukey's test ($P < 0.05$).

RESULTS

Thinning of Flower Clusters and Fruitlets

Although each year the number of flower clusters per tree before the reduction was different (Tab. II), after the reduction, similar numbers per tree were reached both years (158.3 ± 28.3 in 2024 and 157 ± 30.7 in 2025). This indicates highly uniform tree structures in the examined orchard.

The highest numbers of manually removed fruitlets were achieved at the 5 mm fruitlet thinning stage (between 627.7 and 641 fruitlets, Tab. III), where the thinning procedure averaged the longest times 25–35 minutes per tree for 2 workers. During the next thinning stage (12 mm fruitlet size), the number of removed fruitlets and the labour time was lower and finally, at the 20 mm fruitlet thinning stage the numbers of removed fruitlets and labour times were the lowest with an average of 2–3 minutes to remove between 21.3 to 29.3 fruitlets in 2024 and an average of 10 minutes to remove 122.3 to 197.0 fruitlets in 2025.

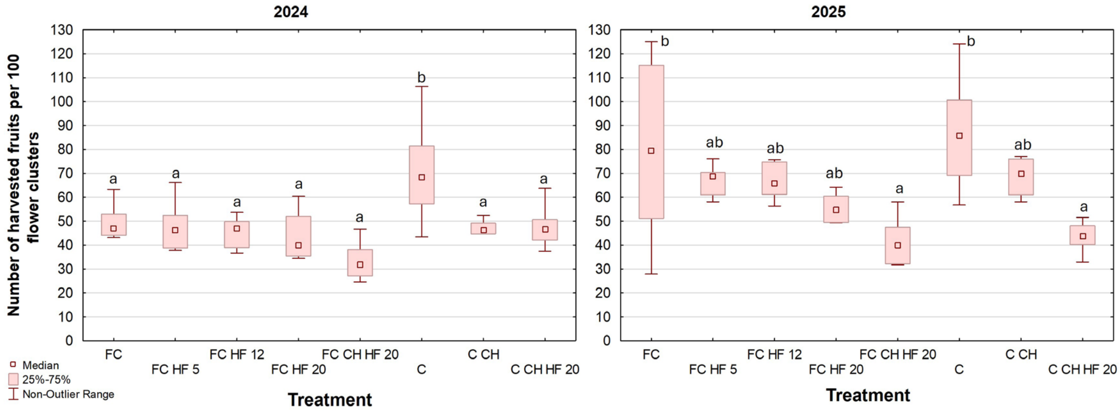
In 2024, the thinning effect expressed as the number of harvested fruits per 100 flower clusters (Fig. 1) was very even across the treatments (between 30 to 50 harvested fruits per 100 flower clusters), except for the control (C) where the numbers were significantly higher (70 harvested fruits per 100 flower clusters). In 2025, the numbers were higher than in 2024, ranging between 40 to 90 harvested fruits per 100 flower clusters, where both treatments with chemical thinning and

II: *Flower clusters before and after the reduction. SD means standard deviation.*

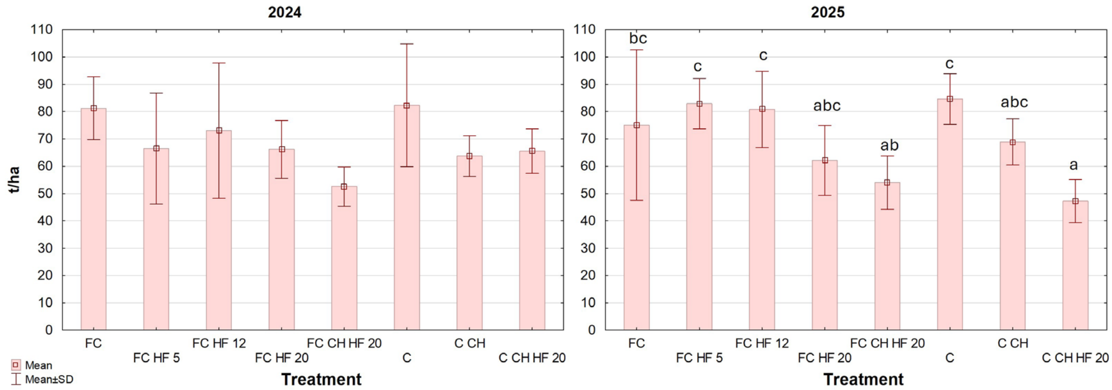
Year	No. of flower clusters		Reduction rate (%)
	Before reduction (average ± SD)	After reduction (average ± SD)	
2024	243.3 ± 50.6	158.3 ± 28.3	34.0 ± 7.4
2025	187.5 ± 35.6	157.4 ± 30.7	15.9 ± 5.9

III: *Number of manually removed fruitlets and labour time per tree, and the dates of hand fruitlet thinning. SD means standard deviation.*

Treatment	2024			2025		
	No. of removed fruitlets (average ± SD)	Labour time (min)	Date (dd.m.)	No. of removed fruitlets (average ± SD)	Labour time (min)	Date (dd.m.)
FC HF 5	641.0 ± 124.0	25–35	15. 4.	627.7 ± 88.2	25–30	2. 5.
FC HF 12	642.8 ± 15.9	20–25	29. 4.	502.3 ± 113.8	20–25	7. 5.
FC HF 20	29.3 ± 11.6	2–3	11. 6.	122.3 ± 21.6	10	11. 6.
FC CH HF 20	24.2 ± 8.0	2–3	11. 6.	163.0 ± 25.0	10	11. 6.
C CH HF 20	21.3 ± 5.0	2–3	11. 6.	197.0 ± 48.8	10	11. 6.



1: *The thinning effect expressed as the number of harvested fruits per 100 flower clusters. Letters (a,b) above error bars indicate grouping according to the Tukey's test (P < 0.05).*



2: *Average fruit yield in 2024 and 2025. SD means standard deviation. Letters (a,b,c) above error bars indicate grouping according to the Tukey's test (P < 0.05).*

hand fruitlet thinning at 20 mm (FC CH HF 20 and C CH HF 20) had significantly lower numbers than the control and the treatment where only flower cluster thinning was performed (FC).

Yield and Quality

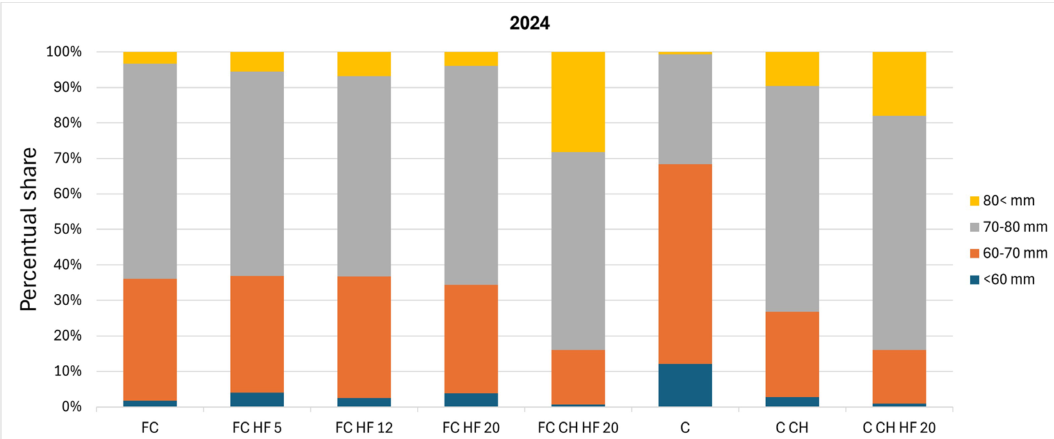
Despite that no significant difference was observed in fruit yield between the treatments in 2024 (Fig. 2), the lowest yield was observed in the treatment where manual thinning of flower clusters and fruitlets at 20 mm stage as well as chemical thinning was performed (FC CH HF 20, less than 60 t/ha). The highest yields (above 80 t/ha) were recorded at the treatments where no thinning (C) or only flower cluster thinning (FC) was performed. The rest of the treatments had similar yields, between 60 to 75 t/ha.

In 2025, again the lowest yield (lower than 60 t/ha) was observed at FC CH HF 20 but also in a similar treatment where no flower cluster thinning was performed (C CH HF 20). Both treatments had significantly lower yields than the control treatment and treatments where flower cluster thinning together with hand fruitlet thinning in the 5 and 12 mm stage was performed (FC HF 5 and FC HF 12, respectively). These treatments reached the highest yields, above 80 t/ha. The rest of the treatments had between 60 to 75 t/ha and were mainly not different from the other treatments.

Besides the reduction of the yield, the flower cluster thinning and the hand or chemical fruitlet thinning affected the percentual share of the fruit sizes (Fig. 3 and 4). In 2024, the fruits up to 70 mm size accounted for around 70 % of the yield in the control treatment, while in treatments where flower cluster thinning was performed it was just around 35 % and in treatments where chemical thinning was performed it was between 16 % and 27 %.

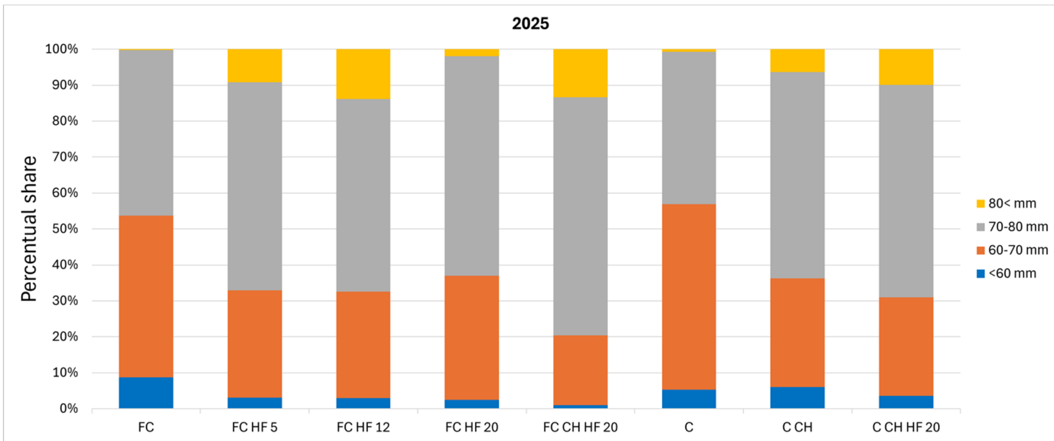
In 2025, the control treatment had again the highest percentual share of fruits up to 70 mm size (around 55 %, Fig. 4), however, similar results were also obtained for the FC treatment (above 50 %) where only flower cluster thinning was performed. The rest of the treatments where hand or chemical fruitlet thinning was performed, the shares of fruits of up to 70 mm size reached between 20 % and 35 %.

Based on the results illustrated in Fig. 3 and 4, the treatment with flower cluster thinning where no subsequent thinning was performed had variable shares of fruit sizes during 2024 and 2025. On the other hand, both years, the treatments where subsequent hand fruitlet thinning regardless the fruitlet size was performed gave very similar results



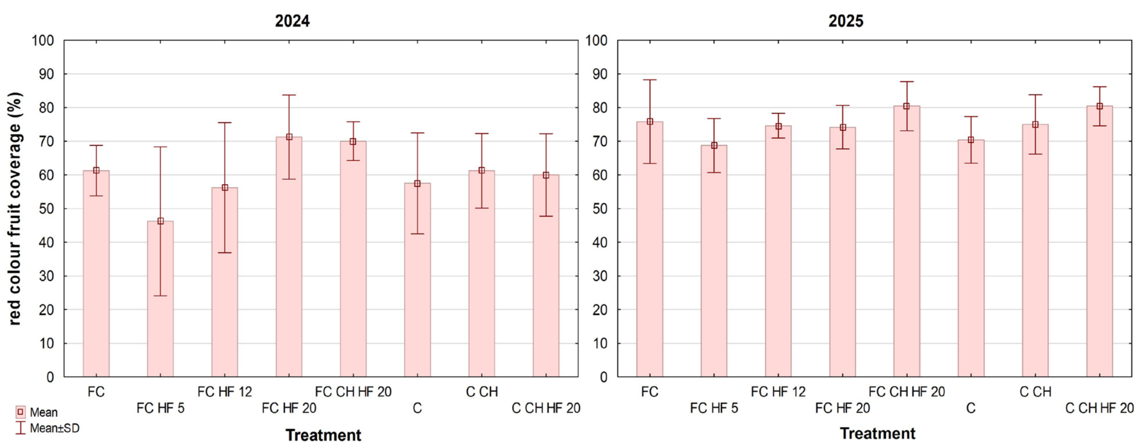
average yield ± SD (t/ha)	FC	FC HF 5	FC HF 12	FC HF 20	FC CH HF 20	C	C CH	C CH HF 20
80< mm	2.73±2.98^{ab}	3.71±3.18^{abc}	5.02±6.57^{abc}	2.57±3.31^{ab}	14.81±11.22^{c}	0.53±0.65^{a}	6.16±5.98^{abc}	11.83±7.26^{bc}
70-80 mm	49.18±16.77	38.24±19.59	41.14±18.36	40.85±17.43	29.34±7.02	25.47±16.20	40.52±15.34	43.18±9.84
60-70 mm	27.95±7.92^{bc}	22.04±5.80^{ab}	25.06±8.12^{ab}	20.24±8.81^{ab}	8.08±8.70^{a}	46.32±17.75^{c}	15.34±11.67^{ab}	9.92±4.73^{ab}
<60 mm	1.39±0.94^{ab}	2.61±1.67^{ab}	1.84±1.27^{ab}	2.57±4.16^{ab}	0.33±0.45^{a}	10.00±12.81^{b}	1.75±2.29^{ab}	0.61±0.41^{a}

3: *Percentual share and yield of fruits according to fruit size categories expressed in t/ha in 2024. SD means standard deviation. Upper case letters (a, b, c) indicate grouping according to the Tukey's test (P < 0.05).*



average yield ± SD (t/ha)	FC	FC HF 5	FC HF 12	FC HF 20	FC CH HF 20	C	C CH	C CH HF 20
80< mm	0,14±0,3^{a}	7,58±3,71^{bc}	11,19±4,17^{c}	1,23±0,92^{ab}	7,21±6,94^{bc}	0,61±0,44^{ab}	4,35±2,67^{abc}	4,66±2,90^{abc}
70-80 mm	34,59±15,46	48,02±9,86	43,33±7,85	37,92±11,26	35,78±5,57	35,84±6,33	39,59±11,39	27,95±7,04
60-70 mm	33,84±15,39^{bc}	24,79±6,28^{ab}	23,94±6,44^{ab}	21,39±6,09^{ab}	10,47±2,26^{a}	43,73±3,44^{c}	20,85±8,78^{ab}	12,96±4,54^{a}
<60 mm	6,53±6,62^{b}	2,55±2,1^{ab}	2,35±0,9^{ab}	1,56±1,53^{ab}	0,54±0,55^{a}	4,47±1,62^{ab}	4,12±2,01^{ab}	1,67±0,86^{ab}

4: *Percentual share and yield of fruits according to fruit size categories expressed in t/ha in 2025. SD means standard deviation. Upper case letters (a, b, c) indicate grouping according to the Tukey's test (P < 0.05).*



5: *Red colour fruit coverage in 2024 and 2025* to the conventional chemical thinning. When the combination of fruitlet thinning and chemical thinning was performed (FC CH HF 20 and C CH HF 20), these treatments gave both years the highest shares of fruits above 70 mm size.

Both years the red colour fruit coverage was not significantly affected by any treatment (Fig. 5). In 2024, the coverage was ranging between approximately 45 % to 70 % while in 2025 the coverage was more even throughout the treatments and, on average higher than in 2025 reaching between around 70 % and 80 %. In both years, the lowest coverage was observed at the FC HF 5 treatment.

Return Bloom

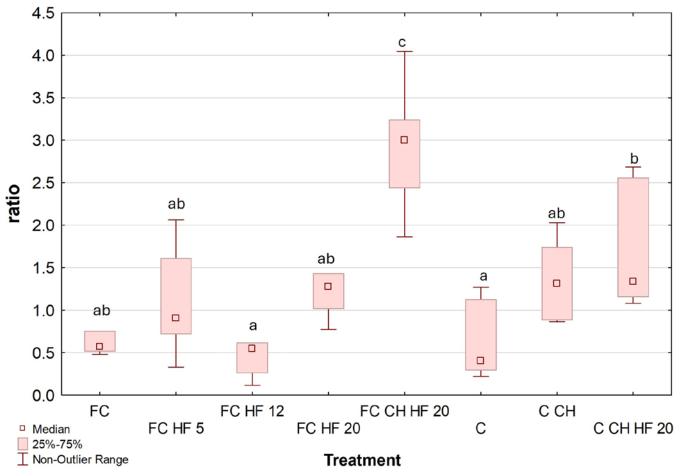
To evaluate the effect of the 2024 treatments on the 2025 return bloom, the ratio between 2025 developed flower clusters and the 2024 number of harvested fruits was calculated. This ratio indicates the ability of trees to produce same amount of fruits in 2025 as in 2024, in consideration when 1 fruit per 1 flower cluster will be developed. Based on this consideration, the best scenario is when the ratio reaches above number 1. According to the Fig. 6, only the treatments where hand fruitlet thining at 20 mm size or the chemical thinning was performed reached the ratios 1 and higher. The highest ratio (around 3) was calculated for FC CH HF 20. On the other hand, the lowest ratio (around 0.5) was calculated for the control, FC and FC HF 12 treatments, meaning that the flower clusters developed in 2025 were only half of the amount of the fruits developed in 2024.

DISCUSSION

Results revealed that the number of removed fruits and the time needed for their thinning was very high for treatments where it was done at 5 and 10–12 mm stages, i.e. before natural or induced drop. The time was higher because the thinning was done by not skilled workers, but even if it would be done by skilled (i.e. faster working) labour, this procedure would be very time consuming. Bound (2019), based on her results, recommends thinning as early as 5 weeks after full bloom (before natural drop). However, our results clearly show that this would be too costly, and it is more appropriate to follow the recommendations of Mathieu *et al.* (2011), that hand thinning should be applied after the induced or natural June drop. The discrepancy between the numbers of removed fruitlets and labour time in 2024 and 2025 in the 20 mm fruitlet thinning stage was due to the shift of vegetation development in 2024, when the vegetation development was 2–3 weeks ahead of that in 2025 where the fruit drop was not completly finished even though the fruits had 20 mm diameter.

The results of the thinning effect gave expected responses showing that control (C) had the highest and the treatment combining all thinning measures (FC CH HF 20) had the lowest numbers of fruits per 100 flower clusters in both years. Interestingly, in the first year the treatment with only flower cluster thinning (FC) was quite similar to other thinning treatments, but in second year the numbers of fruits per 100 flower clusters were higher and more variable, meaning, that in the second year, the natural fruitlet drop was lower and variable among trees. In both years the thinning effect of chemical thinning alone (C CH) was comparable with treatments where flower cluster thinning was combined with hand fruitlet thinning (FC HF5, FC HF12 and FC HF 20). This shows that the chemical treatment alone had similar effect on thinning as labourious hand thinning.

The yield and fruit size predict the amount of the income. Fruits above 70 mm size present higher economical incomes for the growers due to the higher price per 1 kg. Therefore, the treatments



6: *Return bloom expressed as the ratio between 2025 developed flower clusters and the 2024 number of harvested fruits. Letters (a,b,c) above error bars indicate grouping according to the Tukey's test ($P < 0.05$).*

with higher percentual shares and total yield of fruits above 70 mm are more interesting for the growers. The results of yield show that in both years, the precise thinning treatments with flower cluster and fruitlet thinning (FC HF5, FC HF12 and FC HF 20) did not significantly outperform the treatment where only chemical thinning (C CH) was performed and the same applies for the ratio and amount of the yield in size above 70 mm. It shows that when a precision two step approach is applied to a standard spindle shaped and pruned trees with good yield potential, no significant increase in yield or size can be expected when compared to chemical thinning, which is contrary to what might be anticipated based on the results of van Hooijdonk *et al.* (2018) or Bound (2019). It is necessary to mention that the results can be different not only based on type of canopy but also variety (Bound, 2019). Results of colouration did not show significant differences and did not favour any treatment. We ascribe worse colouration in the first year to much earlier harvest time without previous substantial temperature variation which enhances colouration.

To be able to properly assess the possible economical impact of a given treatment, a multi-year evaluation of that management on identical trees would be necessary. Such an approach would allow a reliable assessment of yield and its stability under real conditions. Since our experiment lasted only two years on previously unaffected trees, we can infer stability only from the return bloom of the first year treated trees. The results showed that generally higher return bloom with a ratio higher than 1 had treatments previously treated by chemical thinning alone (C CH) or in combination (FC CH HF 20, C CH HF 20). Surprisingly, in comparison with the results of van Hooijdonk *et al.* (2014) or Mathieu *et al.* (2011) the thinning treatments combining flower cluster thinning and fruitlet thinning (FC HF 5, FC HF 12, FC HF 20) had the ratio just close or lower than 1. We think that the reason is the relatively high used crop load of 6 flower clusters and fruits per 1 cm^2 which could be for some varieties too high (Mathieu *et al.*, 2011). Further, most probably the main reason why chemically trated trees had generally higher return bloom is the use of 6-benzyladenine in spray mixture. This active ingrediency is known not only for the thinning activity but also as flower set enhancer for next season (Greene *et al.*, 2016). The precise crop load treatments without chemical thinning did not show to be reliable in ensuring sufficient return bloom.

The results of Bound *et al.* (2019) support the economic advantages of a precision approach to thinning, even when manual fruit thinning is used. However, the results of our trials in a standard slender-spindle orchard indicate that the treatment using only chemical thinning is economically more advantageous. In both years, it produced similarly high yields, comparable improvements in size-class distribution, very good return bloom ensuring potential yield stability, and required no costs for labor-intensive manual thinning of blossoms and fruitlets. Based on our findings, we therefore do not consider the use of a precision approach to crop-load regulation, as it was applied for used type of planting, to be beneficial. Its application would require comprehensive changes in pruning and training of the trees (Lauri, 2008; Mathieu *et al.*, 2011).

The simple cheap chemical thinning seems to remain the better choice not only for comparable yield results and low costs but also due to unstable spring conditions in Central Europe. Fruitlet chemical thinning allows to decide about thinning intensity later in the frost safe period and based on fruit set consistency (Costa and Botton, 2022). This further reduces the importance of flower or flower cluster thinning, especially when effective chemicals for late thinning (Costa and Botton, 2022) and effective models (Robinson *et al.*, 2023; Hillmann *et al.*, 2025) are developed. However, flower cluster thinning or artificial spur extinction and precision crop load management can remain meaningful for certain conditions, planting types and varieties (Mathieu *et al.*, 2011; van Hooijdonk *et al.*, 2018; Bound, 2019; Robinson *et al.*, 2023). It is applicable in organic farming and it may also become relevant if robotic technology for flower cluster thinning or another precise thinning technology becomes available (Zhang *et al.*, 2019; Robinson *et al.*, 2021; Karkee, 2024). For its use it will be necessary to always consider not just separate application of crop load strategy but the change of whole growing and management system.

CONCLUSION

Based on the results, we conclude that precise crop load management did not bring an extra yield or quality on standard pruned spindle trees of the Gala variety when compared to chemical thinning. Also, the timing of hand fruitlet thinning did not substantially influence the final performance and return bloom. There was no significant difference to standard chemically treated tress and, considering the high labour cost we do not see the precision crop load management suitable for the standard Gala variety and used planting system.

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