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The Effects of Different Winter Pruning Intensities on The Proportion of Fruiting Branches and Fruit Quality of Kiwifruit

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Abstract Kiwifruit is an important economic fruit tree in China. Reasonable winter pruning is a key measure to achieve high yield and good quality of kiwifruit. This paper conducted a systematic study on the effects of different winter pruning intensities (light pruning, moderate pruning, and heavy pruning)on the tree structure and fruiting performance of kiwifruit. The results showed that the intensity of winter pruning directly affects the formation of fruiting branches and fruit quality of kiwifruit: as the pruning intensity increases, the number of fruiting branches and their proportion in the new shoots decrease, but the fruiting branches per plant are more robust; under heavy pruning treatment, the single fruit quality and soluble solid content of the fruit significantly increase, and the appearance and intrinsic quality of the fruit are optimized, but the number of fruiting branches per plant and total yield decrease; light pruning treatment increases the number of fruiting branches and fruits, increases the initial yield, but causes problems such as smaller fruits and reduced sugar content, resulting in a decline in quality. Moderate pruning at an appropriate level can maintain a high yield while also taking into account fruit quality, achieving a coordinated balance between yield and quality. The research provides a scientific basis for optimizing the intensity of winter pruning in kiwifruit orchards and is of great significance to the quality and economic benefits of kiwifruit products in the industry.

Keywords Kiwifruit; Winter pruning; Pruning intensity; Resulting branches; Fruit quality

1 Introduction

Kiwifruit (scientific name: Actinidia chinensis)originated from China. To be precise, the reason why this fruit has spread to so many countries around the world is largely due to its delicious taste and high nutritional content (Shu et al., 2023). Currently, in major kiwi-producing areas in China, such as Shaanxi and Sichuan, the planting scale is considerable, and their area and output have ranked among the top in the world (Gao et al., 2022). However, a large production does not necessarily mean good quality. Especially in recent years, people have placed greater emphasis on quality. Whether the planting is good or not, and whether the pruning is done properly, the differences become immediately apparent. Especially in pruning, it's not just a matter of how much to prune; it directly affects the structure of the tree, the number of fruits produced, and the shape of the fruits (Medič et al., 2021; Patiyal et al., 2024). Some orchards, because they are reluctant to prune or do it carelessly, not only have messy tree crowns but also produce small fruits, with low yields and difficult to sell at good prices. Therefore, whether to prune in winter and how to do it actually lays the foundation for the next year's harvest.

Winter pruning is an important management measure for kiwifruit during the dormant period (Angami et al., 2022). By removing overly dense, diseased, pest-infested, and weak branches, as well as shortening overlong branches, it regulates the structure of the tree and balances growth and fruiting (Zhang et al., 2018). Winter pruning improves the ventilation and light penetration conditions of the tree crown, promotes the renewal of inner branches and the balanced distribution of nutrients, and directly affects the number, distribution, and bud and flower emergence of the next year's fruiting branches (Angami et al., 2022). Moderate winter pruning can make the tree structure reasonable, distribute the fruiting branches and nutrient branches evenly, ensuring there are sufficient healthy fruiting branches for the next year while avoiding excessive tree vigor that leads to nutrient waste (Bound, 2022). Different pruning intensities have different effects on tree vigor regulation: heavy pruning stimulates the emergence of dormant buds and the renewal of new shoots, which is conducive to the regression of

fruiting sites; light pruning, due to the retention of more branch and bud nodes, causes the fruiting sites to gradually move outward, and the tree is prone to weakening due to excessive load (Bound, 2022). Therefore, winter pruning plays an important role in balancing the structure of kiwifruit trees and regulating their fruiting habits.

Currently, the intensity of winter pruning in production is mostly determined based on experience, which may lead to two extreme situations: overly heavy pruning results in insufficient fruiting branches and reduced yield, while overly light pruning causes dense branches and leaves and poor fruit quality. Exploring the effects of different winter pruning intensities on the formation of fruiting branches and fruit quality of kiwifruit is of great significance. On one hand, it can clarify the physiological mechanism by which pruning intensity affects fruiting habits and fruit development, providing a basis for scientific pruning; on the other hand, by comparing the changes in yield and quality under different intensities, it can guide fruit farmers to select appropriate pruning levels (Patiyal et al., 2024). Therefore, this study sets up different winter pruning intensity treatments to evaluate their effects on the proportion of fruiting branches, fruit quality, and yield stability of kiwifruit, and selects the optimized pruning strategy to achieve coordinated improvement of yield and quality in kiwifruit orchards.

2 Research on Winter Pruning Techniques for Kiwifruit at Home and Abroad

2.1 Research progress on winter pruning techniques of kiwifruit in domestic and foreign countries

Countries that are major producers of kiwifruit, such as New Zealand and Italy, have established relatively complete winter pruning systems (Patterson et al., 2011). For instance, New Zealand uses "T"-shaped trellises and other pruning methods, and through winter pruning, it controls the number of buds per plant to balance yield and quality; research in Italy also indicates that moderate pruning can increase the fruit commercial rate and dry matter content (Figure 1) (Shu et al., 2023).

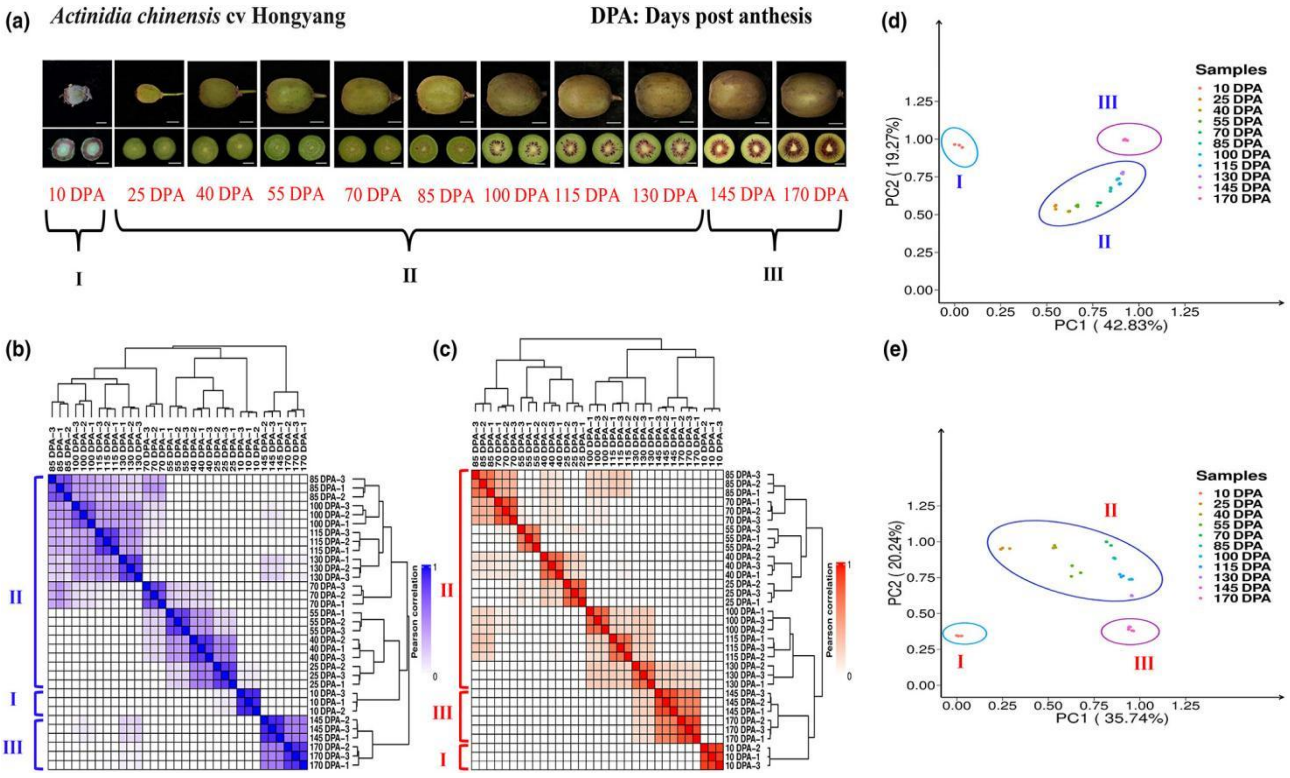

Figure 1 Summary of metabolome and transcriptome data sets. (a) Phenotypic changes in kiwifruits (*Actinidia chinensis* cv Hongyang) at 11 different fruit developmental and ripening stages (FDRSs). Intact and sectioned kiwifruits were photographed at 10, 25, 40, 55, 70, 85, 100, 115, 130, 145, and 170 d postanthesis (DPA). Bar, 1 cm. (b, c) Cluster analysis for metabolomes (b) and transcriptomes (c). The color scales 0-1 represent Pearson correlation coefficient. (d, e) Principal component analysis for metabolomes (d) and transcriptomes (e). Kiwifruits at the 11 FDRSs can be categorized into three major Groups I, II, and III based on purple, green, or yellow phenotypes in pericarps (a), metabolomes (b, d), and transcriptomes (c, e) (Adopted from Shu et al., 2023)

In China, although the development of kiwifruit industry is relatively late, winter pruning technology research has gradually deepened in recent years. Many experiments have compared the effects of heavy pruning and light pruning on the sprouting, flowering, and yield of kiwifruit, and proposed corresponding pruning parameter suggestions. Overall, both domestic and foreign countries recognize the important role of winter pruning in kiwifruit yield and quality, but the optimal pruning patterns for different varieties and ecological conditions still need further exploration (Patiyal et al., 2024).

2.2 The mechanism of the effect of pruning intensity on the formation of fruiting branches of fruit trees

Pruning intensity regulates the distribution of vegetative growth and reproductive growth by influencing the germination of buds and the growth of new shoots (Schupp et al., 2017). Heavy pruning removes a large number of buds and shoots, concentrating nutrients on the remaining few buds, resulting in a high germination rate and robust shoots for the following spring, but a decrease in the total number of fruiting branches (Al-Saif et al., 2023). At the same time, heavy pruning weakens the apical dominance, stimulating the germination of hidden buds at the lower part, and accelerating the renewal of new shoots (Suchocka et al., 2021). Light pruning retains a large number of buds and shoots, distributing the nutrients and hormones of the tree body, and each bud receives limited resources, leading to a decrease in the germination rate and growth vigor of the shoots. Although the total number of new shoots increases, many of them are weak, and the quality of the fruiting branches is not high. Additionally, the large retention of top buds makes the apical dominance still prominent, and some lower buds are inhibited and unable to germinate (Tosto et al., 2023). Thus, heavy pruning tends to form fewer but stronger fruiting branches, while light pruning produces more but weaker fruiting branches. Different pruning intensities largely determine the differences in the number and quality of fruiting branches in the following year.

2.3 Research status and limitations of the relationship between pruning measures and fruit quality

Studies have shown that the fruit load and tree crown structure have a significant impact on fruit quality (Bacelar et al., 2024). Moderate winter pruning of kiwifruit improves the ventilation and light penetration of the tree crown, enhances photosynthetic efficiency and leaf-to-fruit ratio, allowing each fruit to obtain more nutrients, thereby increasing the weight of each fruit and the content of soluble solids (Liao et al., 2020; Patiyal et al., 2024). On the contrary, insufficient pruning leads to excessive fruiting, resulting in insufficient nutrition for each fruit, often causing problems such as smaller fruits, reduced sugar content, and delayed maturity, which leads to a decline in quality (Al-Saif et al., 2023). Many experiments have qualitatively described the effects of different pruning methods on the appearance and internal quality of fruits, such as heavy pruning can increase the sugar content and vitamin C content of the fruits (Shashi et al., 2022). However, the underlying mechanism by which pruning intensity affects fruit quality is still unclear, and the interactive effects of pruning and quality under different ecological conditions have not been systematically studied. At the same time, most studies are limited to data from a single year and ignore the influence of interannual climate and tree vigor changes. In the future, long-term multi-factor experiments combined with physiological index analysis are needed to comprehensively reveal the relationship between pruning measures and fruit quality, providing scientific basis for optimizing kiwifruit pruning regulation.

3 Experimental Materials and Research Methods

3.1 Overview of the Experimental Area and Test Kiwifruit Varieties

This experiment was conducted in a standardized kiwifruit orchard in Zhouzhi, Shaanxi Province. The climate is temperate continental, the soil is mainly loam with good fertility and a thick underground layer. The orchard planted 'Hayward', a relatively common variety of green-fleshed kiwifruit. All the trees used in the experiment were female, 8 years old, in their peak fruiting stage, and growing relatively uniformly. The orchard used T-shaped trellises, with a plant spacing of 3 meters × 4 meters. To make the experiment more comparable, the selected plants underwent uniform fertilizer and water management and pest and disease treatment the previous autumn, ensuring that everyone started at a similar level. Finally, several trees with similar growth were selected and randomly divided into several treatment groups according to the plan.

3.2 Winter pruning intensity treatment settings and experimental design

The winter pruning is carried out during the dormant period after fruit harvest. The severity of pruning is

determined based on the number of remaining branches, and it is divided into three groups: heavy pruning, medium pruning, and light pruning (Holz et al., 2025). For the heavy pruning group, each tree is left with about 6 main fruiting branches, with a total bud count of approximately 30; for the medium pruning group, it is slightly more relaxed, with 10 main branches and about 50 buds (Özkul et al., 2022; Barcia et al., 2023); for the light pruning group, each tree has more than 15 main branches, with about 80 bud points. There is a significant difference in the number of remaining branches among the three treatments. The experiment adopts a random block design, with 3 replicates for each treatment, and each replicate selects 5 consecutive trees (Santos et al., 2023). The pruning is carried out by the same group of technicians to avoid deviations caused by human differences. Apart from pruning, other field management such as water and fertilizer supply, pest and disease control, etc. are kept uniform to minimize the complexity and ambiguity of influencing factors.

3.3 Data collection indicators and statistical analysis methods

As the next long season arrived, the recording work began. We counted the number of each type of emerging fruiting branches and nutrient branches on each plant, calculated the proportion to reflect which part was more dominant, and also observed how these branches were distributed within the tree crown (Anderson et al., 2021). Regarding yield, we checked how many fruits each plant produced, the total yield, and the average weight of each fruit (Mota et al., 2022). As for the quality of the fruits, it was not overlooked either: externally, we mainly checked if the size and shape were regular, and internally, we measured the sugar content, acidity, and vitamin C content (Balık et al., 2023). All these indicators were measured using conventional methods for fruit tree quality. After obtaining the data, we used one-way analysis of variance to make comparisons. Whether the differences between groups were significant was determined by the subsequent LSD method, and the statistical significance level was set at 0.05.

4 Effects of Different Winter Pruning Intensities on the Proportion of Resulting Branches

4.1 Effects of winter pruning intensity on the number and distribution of resulting branches

The intensity of winter pruning significantly affects the number and spatial distribution of fruiting branches in kiwifruit (Angami et al., 2022; Patiyal et al., 2024). The heavy pruning treatment, which only retains a small number of fruiting mother branches, results in a significant reduction in the number of resulting branches per plant the following year, which is significantly less than that of the light pruning treatment. The resulting branches of the heavy pruning plants are mainly concentrated in the lower and middle parts of the main vine, which have better light conditions and form a uniform distribution with strong branches, and are less likely to have overlapping. The resulting branch number and distribution of the medium pruning treatment are between the two. The number of resulting branches is moderate, and they are distributed in all parts of the tree crown. The light pruning treatment retains the most bud sprouts, and the number of resulting branches per plant is the highest, but the distribution is uneven: a large number of resulting branches are concentrated in the upper outer part of the tree crown, while many weak resulting branches also grow in the inner and lower parts, resulting in messy foliage, local congestion, and shading of branches from each other, which is not conducive to the uniform growth of fruits (Tosto et al., 2023). It can be seen that as the pruning intensity changes from heavy to light, the number of resulting branches increases but the uniformity of distribution decreases.

4.2 Relationship between winter pruning intensity and proportion of nutritive branches and resulting branches

Different winter pruning intensities directly affect the proportion of resulting branches and nutritive branches in the new shoots of the current year, reflecting the balance between reproductive growth and nutritional growth (Bevacqua et al., 2021). Heavy pruning treatments retain fewer bud numbers, and although the newly emerged shoots are mostly thick branches, many of them are non-resulting nutritive branches, resulting in a relatively low proportion of resulting branches. This presents a characteristic of "few but strong" branches. Light pruning treatments retain a large number of bud numbers, and the number of newly emerged shoots increases significantly. The proportion of branches bearing flower buds and resulting in fruits also increases. The proportion of resulting branches is significantly higher than that of heavy pruning, presenting a characteristic of "many but fine" branches. Moderate pruning treatments result in a proportion of resulting branches between the two extremes. The number

of nutritive branches and resulting branches is relatively balanced, with approximately half of the new shoots being resulting branches. A low proportion of resulting branches (heavy pruning) means insufficient fruit load, although the single fruit quality is high, the yield potential is not fully exerted. A high proportion of resulting branches (light pruning)indicates that the tree is over-fruiting, and the nutrients allocated to each single fruit are reduced, affecting fruit development (Al-Saif et al., 2023). Therefore, an appropriate pruning intensity should maintain the resulting branch proportion at a moderate level to balance tree growth and fruiting, ensuring stable and high-quality yield.

4.3 Analysis of the differences in result branch formation under different pruning treatments

The result branches formed by different winter pruning treatments show a relationship of mutual increase and decrease in quantity and quality (Khokhar et al., 2020). The result branches formed by heavy pruning have a smaller quantity but due to the concentration of nutrients, each branch is relatively thick, has large leaves, and has strong photosynthetic capacity, and the quality of the flower buds formed that year is also higher (Al-Saif et al., 2023). The result branches formed by light pruning have a larger quantity, but each branch receives limited nutrients. They tend to be slender and weak, with smaller leaves. These weak branches often bear more fruits, but due to insufficient assimilation supply, they are prone to poor fruit development or early fruit drop. The result branches formed by medium pruning have an appropriate quantity and growth vigor, without excessive vigorous shoots or widespread thin and weak branches. The difference in pruning intensity also affects the renewal of the result site: heavy pruning promotes the replacement of old branches by new ones, and the result site shows a tendency to contract; light pruning relies more on the original result branch group to continue fruiting, and the result site gradually moves outward (Suchocka et al., 2021). Thus, it can be seen that the pruning intensity should be balanced according to the production goals, and an appropriate intensity should be selected to balance the quantity and quality of the result branches.

5 Effects of Different Winter Pruning Intensities on Fruit Quality

5.1 Effects on fruit appearance quality

The size and appearance of the fruits are closely related to the extent of pruning (Benzina et al., 2023). In the case of heavy pruning, the fruits generally appear larger, not only in terms of weight but also in terms of their more regular shape. It's not that there are any special techniques involved; it's simply because there are fewer fruits, resulting in more nutrients being distributed, and thus the fruits naturally become plump (Al-Saif et al., 2023). In the case of light pruning, the situation is somewhat different. Although there are more fruits, the tree has limited resources, so each fruit receives less, and the proportion of small fruits immediately increases. Additionally, the tree crown is too dense, and the light is poor, causing some fruits to have uneven colors (Zhen et al., 2025). Moderate pruning neither too light nor too heavy, the fruits perform relatively normally, with better single fruit weight and fruit shape compared to light pruning. In other words, pruning too lightly actually affects the quality of the commercial fruits. Heavy pruning results in fewer fruits, but the fruits do look more "attractive".

5.2 Effects on the intrinsic quality of fruits (soluble solids, titratable acid, etc.)

The different intensities of winter pruning result in variations in the leaf-to-fruit ratio, thereby affecting the intrinsic quality of the fruits (Rathod et al., 2020; Makwana et al., 2024). The heavy pruning treatment has a higher leaf-to-fruit ratio, and each fruit accumulates more photosynthetic products, leading to a significant increase in its soluble solids (sugar)content, which is approximately 1-2 percentage points higher than that of the light pruning treatment on average. The fruits are sweeter. The titratable acid content of the heavily pruned fruits is slightly lower than that of the light pruning treatment, and the sugar-acid ratio is higher, resulting in a better flavor. This is because heavy pruning reduces the load, allowing the fruits to mature more fully. More acid is consumed while more sugar accumulates (Figure 2) (Patiyal et al., 2024). On the other hand, the light pruning treatment has too many fruits, and some of the fruits are not fully ripe, resulting in lower sugar content and higher acid content, and a less flavorful taste. The vitamin C content of the heavily pruned fruits is also slightly higher than that of the light pruning fruits, which may be related to improved maturity and light conditions (Al-Saif et al., 2023). In general, a moderate to heavy winter pruning intensity is beneficial for enhancing the intrinsic quality of kiwifruit fruits (increasing sugar content and improving flavor), while too light pruning reduces the soluble solids content and quality of the fruits due to excessive load.

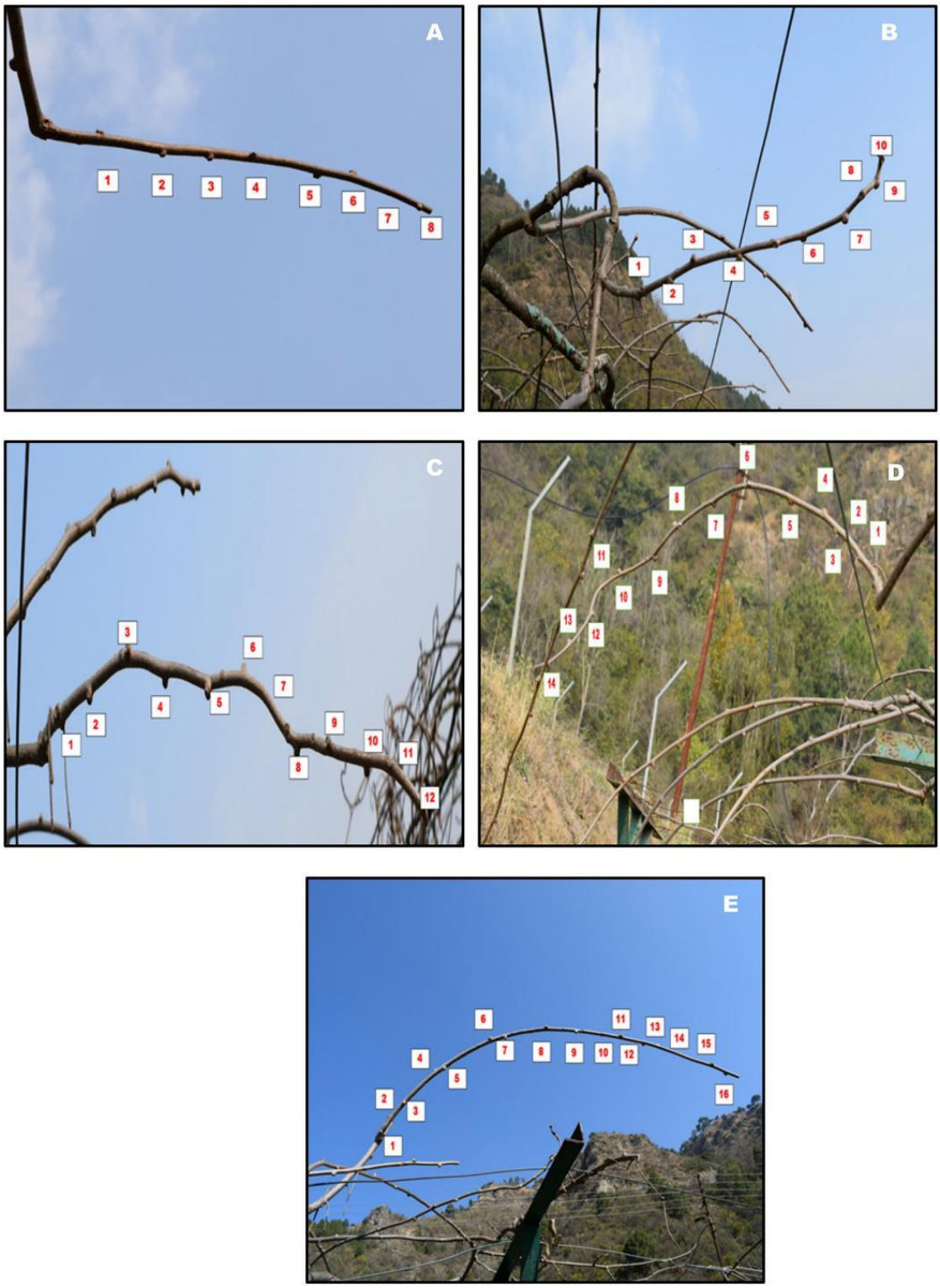

Figure 2 Different cane pruning levels; A: Pruning up to 8 nodes; B: Pruning up to 10 nodes C: Pruning up to 12 nodes; D: Pruning up to 14 nodes; E: Pruning up to 16 nodes (Adopted from Patiyal et al., 2024)

5.3 Comprehensive evaluation and analysis of winter pruning intensity and fruit quality

The overall fruit quality under different winter pruning intensities was comprehensively evaluated. The heavy pruning treatment resulted in the best overall fruit quality, with large and uniform fruits and high sugar content; the light pruning treatment had the poorest quality, with a high proportion of small fruits and low sugar content; the medium pruning treatment was in the middle. Although heavy pruning reduced the yield, it increased the proportion of high-quality fruits, and the economic benefits were not necessarily reduced (Fallahi et al., 2002);

light pruning had a high yield but a low proportion of high-quality fruits, and its commercial competitiveness was affected; medium pruning achieved a better balance between yield and quality (Robinson et al., 2006). The comprehensive quality scoring results also showed that the heavy pruning treatment had the highest score, followed by the medium pruning, and the light pruning had the lowest score, which was consistent with the trends of each individual indicator. This indicates that increasing the winter pruning intensity generally benefits the improvement of fruit quality, but it needs to be weighed and chosen based on the yield requirements. In actual production, if the target market is for high-end fresh sales, a focus on pruning for high-quality fruits can be prioritized; if more emphasis is placed on yield or processing, a slightly lighter pruning can be adopted, but it is necessary to prevent excessive decline in quality that may affect the income.

6 Comprehensive Analysis of the Coordination between Winter Pruning Intensity and Yield and Quality

6.1 Impact of winter pruning intensity on per-plant yield and stable yielding capacity

The intensity of winter pruning directly affects the number of fruits produced by each plant in the following year, thereby determining the per-plant yield. Light pruning results in the most buds remaining, and the highest number of per-plant set fruits and yield in the current year; heavy pruning results in the fewest buds remaining, and the lowest per-plant yield; moderate pruning is in the middle. However, high yield often contradicts stable yield. Light pruning causes the tree to be overburdened, resulting in high yield in the current year but possibly depleting the tree's vigor, leading to poor flower bud differentiation and easy reduction in yield in the following year or even the occurrence of alternate years (Robinson et al., 2006). Continuous light pruning with high load will cause insufficient nutrient accumulation in the plant and reduced adaptability, resulting in more significant yield fluctuations under unfavorable climatic conditions. Heavy pruning, due to the low load, allows the tree to have more nutrients for its own growth and storage, enabling the plant to recover its growth vigor and produce high-quality flower buds in the following year, reducing the likelihood of alternate years and achieving more stable yield. Moderate pruning has an appropriate per-plant fruit load, does not severely weaken the tree's vigor, and thus has smaller fluctuations in yield between years. Overall, light pruning can achieve short-term high yield but poor stable yield; heavy pruning leads to reduced yield in the current year but is beneficial for the plant to accumulate nutrients and achieve long-term stable yield; moderate pruning achieves a balance between yield and stable yield. Therefore, when formulating pruning plans, one should weigh immediate yield and long-term stable yield, and choose an appropriate pruning intensity based on production goals.

6.2 Analysis of the relationship between result branch ratio and fruit quality

The result branch ratio is a key indicator that links the intensity of winter pruning and fruit quality . Generally speaking, an excessively high result branch ratio indicates that the tree is overburdened with fruit, resulting in reduced nutrient allocation to individual fruits and a decline in fruit quality; conversely, an excessively low result branch ratio suggests a lack of fruit production, although the quality of individual fruits is high, the total yield is insufficient (Costa et al., 2004). The correlation analysis in this study indicates that indicators such as the average weight of a single fruit and the soluble solids content of kiwifruit are significantly negatively correlated with the result branch ratio: when the result branch ratio increases from approximately 50% to above 70%, the average weight of a single fruit and sugar content of the fruit significantly decrease (Richardson et al., 2004). On the contrary, when the result branch ratio is controlled at around 50%, the fruit quality and yield achieve a better balance (Fallahi et al., 2002). Based on this, it can be speculated that there is an appropriate range of result branch ratio (approximately 50%)in a kiwifruit orchard, within which both high fruit quality and a certain yield can be achieved. Once the result branch ratio is too high, fruit quality will rapidly decline; if it is too low, the yield potential of the orchard will not be fully exploited. In production, by adjusting the intensity of winter pruning and pruning flowers and fruits, the result branch ratio can be maintained within a reasonable range to achieve coordinated development of fruit quality and yield.

6.3 Evaluation of appropriate winter pruning intensity and optimization suggestions

Based on the above analysis, the suitability of different winter pruning intensities can be evaluated and optimization suggestions can be proposed (Robinson et al., 2006). Heavy pruning focuses on improving fruit

quality and is suitable for orchards aiming for high-quality fruits. A certain reduction in yield can be accepted in exchange for high quality. In this case, a high pruning intensity is a reasonable choice. However, to avoid excessive heavy pruning that weakens yield, in production, summer pruning and reasonable fertilization can be supplemented to increase the productivity of individual leaves, thereby compensating for the shortage of fruit quantity (Costa et al., 2004). Light pruning treatment has a high short-term yield, but from the perspectives of fruit quality and tree health, it is not advisable. Unless in specific circumstances before variety renewal, a pursuit of temporary high yield is needed, conventional production does not recommend long-term use of light pruning and should gradually transition to a stronger pruning mode. Moderate pruning treatment is suitable for most commercial orchards and is a reliable strategy for balancing yield and quality (Fallahi et al., 2002). During implementation of moderate pruning, the intensity can be appropriately adjusted according to the tree vigor: plants with extremely vigorous growth can be slightly more heavily pruned to control growth, while plants with weaker growth can be pruned slightly less to maintain branches, thus achieving tailoring to the tree. Different regions and varieties should optimize the winter pruning intensity strategy based on actual conditions. In summary, determining the winter pruning intensity should follow the principle of moderate balance, preventing excessive fruit production that leads to quality decline, and avoiding excessive pruning that wastes production capacity, in order to achieve the coordinated unity of yield and quality in the kiwifruit orchard.

7 Case Study: Analysis of the Application Effects of Different Winter Pruning Methods in a Typical Orchard

7.1 Basic information of the case orchard and implementation plan of winter pruning techniques

This study selected a kiwifruit orchard in Zhouzhi County, Shaanxi Province for case analysis (Richardson et al., 2004). In the previous few years, this orchard had been using a relatively mild winter pruning method, although the yield was high, the fruit size was inconsistent, and the improvement in quality was limited (Fallahi et al., 2002). In the winter of 2024, under the guidance of technicians, the orchard divided into two winter pruning methods for comparison: one maintained the traditional mild pruning (each tree retained approximately 15 result mother branches, with light shortening), and the other implemented enhanced heavy pruning (each tree selected approximately 10 thick result mother branches, and all other branches were pruned or heavily shortened, with each mother branch retaining only 2-3 buds). Both schemes strictly bent and tied the branches to ensure uniform distribution of the result mother branches. The winter pruning operations were completed strictly according to the plan, laying the foundation for the following spring bud emergence and subsequent observations (Robinson et al., 2006).

7.2 Proportion of resulting branches and fruit quality under different winter pruning intensities

In the following spring and summer, we compared the proportion of resulting branches, yield, and fruit quality in the two pruning treatment areas (Robinson et al., 2006). The results showed that in the heavy pruning area, the number of new shoots per plant was approximately one-third less than that in the light pruning area, and the proportion of resulting branches was about 45%. In the light pruning area, the proportion of resulting branches was as high as approximately 70% (Fallahi et al., 2002). During the fruit growth process in the heavy pruning area, due to good ventilation and light penetration in the tree canopy, the fruits grew fully and were generally larger in size; in the light pruning area, the dense foliage led to shading for the inner fruits, resulting in smaller single fruits. During harvest, the average single fruit weight and sugar content of the heavy pruning area were significantly higher than those of the light pruning area, and the single fruit weight and soluble solids content were significantly increased, with better fruit flavor. The proportion of fruits meeting the standard of commercial grade (large fruits, high sugar content)in the heavy pruning area was approximately 85%, much higher than 60% in the light pruning area. Due to the large number of fruits, the single yield per plant in the light pruning area was about 25% higher than that in the heavy pruning area. However, the heavy pruning area achieved the same or even slightly higher per-plot output value compared to the light pruning area due to the higher quality of its fruits (Costa et al., 2004). This case confirmed the aforementioned experimental rule: increasing the intensity of winter pruning would reduce the number of single fruits per plant, but significantly improve fruit quality, and achieve compensation in economic benefits.

7.3 Insights and promoting value of case analysis for production practice

The above cases provide significant insights for production practice (Robinson et al., 2006). Firstly, moderately increasing the intensity of winter pruning can indeed significantly improve fruit quality, correcting the previous problem of solely pursuing yield while neglecting quality. It reminds fruit farmers to change their mindset and pay more attention to fruit quality and economic benefits. Secondly, the case demonstrates that through on-site comparison and demonstration, fruit farmers' concerns about reduced yield due to heavy pruning can be eliminated: as long as the supporting management is in place, the reduced yield from heavy pruning can be compensated for and even exceeded by the higher prices brought about by improved fruit quality (Costa et al., 2004). Therefore, in areas with the necessary conditions, similar pruning models can be demonstrated to allow more fruit farmers to see the benefits of high-quality fruits and increase their enthusiasm for adopting scientific pruning. Additionally, the case emphasizes the meticulous management of "tree-specific pruning": for plants with excessive vigor, the pruning intensity should be increased to control growth; conversely, for plants with weak vigor, light pruning should be carried out to retain fruiting branches. Such categorized measures can achieve balanced and stable production throughout the orchard. Through the publicity and training of agricultural technology promotion departments, this proven winter pruning model can be widely promoted within a larger scope, thereby improving the standardized management level of kiwifruit production.

8 Conclusions and Outlook

Through the comparison of different winter pruning intensities, the following main conclusions were obtained, The intensity of winter pruning significantly affects the number and proportion of fruiting branches of kiwifruit. Heavy pruning results in fewer fruiting branches but with thicker branches, and a low proportion of fruiting branches; light pruning results in more fruiting branches but with some branches being thin and weak, and a high proportion of fruiting branches; moderate pruning results in an appropriate number and proportion of fruiting branches, with balanced distribution of branches. The intensity of winter pruning affects fruit quality by regulating the load. Heavy pruning increases the weight of individual fruits and the content of soluble solids, reduces fruit acidity, and significantly improves the appearance and intrinsic quality of the fruits; light pruning reduces the weight of individual fruits, decreases sugar content, and has poor quality; moderate pruning results in fruit quality between the two extremes. The intensity of winter pruning has an inverse relationship with yield. Heavy pruning reduces the yield of individual plants in the current year, but is beneficial for restoring tree vigor and improving subsequent stable yield; light pruning leads to significant increase in yield in the current season, but is prone to causing tree decline and uneven results in successive years; moderate pruning can achieve a higher and stable yield, achieving a balance between yield and quality.

Based on the results of this study, the following application suggestions for winter pruning intensity are proposed in production practice: For commercial orchards, a moderate intensity of winter pruning is recommended to simultaneously achieve high yield and good quality. For orchards targeting the high-end fresh market, a focus on pruning for high quality can be adopted; if more emphasis is placed on yield or processing, a slightly lighter pruning can be applied while prioritizing total yield, but it is necessary to prevent excessive decline in quality that may affect profits. For orchards with weak tree vigor or insufficient yield, a slightly lighter pruning can be retain more fruiting buds and increase the fruiting volume in the next year， but it must be accompanied by flower and fruit thinning to avoid a decline in fruit quality due to excessive fruiting. In summary， the intensity of winter pruning should be flexibly adjusted according to the tree vigor， variety， and cultivation goals， and tailored to the specific tree to achieve the best balance between kiwifruit yield and quality while ensuring the health of the tree.

Although this research has made certain progress, there are still some shortcomings that require further investigation. Firstly, the trial period is only one year, lacking assessment of the long-term cumulative effects of different winter pruning intensities (such as on tree vigor and the changes in annual yield over multiple years). Future studies should conduct multi-year and multi-site continuous trials to observe the long-term responses of kiwifruit tree growth and yield quality under different pruning strategies. Secondly, this research mainly focuses on yield and conventional quality indicators, lacking in-depth analysis of the impact of pruning intensity on the

deep qualities of fruits (such as aroma substances, nutritional components) and internal physiological mechanisms (such as carbohydrate distribution, changes in endogenous hormones, etc.). Subsequent research can strengthen the measurement of these aspects to reveal a clearer causal relationship between pruning measures and fruit quality and tree physiology. Moreover, with the development of orchard management technologies, future studies can explore the use of sensor monitoring, big data analysis, and artificial intelligence technologies to optimize winter pruning decisions. For example, applying machine vision to assess the density of tree crown branches and leaves to assist in judging the pruning intensity, or developing kiwifruit winter pruning robots to improve the accuracy and efficiency of pruning. In conclusion, more in-depth and systematic research is needed to address these shortcomings, providing more scientific and comprehensive theoretical guidance for winter pruning management of kiwifruit, and promoting the kiwifruit industry towards a direction of high quality, efficiency, and sustainability.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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