Environmental and Experimental Biology (2025) 23: 175–182
http://doi.org/10.22364/eeb.23.19

Original Paper

Environmental and Experimental Biology

ISSN 2255-9582

UNIVERSITY OF LATVIA

Relationship between pruning severity and reproductive performance in commercial pear orchards

Abdelkader Harizia[1]*, Abdelkader Benguerai[1], Yahia Boukhari[2], Souad Makhloufi[3], Houari Yerrou[1], Sabrina Benzina[1]

[1]Laboratory of Research on Geo-Environment and Spaces Development, Faculty of Nature and Life Sciences, University of Mascara, Algeria
[2]Laboratory of Geomatics, Ecology and Environment, Faculty of Nature and Life Sciences, University of Mascara, Algeria
[3]Scientific and Technical Research Center of Arid Regions, Biskra, Algeria

*Corresponding author, E-mail: abdelkader.harizia@univ-mascara.dz

Abstract

Pruning is a key horticultural practice, which strongly influences flowering, fruit set, and overall yield in pear orchards. This study evaluated the effects of severe (short) versus conventional (long) winter pruning on reproductive performance and yield of 'Santa Maria' pear trees grown in an intensive orchard in Algeria. The findings demonstrated that severe pruning promoted floral bud initiation, increased flower abundance, and improved fruit set, with fruit set rates of 40.9% under severe pruning and 37.4% under conventional pruning. Strong positive correlations among floral bud number, flower density, and fruit set highlighted the coordinated nature of the reproductive response. Overall, severe winter pruning enhanced reproductive development and yield without compromising fruit set efficiency. These results suggest that optimizing pruning intensity may be an effective strategy to enhance productivity and sustainability in commercial pear production systems.

Key words: commercial orchard, flowering traits, fruit set, 'Santa Maria' pear, winter pruning intensity.
Abbreviations: BBCH, Biologische Bundesanstalten, Bundessortenamt und Chemische Industrie standard scale; FSR, fruit set rate; NFB, fruit buds; NFS, set fruit; NOF, open flowers; NVB, vegetative buds.

Introduction

The common pear (*Pyrus communis* L.), a pomaceous fruit cultivated primarily in temperate regions, is often affected by biennial bearing, leading to alternating years of high and low yields. This phenomenon is particularly pronounced in high-quality cultivars prone to irregular fruiting (Jonkers 1979). Despite advances in cultivar selection and orchard management, factors such as planting density, fruit set, branch type, rootstock, pruning practices, and the use of growth regulators continue to play a critical role in fruit bud formation and overall productivity. Since the early 2000s, pear orchards have been classified according to planting density (trees ha^{-1}) into five categories: low (1000 – 1500), medium (1500 – 3000), high (3000 – 4000), very high (4000 – 8000), and ultra-high (over 8000) (Öztürk, Faizi 2023). High-density systems, while designed to promote early cropping, typically require more intensive management inputs. Supporting this, it was reported that quince rootstocks in high-density plantings enhance yield, fruit quality, and production efficiency in the 'Santa Maria' cultivar, whereas pear seedling and clonal rootstocks under low-density systems promote superior tree morphological development (Öztürk, Faizi 2023). Similarly, it was observed that in 'Santa Maria', yield efficiency increased at lower planting densities as trees aged, while fruit quality remained largely unaffected by planting density (Sansavini 2000).

To mitigate biennial bearing and achieve more consistent annual yields, practices such as partial deflowering and the targeted application of growth regulators have proven effective (Chen et al. 2012). In modern intensive orchard systems, integrated cultural approaches, including fruit thinning, strategic pruning, and the use of appropriate rootstocks, are increasingly employed to regulate crop load and stabilize production. Among these practices, pruning is particularly critical; beyond shaping tree architecture and enhancing light penetration, it balances vegetative growth and reproductive development by modulating resource allocation (Persello et al. 2019).

When carefully managed, pruning helps sustain the balance between vegetative growth and yield, thereby supporting regular fruit set and reducing the incidence of biennial bearing. Modern high-density planting systems have markedly improved orchard productivity, delivering higher yields per unit area than traditional layouts. This advantage is largely attributed to more efficient use of solar radiation, greater uptake of water and nutrients, and enhanced photosynthetic performance (Ladaniya et al. 2021). In these systems, pruning is typically carried out during winter dormancy, a period known to stimulate subsequent vegetative growth, delay flowering, and, in some cases, moderate fruit set. As trees age and natural vigour declines, more severe pruning may be required to rejuvenate the canopy, stimulate new shoot development, and maintain fruit size (Mika, 2011; Benzina et al. 2023).

In Algeria, pear cultivation occupies approximately 19 281 ha, with a total production of 170 055 metric tons in 2023 and an average yield of 8.82 t ha^{-1} (FAOSTAT, 2023). The main cultivars include 'Santa Maria', 'Williams Rouge', and 'Dr. Jules Guyot', with 'Santa Maria' valued for its moderate vigour and adaptability to various orchard systems, including super-intensive designs (Küçüker, Ağlar 2021). Despite its commercial relevance, studies on the productivity of 'Santa Maria' in Algerian growing conditions remain limited. Most orchards are managed with low-intensity winter pruning and occasional thinning; however, yields continue to fall below the global average of over 15 t ha^{-1}.

This study was therefore designed to investigate the effects of two winter pruning intensities on flowering and fruit set in 'Santa Maria' pear trees, with the aim of enhancing productivity and optimizing orchard management under Algerian conditions. Given the importance of cultivar-specific pruning strategies for maximizing yield and mitigating biennial bearing, this research focused on evaluating how pruning severity influences the reproductive performance of 'Santa Maria' in intensive orchard systems.

Materials and methods

Site description and management

The study was conducted in northwestern Algeria (Sidi Ali Benyoub region), in a semi-arid climate (16.9 °C average temperature, 284 mm annual precipitation). The commercial orchard includes 23 ha of pears (*Pyrus communis* L.). The soil texture was silty-calcareous, slightly alkaline, with moderate active lime, low phosphorus and micronutrients, and low exchangeable aluminium, posing some chlorosis risk but not Al toxicity. The experimental orchard was planted in 2004 with the 'Santa Maria' pear cultivar grafted onto BA29 quince rootstock. The 'Santa Maria' cultivar is characterized by a vigorous, semi-upright growth habit, distinguished by high productivity, early fruiting, and a dense canopy structure. The rows and the intra-row tree spacing were 4.0 and 1.5 m, respectively, which corresponds to a high-density design of 1667 trees ha^{-1}. The orchard was managed using the vertical axis training system. The orchard management included light winter pruning, drip irrigation supplied by two emitters of 8 L h^{-1} per tree, fertilization with 200 kg ha^{-1} NPK (15-15-15) supplemented by 30 kg ha^{-1} nitrogen fertigation, and mechanical weed control along the tree rows using a windrower.

Experimental design and pruning treatment

The experiment was designed to evaluate the effects of winter pruning intensity on various productivity parameters in pear trees. A randomized complete block design was implemented in a trial orchard consisting of 24 rows, each containing 66 trees. The orchard was divided into two equal groups: control and treatment. Within each group, 15 trees were randomly selected starting from the second row and distributed systematically across three consecutive rows (five trees per row, three replicates). A buffer zone of ten rows separated the two groups to minimize potential treatment interference. Trees in the treatment group received severe winter pruning, while control trees underwent standard light pruning. All selected trees were clearly marked with surveyor's tape and numbered sequentially from 1 to 15 on the trunk using lime paint.

Pruning was carried out on November 24, 2016, using secateurs disinfected with sodium hypochlorite to prevent contamination. In the severe pruning treatment, all water sprouts and some simple shoots were removed, with the remaining shoots were cut back to four or five buds depending on tree vigour, preserving approximately one-third of the current year's growth. In contrast, control pruning, reflecting standard orchard practices, involved the removal of water sprouts while retaining the maximum number of buds per shoot, thereby maintaining longer branches. These contrasting pruning intensities were intended to elucidate their effects on subsequent flowering and fruit set in an intensive production system (Fig. 1).

Data collection

The fresh weight of wood removed from each pruned tree was measured immediately after pruning. Assessments of buds and reproductive traits included counts of vegetative buds (NVB), fruit buds (NFB), open flowers (NOF), and set fruit (NFS), recorded using a mechanical counter (Fig. 2). Phenological monitoring was conducted from November 2016 to April 2017, spanning the period from winter pruning through fruit set. Observations commenced at bud dormancy on November 20 and continued through subsequent developmental stages. Each parameter was recorded when at least 50% of the trees had reached the corresponding phenological phase, following BBCH-scale observation protocols (Meier 2001).

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics (version 27). Descriptive statistics were calculated for all vegetative and reproductive parameters, including NVB, NFB, NOF, NFS, and pruned wood mass. The

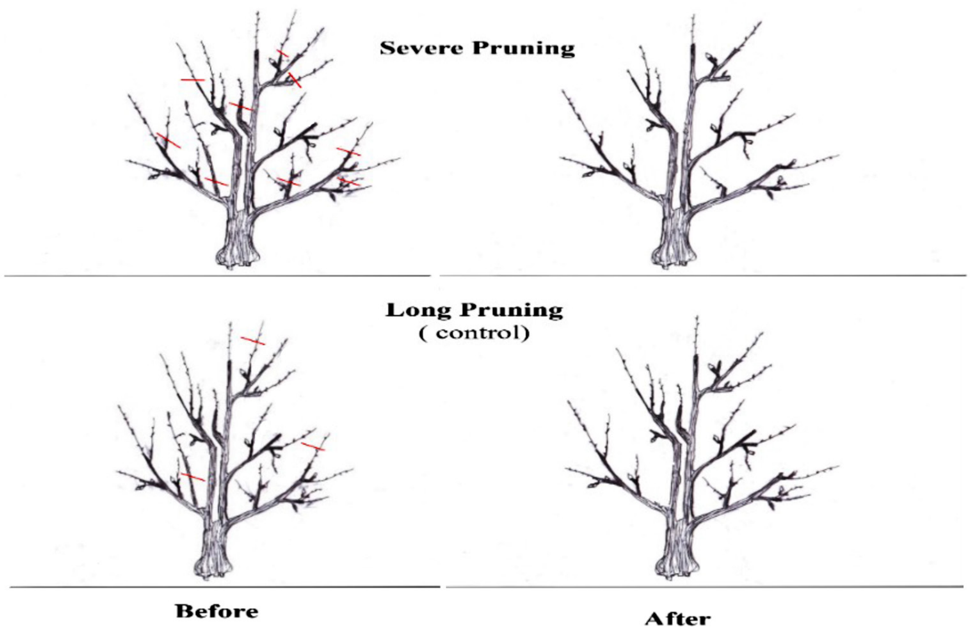

Fig. 1. Pruning treatments applied to pear trees in the experimental orchard (red lines indicate the branches removed).

normality of variables within each group (control and treatment) was assessed using the Shapiro-Wilk test. NVB (control: $p = 0.009$; treatment: $p = 0.217$) and NOF (control: $p = 0.004$; treatment: $p = 0.440$) did not consistently meet normality assumptions, warranting the use of the non-parametric Mann–Whitney *U* test for comparisons of these variables. For all other variables satisfying normality, independent samples *t*-tests were applied. Pearson or Spearman correlation analyses were conducted to evaluate relationships among vegetative and reproductive traits and pruning intensity (wood removed). Multiple linear regression analysis was used with NFS as the dependent variable and NVB, NFB, NOF, and pruning treatment as independent variables. Principal component analysis was employed to reduce dataset dimensionality and summarize interrelationships among potentially correlated traits while preserving most of the original variability. A significance threshold of $p < 0.05$ was used for all tests.

Results

Key phenological stages

Table 1 summarizes the key phenological events observed in 'Santa Maria' pear trees. This cultivar progressed rapidly through developmental stages following winter dormancy. Inflorescence emergence occurred between March 20 and 24, 2017, approximately five months after dormancy onset. Flowering commenced on March 25 and lasted 28 days, concluding on April 14. Fruit set was recorded on April 16, further confirming the early-flowering characteristics of 'Santa Maria' under the conditions of the experimental orchard.

Fresh pruning wood mass

Winter pruning of 'Santa Maria' pear trees resulted in the removal of 39.35 and 64.10 kg of fresh wood in the control and severe pruning groups, respectively (Table 2).

Fig. 2. Experimental site and measured trait parameters in the 'Santa Maria' pear orchard. a, dormant trees; b, marked trees; c, vegetative and floral buds; d, open flowers; e, fruit set.

Table 1. Key phenological stages and corresponding dates for 'Santa Maria' pear in the Sidi Ali Benyoub region

Phase	Phenological stage	BBCH code	Observation date
Winter dormancy	Winter bud	00	20/11/2016
Inflorescence emergence	Bud swelling	51	20/03/2017
	Mouse-ear stage	54	22/03/2017
	Pink bud stage	57	24/03/2017
Flowering	Beginning of flowering	61	25/03/2017
	Full flowering	65	06/04/2017
	Flowers fading	67	10/04/2017
	End of flowering	69	14/04/2017
Fruit development	Fruit set	71	16/04/2017

Table 2. Fresh mass of pruned wood for 'Santa Maria' pear trees in the experimental plot

Pruning treatment	Total mass removed (kg)	Mean per tree (kg) ± SE	Range	Pruning intensity (%)	*df*	*p*
Control	64.10	4.27 ± 0.42	1.75 – 7.30	61.96	19.37	0.002
Severe pruning	39.35	2.62 ± 0.19	1.45 – 4.00	38.04		

This corresponded to mean per-tree values of 2.62 kg for the control and 4.27 kg for the treatment group. Pruning intensity, expressed as the proportion of total wood mass removed, was 38% for the control and 62% for the severe pruning. An independent samples *t*-test confirmed a statistically significant difference between the two pruning intensities ($t = -3.56$, degrees of freedom = 19.37, $p = 0.002$), validating the experimental treatments. These findings establish fresh wood weight as a robust quantitative metric of pruning severity, providing a basis for correlating pruning intensity with subsequent variations in vegetative growth and reproductive parameters.

Effect of pruning on productivity parameters

The results presented in Table 3 reveal minor differences in vegetative bud development among the pruning treatments. Productivity parameters were recorded during the period from 20 March to 16 April 2017.

The average number of vegetative buds (NVB) per tree was 105.4 in the control group and 103.6 in the severely pruned group, with bud counts ranging from 59 to 185 in controls and 92 to 121 in treated trees. Despite a slightly higher mean in controls, the difference was not statistically significant (Mann–Whitney *U* test, $U = 144$, $p = 0.202$), indicating that severe winter pruning did not significantly affect vegetative bud production. This suggests a resilience or compensatory capacity in bud formation under varying pruning intensities.

In contrast, reproductive parameters showed highly significant differences between treatments. Severely pruned trees exhibited a markedly greater mean number of fruit buds (NFB), at 175.7 per tree compared to 81.1 in controls ($t = -12.33$, $df = 19.04$, $p < 0.001$). Similarly, fruit set (NFS) increased substantially from 83.7 in control trees to 207.0 in severely pruned trees ($t = -16.55$, $df = 20.48$, $p < 0.001$). These results demonstrate that severe pruning strongly enhances reproductive development, promoting greater flowering and fruit set in 'Santa Maria' pear trees.

Correlation analysis revealed strong positive relationships among key reproductive traits. The number of fruit buds (NFB) was highly correlated with both the number of open flowers (NOF; $\rho = 0.92$, $p < 0.001$) and fruit set (NFS; $\rho = 0.88$, $p < 0.001$). Similarly, a strong association was observed between NOF and NFS ($\rho = 0.87$, $p < 0.001$), indicating a tightly coordinated progression from bud formation to flowering and fruit development. The fresh mass of pruned wood, serving as a proxy for pruning intensity, demonstrated moderate positive

Table 3. Effect of pruning type on productivity of 'Santa Maria' pear trees. Data represent means per tree ± standard error (SE) with range. The experiment was conducted with 3 replicates, each consisting of 5 individual trees per row, totaling 15 trees per treatment

Variable	Control		Treatment	
	Mean per tree ± SE	Range	Mean per tree ± SE	Range
Vegetative buds	105.40 ± 11.03	59 – 185	103.60 ± 2.16	92 – 121
Flower buds	81.13 ± 7.04	34 – 128	175.73 ± 3.04	150 – 193
Open flowers	224.06 ± 28.84	102 – 375	506.06 ± 6.51	455 – 560
Set fruit	83.67 ± 6.67	47 – 123	207.00 ± 3.31	189 – 235

Table 4. Pearson correlation matrix among vegetative and reproductive parameters in 'Santa Maria' pear trees. NVB, vegetative buds

	Variable	NVB	NFB	NOF	NFS
Pearson correlation	Flower buds (NFB)	0.145			
	Open flowers (NOF)	0.210	0.972		
	Set fruit (NFS)	0.085	0.953	0.951	
	Fruit set rate (FSR)	–0.363	–0.335	–0.387	–0.125
p	Flower buds (NFB)	0.222			
	Open flowers (NOF)	0.132	0.000		
	Set fruit (NFS)	0.327	0.000	0.000	
	Fruit set rate (FSR)	0.024	0.035	0.017	0.255

correlations with NFB ($\rho = 0.54$, $p = 0.002$), NOF ($\rho = 0.51$, $p = 0.004$), and NFS ($\rho = 0.51$, $p = 0.009$), highlighting that increased pruning severity promoted reproductive output. In contrast, the correlation between pruned wood mass and vegetative bud number (NVB) was negligible and non-significant ($\rho = -0.11$, $p = 0.56$), further emphasizing that pruning intensity predominantly influences reproductive rather than vegetative traits.

The multiple linear regression model incorporating NVB, NFB, NOF, and pruning treatment as predictor variables accounted for 96.7% of the variance in fruit set (NFS) ($R^2 = 0.967$, $F(4,25) = 185.75$, $p < 0.001$). This robust model underscores the critical roles of reproductive trait development and pruning intensity in determining fruit set outcome.

Fruit set efficiency, calculated as the percentage of open flowers that developed into fruits (NFS/NOF × 100), was slightly higher in the severely pruned group at 40.9% compared to 37.4% in controls. This indicates that severe winter pruning not only increased the absolute number of flowers and fruits but also marginally improved the conversion rate of flowers to mature fruits. Importantly, these increases remain within species-typical fruit set ranges, suggesting that pruning enhances reproductive efficiency without risking over-cropping or physiological stress.

Together, these results demonstrate that short, severe winter pruning markedly enhances reproductive development in 'Santa Maria' pears by promoting flower bud formation, flowering, and fruit set while maintaining stable vegetative growth.

To explore the relationships among productivity traits in 'Santa Maria' pear trees, Principal component analysis was performed, providing a comprehensive multivariate view of trait variation under contrasting pruning treatments. The correlation matrix (Table 4) showed very strong positive correlations among reproductive traits – floral bud number, open flowers, and fruit set with coefficients exceeding 0.95 ($p < 0.001$), indicating a highly coordinated reproductive developmental response. In contrast, vegetative bud number (NVB) exhibited a moderate negative correlation with fruit set rate ($r = -0.363$, $p = 0.024$), and excessive flowering displayed a similar negative association with fruit set efficiency ($r = -0.387$, $p = 0.017$), reflecting likely internal resource competition that may diminish fruiting success.

Bartlett's test of sphericity ($\chi^2 = 190.25$, $p < 0.001$) confirmed the data's suitability for PCA, ensuring that the correlation matrix was factorable. The Varimax-rotated component matrix (Table 5) identified two principal components accounting collectively for 100% of the explained variance: Component 1 explained 67.3% and was strongly loaded by floral buds (0.977), open flowers (0.966), and fruit set (0.987); Component 2 explained 32.7%, capturing the inverse relationship between vegetative growth (NVB: 0.837) and reproductive efficiency (fruit set rate: –0.799). This two-component solution highlights a key physiological trade-off where increased vegetative vigour may limit the proportion of flowers that successfully develop into fruits.

The variables plot (Fig. 3) vividly illustrates these associations, showing reproductive traits tightly grouped along the first principal component, while vegetative growth and fruit set efficiency oppose each other along the second axis, supporting an antagonistic dynamic. The individuals plot (Fig. 4) reveals a clear and significant separation between control and severely pruned trees, which cluster distinctly along PC1, reflecting the strong impact of pruning intensity on the multivariate phenotype of 'Santa Maria' trees.

Table 5. Rotated component matrix (Varimax with Kaiser normalization)

Variable	Component 1	Component 2
Vegetative buds	0.018	0.837
Flower buds	0.977	0.162
Open flowers	0.966	0.236
Set fruit	0.987	–0.004
Fruit set rate	–0.202	–0.799

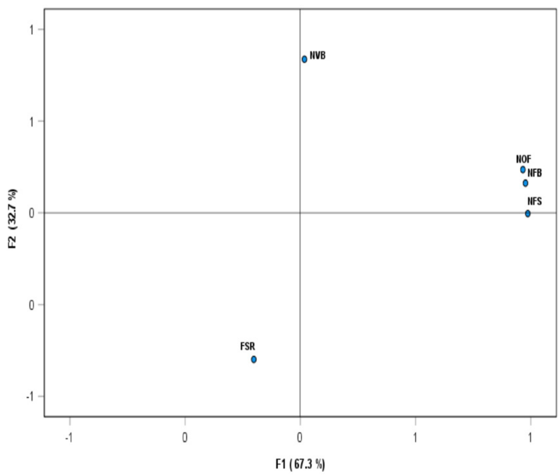

Fig. 3. Principal component analysis of 'Santa Maria' pear trees based on vegetative and reproductive traits (NVB, NBF, NOF, NFS, and FSR).

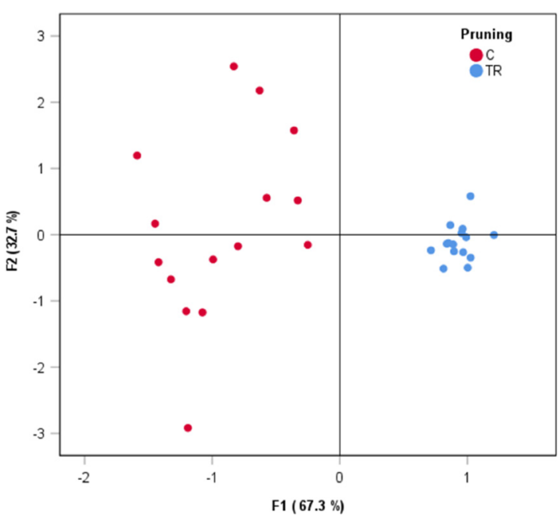

Fig. 4. Two-dimensional biplot analysis of principal components analysis for the relationship between vegetative and reproductive traits and the two pruning treatments (C, control pruning, and TR, severe pruning) in 'Santa Maria' pear trees.

Discussion

Pruning is a key agronomic practice in commercial pear production, aimed at optimizing canopy architecture and enhancing fruit production (Aguiar et al. 2011). Despite its widespread use, quantitative data on how pruning intensity specifically influences the performance of the 'Santa Maria' cultivar remain limited. Our results clearly indicate that severe pruning profoundly affects reproductive development. While vegetative bud counts per tree remained relatively stable (103.6 for severe pruning vs. 105.4 for long pruning), the number of fruit buds, open flowers, and set fruits were dramatically increased under severe pruning. Specifically, severely pruned trees bore more than twice as many fruit buds (175.73 vs. 81.13), more than double open flowers (506.06 vs. 224.06), and substantially more set fruits (207.00 vs. 83.67), confirming pruning severity as a key driver of reproductive resource allocation.

These outcomes are consistent with the well-established physiological principles governing bud differentiation, where the balance of carbohydrates and mineral nutrients during critical phenological phases dictates whether buds develop into vegetative or reproductive structures (Silveira et al. 2017). Severe pruning reduces overall photosynthetic capacity and carbohydrate reserves by removing shoot biomass, triggering reallocation of assimilates towards vigorous regrowth, especially near pruning cuts (Mika 2011). This mechanical disruption alters hormonal balances, particularly among auxins, cytokinins, and gibberellins, facilitating the release of apical dominance and activation of dormant buds (Marini 2009). The timing of pruning further modulates the partitioning of photoassimilates during summer growth phases, with adequate supplies of nitrogen, boron, and potassium during early bud development acting as critical cofactors for floral induction and enhanced flower formation (Jackson 2003; Deckers, Schoofs 2004; Costes et al. 2006). The stimulation of vegetative growth following pruning observed in our study aligns with previous findings across fruit tree species (Jorquera-Fontena et al. 2014; Braham, Amor 2018; Persello et al. 2019; Benzina et al. 2023).

Despite the pronounced differences in reproductive structures, fruit set was only slightly higher in treated trees (40.90%) compared to controls (37.34%). This suggests that post-flowering processes, such as pollination success, fertilization efficiency, and physiological fruit drop, remain critical determinants of final fruit set. Similar findings have been reported in recent studies, which emphasize that even when floral density is increased through pruning or other cultural practices, post-anthesis factors largely govern fruit retention and yield outcomes (Canal et al. 2023; Gomasta et al. 2024). The high variability observed between flower and fruit numbers is likely due to the tree's inherent self-thinning mechanism, which optimizes resource allocation in response to fluctuating environmental conditions and internal competition (Nakamura-Yamaguchi et al. 2020). In pear trees, self-thinning involves the selective abscission of excess flowers and young fruits to balance sink demand and maintain optimal growth and fruit quality (Dussi et al. 2008; Iwanami et al. 2018). This physiological process reflects the tree's ability to regulate its reproductive load, thereby ensuring sustainable development under variable resource availability.

In our study, severely pruned 'Santa Maria' trees produced an average of 506.06 open flowers per tree, which can be classified as "excessive" flowering in the context of resource allocation and fruit set efficiency. By comparison, conventionally pruned trees showed a significantly lower average number of open flowers at 224.06 per tree. Typical open flower counts for 'Santa Maria' under standard management range between 300 and 450 flowers per tree

(Öztürk, Faizi 2023). Other pear cultivars such as 'Williams' and 'Abate Fetel' generally exhibit lower flower numbers, often below 400 flowers per tree under similar conditions (Ikinci et al. 2014; Almeida et al. 2020). Excessive flowering, as observed with severe pruning, may lead to increased competition among developing fruits and reduced fruit set efficiency, consistent with the negative correlation we observed between flower number and fruit set rate.

The negative correlation between the number of open flowers and fruit set rate highlights how excessive flowering can diminish reproductive efficiency. This phenomenon is widely reported and is attributed to competition among flowers and developing fruitlets for limited resources such as carbohydrates, water, and nutrients (Stover 2000; Silveira et al. 2017). When flower production surpasses the tree's capacity, increased flower and fruitlet abscission occurs, reducing the proportion of flowers that develop into mature fruits. Therefore, managing flowering intensity through pruning and other cultural practices is essential to balance flower abundance and optimize fruit set, yield, and quality.

When the floral load exceeds the physiological capacity of the tree, many flowers undergo abscission or fail to develop into fruits, resulting in a reduced fruit set percentage (Jackson 2003). Additionally, an overabundance of flowers can limit effective pollination and fertilization due to reduced pollinator efficiency or internal hormonal regulation (Essenberg 2013). These processes exemplify the biological trade-off between reproductive potential and the allocation of limited resources. Consequently, achieving optimal, not maximum, flowering is critical for ensuring consistent and efficient fruit production (Kumar et al. 2019).

The impact of pruning on tree performance is influenced not only by immediate physiological responses but also by the orchard's pruning history and prevailing environmental conditions. Favourable spring temperatures during the observation period likely promoted both vegetative recovery and reproductive development following winter pruning. Temperature-driven metabolic activity enhances carbohydrate mobilization and hormonal signaling, which are critical for bud break and shoot growth (Fischer, Defilippi 2020). Additionally, cumulative pruning effects modulate tree vigour, with historical pruning intensity shaping recovery dynamics and canopy architecture over time (Rajaona et al. 2011). Effective pruning management must therefore consider these temporal and environmental factors to optimize growth, balance source-sink relationships, and sustain orchard productivity.

The differences in cultivar habit type, rootstocks, and training systems can significantly influence pruning outcomes and productivity traits in pear orchards, including those observed in this study on 'Santa Maria' pears. Cultivar growth habits affect tree architecture and fruiting patterns, which shape pruning needs; for instance, spur-type cultivars may require different pruning intensity than those with vigorous shoot growth. Rootstock choice is crucial, as it influences vegetative vigour, precocity, yield potential, and fruit quality. Quince rootstocks, such as BA29, are commonly used in high-density plantings and help control vigour while promoting early and efficient cropping. Notably, BA29 exhibits superior adaptability to highly calcareous soils under semi-arid climates, making it particularly suitable for 'Santa Maria' grown under such challenging conditions (Ikinci et al. 2014). Training systems also interact with pruning by affecting canopy structure and light interception, which in turn influence flowering and fruit set. High-density systems designed to accelerate cropping and maximize yield require more intensive management practices, including precise pruning and canopy control. These factors collectively underline the importance of integrated selection and management of cultivar, rootstock, and training system to optimize vegetative-reproductive balance and orchard productivity in 'Santa Maria' pears (Ikinci et al. 2014; Öztürk, Faizi 2023).

While our findings indicate that severe pruning had minimal impact on vegetative bud production, it significantly increased the number of fruit buds, flowers, and fruit set, thereby enhancing overall productivity per tree and per hectare compared to conventional long pruning. Importantly, fruit set percentage remained stable, suggesting that the increase in reproductive structures did not compromise fruit initiation or developmental success.

Nevertheless, the long-term application of severe pruning requires caution, as it may provoke trade-offs that affect fruit size, quality, and sustained tree vigour. The outcomes of pruning are modulated by a complex interplay of factors such as pruning timing and severity, cultivar characteristics, rootstock vigour, tree age, training system, and environmental conditions. Different cultivars vary in their sensitivity to pruning intensity, reflecting differences in resource allocation, photosynthetic efficiency, and fruiting habits. Excessive fruiting can lead to smaller fruit size and diminished market value, whereas insufficient fruit set results in yield inefficiency and lost production opportunities.

Literature on the long-term effects of pruning on yield stability and tree health is mixed. Some studies report yield increases following pruning (Avilan et al. 2003), while others find no significant impact (Albarracín et al. 2017), and some note yield reductions potentially related to over-pruning or resource depletion (Oosthuyse 1997). These contrasting outcomes underscore the necessity for long-term, cultivar-specific research to optimize pruning strategies that balance vegetative vigour and reproductive output sustainably.

Conclusions

Practically, these findings suggest that severe winter pruning shifts resource allocation toward reproductive development, enhancing flower bud formation, flowering, and fruit set, while balancing vegetative growth within limits that avoid excessive competition. Such a strategic pruning approach can improve reproductive efficiency and yield without compromising tree health. This multidimensional understanding provides valuable guidance for orchard managers aiming to optimize pruning practices for maximal productivity and sustainable tree performance in intensive pear cultivation systems.

This study demonstrated that severe winter pruning enhances fruit bud formation, flowering, and fruit set in 'Santa Maria' pear trees without reducing fruit set efficiency. These findings highlight the potential benefits of targeted pruning on reproductive traits. However, since this study covered only one season and did not directly measure total yield or fruit quality, further long-term research is needed to validate these effects and develop specific pruning guidelines. Future studies should also consider integrating pruning with nutrient management and flower thinning to better optimize fruit production.

Acknowledgements

The authors would like to express their sincere gratitude to the orchard manager of Sidi Ali Beyoub for his dedicated assistance, support, and facilitation throughout the research activities conducted in the commercial pear orchards.

References

Aguiar E.B., Bicudo S.J., Curcelli F., Figueiredo P.G., Cruz S.C.S. 2011. Pruning dates and productivity of cassava. *Pesqui. Agropecu. Bras*. 46: 1463–1470.

Albarracin V., Hall A.J., Searles P.S., Rousseaux M.C. 2017. Response of vegetative growth and fruit yield to winter and summer mechanical pruning in olive trees. *Sci. Hortic.* 225: 185–194.

Avilan L., Martinez G., Marin R.C., Rodriquez M., Ruiz J., Escalante H. 2003. Square and pyramidal pruning effect on mango production. *Argon. Trop.* 53: 239–257.

Benzina S., Harizia A., Elouissi A., Canelo T., Bonal R. 2023. Effects of winter pruning intensity on the interactions between the apple tree and rosy apple aphid *Dysaphis plantaginea* (Hemiptera: Aphididae). *J. Plant Dis. Protect.* 130: 1239–1250.

Canal D., Escudero F.L.G., Mendes L.A., da Silva Ferreira M.F., Turchetto-Zolet A.C. 2023. Genome-wide identification, expression profile and evolutionary relationships of TPS genes in the neotropical fruit tree species *Psidium cattleyanum. Sci. Rep.* 13: 3930.

Chen X., Bao J., Chen Y., Chen T., Zhang C., Huang X. 2012. Effect of hormone treatments on deformed fruit development in pear. *Afr. J. Biotechnol.* 11: 10207–10209.

Deckers T., Schoofs H. 2004. Growth reduction and flower bud quality on pear trees. *Acta Hortic.* 636: 249–258.

Dussi M. C., Giardina G., Reeb P., Gastiazoro J. 2007. Thinning programs in pears cv. Williams. *Acta Hortic.* 800: 119–130.

Essenberg C.J. 2013. Explaining the effects of floral density on flower visitor species composition. Amer. Nat. 181: 344–356.

FAOSTAT 2022. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat

Gomasta J., Sarker B.C., Haque M.A., Anwari A., Mondal S., Uddin M.S. 2024. Pruning techniques affect flowering, fruiting, yield and fruit biochemical traits in guava under transitory subtropical conditions. *Heliyon* 10: e03810.

Ikinci A., Bolat I., Ercisli S., & Kodad O. 2014. Influence of rootstocks on growth, yield, fruit quality and leaf mineral element contents of pear cv. 'Santa Maria' in semi-arid conditions. *Biol. Res.* 47: 71.

Iwanami H., Moriya-Tanaka Y., Honda C., Hanada T., Wada M. 2018. A model for representing the relationships among crop load, timing of thinning, flower bud formation, and fruit weight in apples. *Sci. Hortic.* 242: 181–187.

Jackson J.E. 2003. *Biology of Apples and Pears.* Cambridge University Press, Cambridge.

Jonkers H. 1979. Biennial bearing in apple and pear: A literature survey. *Sci. Hortic.* 11: 303–317.

Küçüker E., Ağlar E. 2021. The effect of the different training systems on yield and vegetative growth of "Santa Maria" and "Deveci" pear cultivars. *J. Agric. Sci.* 31: 870–875.

Kumar R., Saroj P. L., & Sharma B.D. 2019. Flower regulation in pomegranate for higher yield, improved quality and enhanced management – a review. *Fruits* 74: 150–166.

Ladaniya M.S., Marathe R.A., Murkute A.A., Huchche A.D., Das A.K., George A., Kolwadkar J. 2021. Response of Nagpur mandarin (*Citrus reticulata* Blanco) to high-density planting systems. *Sci. Rep.* 11: 10845.

Marini R.P. 2009. *Physiology of Pruning Fruit Trees.* Virginia Cooperative Extension, Virginia Tech, Petersburg, Virginia.

Meier U. 2001. Growth stages of mono- and dicotyledonous plants. BBCH Monograph. Federal Biological Research Centre for Agriculture and Forestry.

Mika A. 2011. Physiological responses of fruit trees to pruning. *Hortic. Rev.* 8: 337–378.

Nakamura-Yamaguchi A., Kitahata N., Nishitani C., Takada N., Terakami S., Sawamura Y., Matsuyama T., Asami T., Nakano T., Saito T., Yamamoto T. 2020. Pattern and trigger of fruit self-thinning in Japanese pears. *Hortic. J.* 89: 367–374.

Oosthuyse S. 1994. Pruning of 'Sensation' mango trees to maintain their size and effect uniform and later flowering. *South African Mango Growers Association Yearbook* 14: 1–6.

Ozturk A., Faizi Z.A. 2023. Comparative evaluation of pear performances under high- and low-density planting systems cv. 'Santa Maria'. *Erwerbs-Obstbau* 65: 667–675.

Persello S., Grechi I., Boudon F., Normand F. 2019. Nature abhors a vacuum: Deciphering the vegetative reaction of the mango tree to pruning. *Eur. J. Agron.* 104: 85–96.

Rajaona A. M., Brueck H., Asch F. 2011. Effect of pruning history on growth and dry mass partitioning of jatropha on a plantation site in Madagascar. *Biomass Bioenergy* 35: 4892–4900.

Sansavini S. 2000. Pear fruiting-branch models related to yield control and pruning. *Acta Hortic.* 596: 627–633.

Silveira F. N., Kretzschmar A. A., Machado B. D., Corrêa D., Rufato L. 2017. Vegetative development of European pear with quince and different application forms of nutrients. *Rev. Brasil. Fruticult.* 39: e-594.

Stover E. 2000. Relationship of flowering intensity and cropping in fruit species. *HortTechnology* 10: 729–732.

Received 26 July 2025; received in revised form 18 September 2025; accepted 22 September 2025