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# The Influence of Different Cultivation Slope Aspects of Loquat on the Risk of Frost Damage During the Flowering Period and the Stability of Yield

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**Abstract** Loquat is a typical subtropical fruit tree. Its flowering and young fruit often have to survive the winter, which makes it particularly vulnerable to cold during the flowering period. Once it encounters low-temperature frost, a reduction in yield is almost inevitable. Especially in mountainous and hilly areas, many people often only consider the variety, but the aspect is equally important. The amount of sunlight received, the heat variation between day and night, and whether cold air is prone to sink and accumulate on different aspects will all cause differences in the minimum temperature during the flowering period, and the probability of frost will also change accordingly. Based on relevant meteorological standards and risk assessment data, and in combination with the background of the 2008 southern low-temperature rain, snow and ice disaster, we have sorted out a connection from aspect to microclimate, then to frost damage, fruit setting and yield stability. It should be noted that on calm, stable and clear nights, radiation frost is more obvious, and cold air often slides down the slope and accumulates in low-lying areas. At this time, the slope position and cold air drainage conditions often affect the temperature distribution together with the aspect. Therefore, when planning the orchard layout, considering the aspect in the comprehensive assessment is more conducive to stabilizing the yield.
**Keywords** Loquat; Aspect; Flowering period frost damage; Orchard microclimate; Yield stability

## 1 Introduction

In the main production areas of Zhejiang, Fujian, loquat trees are not only confronted with typhoons and drought throughout the year, but what really worries fruit farmers are the cold air masses that occur during the transition from winter to spring. These cold air masses tend to linger during the flowering and early fruiting stages, and when the temperature drops, the flowers wither and the fruits turn brown. In severe cases, growth may even cease, ultimately leading to a decline in the fruit setting rate. The meteorological standards focus on these two stages, using the daily minimum temperature and the proportion of affected areas as the basis for classification. In other words, there are clear thresholds for whether the temperature reaches the critical point and how long the cold lasts (Sun et al., 2024). Over the past few decades, the overall number of freeze events has decreased, but in some years, large-scale severe disasters still occur suddenly. This intermittent extreme impact has persisted. Therefore, rather than waiting for weather changes, it is more practical to consider factors such as slope orientation when establishing orchards and manage the controllable factors in advance to ensure stable production (Liu et al., 2023).

Many fruit farmers have experienced that on the same mountainous area, the severity of freezing varies. In the end, the microclimate of the orchard is inseparable from the influence of terrain and surface conditions. With different slopes, the amount of sunlight received during the day varies, and the heat retention of the soil and tree canopy also differs; more heat is stored during the day, and the cooling process at night tends to be slower. However, on a clear and windless night, the ground loses heat strongly, and the cold air becomes heavier, flowing down the slope and accumulating in low-lying areas. At this time, the lowest temperature often follows the terrain (Dobos et al., 2025). The efficiency of heat dissipation and whether a “cold pocket” is formed at a certain location often determine which part of the orchard in the same area suffers more severe freezing. Relevant technical documents also remind that when choosing the site for orchard construction, one should consider the slope and orientation, as well as whether the cold air can be naturally discharged, and even the row direction should be coordinated (Chen et al., 2024). From this perspective, during the same cold wave, the freezing damage in different slope directions of the persimmon orchards is obvious, which is actually not surprising.

Rather than simply comparing the differences in slope orientation by a few degrees, this study is more concerned with the underlying process: In which aspects does the slope orientation actually contribute to the formation of flower bud freezing damage? Therefore, by integrating the critical temperature for flower bud freezing, previous understandings of terrain and heat distribution, as well as the facts during typical frost events, we attempt to outline a connection path starting from the slope orientation, passing through small climate changes, the speed of phenology, to the opportunity of low-temperature exposure, and ultimately affecting yield formation. Based on this line of thinking, three hypotheses are proposed: First, sunny slopes accumulate more heat during the day and cool down more slowly at night, making the probability of the flower bud reaching the freezing damage threshold relatively lower; second, if the phenology is advanced, in years when the cold air arrives later, it may be more prone to freezing damage; third, the slope orientation does not act alone; the height of the slope and the conditions for cold drainage will change its influence, and there may also be significant differences within the same slope orientation. These related understandings can provide references for orchard site selection and spatial layout.

## 2 Research on Frost Damage during Loquat Blossoming Period and Slope Orientation Effect

### 2.1 Research progress on mechanism and evaluation indicators of loquat flower frost damage

When it comes to frost damage, what we usually see is blackened flowers and browned fruits, but what actually changes is at the cellular level. When the temperature drops sharply, ice formation will “squeeze” the water out of the cells and damage the membrane structure; how severely the cells are damaged is not only determined by the lowest temperature, but also related to how fast the temperature drops and how long it remains low (Wang et al., 2024). For loquats, the flower and young fruit periods are the most sensitive. The current standards classify flower frost damage mainly based on the daily minimum temperature, and also combine the proportion of flower damage for judgment.

The lower the temperature and the higher the damage rate, the more severe the grade becomes; at the young fruit stage, the duration of low temperature is also taken into account, emphasizing the influence of the cumulative time of threshold values (Zhao et al., 2025). In physiological experiments, treating with -3 ℃ for 12 hours, the responses at different developmental stages are not the same. After the cell membrane is damaged, related active substances increase, but the overall cold resistance ability still shows a difference where the flower bud is strong, the flower is second, and the young fruit is the weakest.

### 2.2 Research on the relationship between slope orientation and fruit tree growth and yield formation

When it comes to slope orientation, the key point is not merely “which side is warmer”, but how these differences in heat and radiation gradually translate into variations in the timing of flowering and the risk of freezing. The FAO mentioned in their technical documents that deciduous fruit trees planted on shady slopes may have their spring flowering delayed, which can help them avoid late frosts; however, for subtropical tree species, it is often recommended to choose sunny slopes, as they can accumulate more solar energy. This is particularly well understood when it comes to loquat - their ability to overwinter their flowers and fruits means that even a small amount of heat in winter can reduce the chances of exposure to catastrophic low temperatures (Figure 1) (Chen et al., 2024).

Of course, this “topography - phenology - risk” connection has also been observed in apple and pear tree species, where freeze damage in the flower period is often related to the minimum temperature, diurnal temperature difference, and can severely affect yield and quality (Lee et al., 2025). The investigation after the 2008 severe cold and snowstorm also mentioned that the terrain differences were obvious, and the responses of different varieties were different, indicating that the site conditions and biological characteristics often work together to exert their effects.

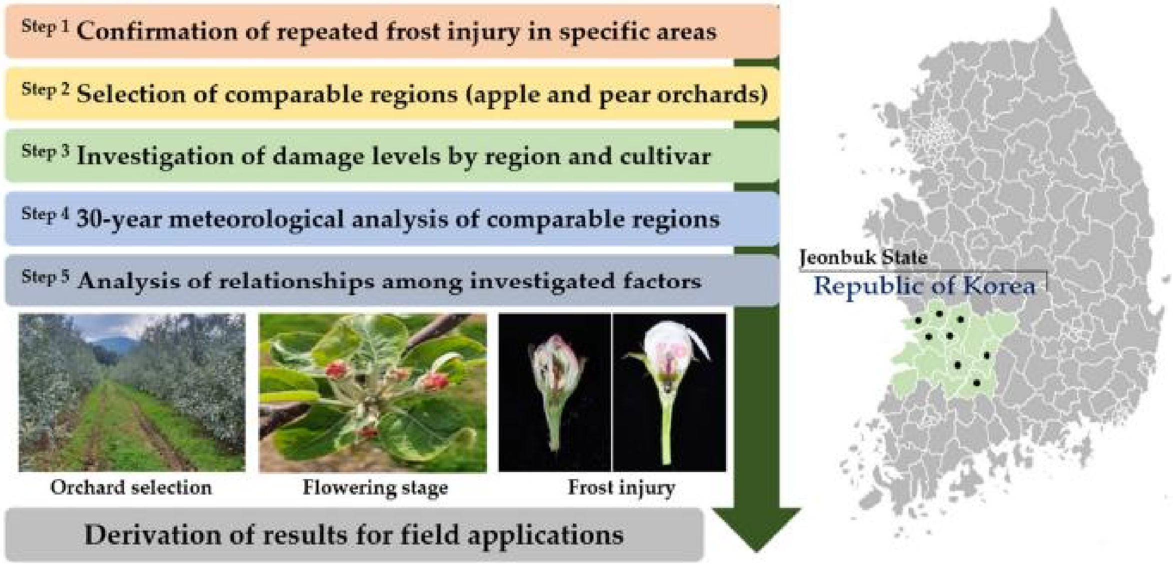


Figure 1 A schematic representation of the experimental process for result derivation (Adopted from Chen et al., 2024)

### 2.3 Orchard micro-topography and agricultural meteorological risk assessment methods

In agricultural meteorological risk assessment, the focus is not solely on the weather itself. Instead, the strength of the disaster-causing factors, the vulnerability of the crops, and the presence of disaster prevention capabilities are all taken into consideration together. The comprehensive assessment conducted in Fujian for loquat adopted such a framework, and the results showed that what actually raised the overall risk was often the disaster-causing danger itself (Li et al., 2021).

Looking at the smaller scale, the influence of the terrain is magnified. Relevant research has found that when the discharge of cold air is not smooth, even if the altitude difference is only about 70 meters, the temperature difference between the lowest points of multiple observation points can reach 6-7 degrees Celsius; if the cold air convergence process and the intensity of inversion are also taken into account, the estimation of the low temperature in the valley will be closer to the actual situation, which is crucial for judging the risk of frost (Zhang et al., 2023). In recent years, some refined forecasts targeting industries have begun to directly incorporate factors such as DEM, slope, and aspect into the models. Some studies have even refined the low-temperature forecast to 200-meter squares, using it to draw a map of the risk of persimmon frost damage.

## 3 Overview of the Study Area and Experimental Design

### 3.1 Natural geography and climatic conditions of the study area

To make the discussion more representative, the "Southeast Coastal Mountainous and Hilly Loquat Production Area" was selected as the prototype region for the study. Fujian is a typical sample among them. It is located along the southeast coast, spanning the mid-temperate zone to the subtropical zone. The proportion of mountainous and hilly areas is high, loquat cultivation is concentrated, and it has been frequently affected by meteorological disasters such as frost (Sun et al., 2022).

From the perspective of the industry background, relevant assessment data shows that as early as 2011, the loquat planting area in Fujian reached $3.5\times10^4$ $hm^2$ and the output was 21.2 million tons, occupying an important position in China. In recent years, under the background of climate change, the number of frost events and frost damage during the flowering and fruiting periods has generally decreased, but it is not stable. There are significant fluctuations between different years, and in some years, large-scale severe disasters may still occur (Wang et al., 2021). Therefore, analyzing the micro-topographic conditions such as slope orientation still has practical relevance.

### 3.2 Different slope directions and sample plot layout

The layout of the sample plots does not aim to cover a wide area but rather to clearly define the layers first. Under the premise of the same altitude zone and similar slope angles, several typical slope directions (north, south, east, west) are compared with each other. If necessary, they can be further subdivided into southeast or southwest. Multiple replicate points are set for each slope direction, with the same varieties, tree ages, and daily management maintained as much as possible to avoid misjudging the differences as terrain effects (García-López et al., 2020). Besides slope direction, slope position is also separately stratified.

Up-slope, middle-slope, and down-slope are all included in the layout. Because on clear and cold nights with little wind, cold air will flow downhill and accumulate at lower elevations, often forming local "cold spots", and there may also be significant differences within the same slope direction (Vitasse et al., 2018). At the same time, the sample plots are arranged as much as possible in accordance with the common practices of slope orchard establishment and contour terraces, so that the planting direction, road layout, etc. of the experimental area are as close as possible to actual production, facilitating the subsequent direct application of the results to orchard site selection and space optimization.

### 3.3 Data collection indicators and monitoring methods

The monitoring content can be arranged into three sections. Let's start with the microclimate and energy conditions. Temperature measurements should be taken at the ground level and at the canopy height, especially focusing on the daily minimum temperature. At the same time, record humidity, wind speed and direction, as well as indicators that can reflect changes in solar radiation or net radiation (Zhang et al., 2020). The second section directly corresponds to the frost damage determination criteria: at the flowering stage, classify by the daily minimum temperature and the flower frost damage rate.

For the fruiting stage, include the minimum temperature, the duration, and the brownness rate of the young fruits. Avoid only considering a single temperature. As for the third section, it can be related to physiological responses and yield formation. For example, measure relative conductivity, observe tissue browning, or use common methods such as electrolyte leakage and TTC reduction to determine the degree of frost damage (Liu et al., 2019). These indicators are often closely related to the minimum temperature and the duration of low temperatures. If it is necessary to achieve more detailed service scales, it can be combined with site data, numerical forecasts, and DEM information (including slope orientation) to conduct spatial correction at the hundred-meter level and draw risk maps.

## 4 Impact of Different Slope Directions on the Climatic Characteristics of Flowering Period

### 4.1 Dynamic changes in temperature along different slopes

The temperature differences brought about by slope directions cannot be simply explained by the phrase "sunny slopes are warmer". The side that receives more sunlight during the day does indeed accumulate more heat, but what happens at night depends on the weather background. On a clear and windless radiation frost night, the ground loses heat more strongly, and the near-ground layer is prone to form an inversion, with the cold air becoming heavier and flowing down the slope, accumulating at lower elevations (Whiteman et al., 2018). At this time, the lowest temperature is often "guided" by the terrain.

In areas with significant topographic variations, this process of releasing cold air and gathering it will widen the temperature difference greatly, even if the altitude difference is not significant, the daily minimum temperature in the same orchard may still differ by several degrees, and the frost risk is naturally uneven (Zhang et al., 2022). Therefore, to determine whether there is a risk for the loquat blossom period, merely relying on regional meteorological station data is not sufficient; it is also necessary to understand the specific slope direction and position, and determine the actual temperature drop in the orchard.

### 4.2 Difference between solar radiation and heat absorption

The reason why aspect is important often starts with solar radiation. The site selection guide has long warned that slope and aspect should be considered together, especially for subtropical tree species, which are more suitable to be placed on sunny slopes, allowing the soil and plants to receive and store more energy (FAO, 2019; Chen et al., 2021). From another perspective, there is more radiation during the day, and the "heat storage capacity" of the ground and canopy is thicker. During the night, when the temperature drops, it can slowly release the heat, somewhat offsetting the cooling effect of radiation.

Of course, different ecosystem conditions vary. However, in field observations, it is not uncommon to see a ranking where the sunny slope has a higher temperature and the shady slope has a lower temperature, and even the near-surface soil temperature shows a similar pattern (Zhou et al., 2020). For loquat, this cumulative thermal environment difference over time precisely coincides with the stage when the flower organs overwinter and are most sensitive to low temperatures, thus ultimately resulting in differences in the probability of freezing.

**4.3 Analysis of frequency of cold air descending and frost formation**

In areas with a high risk of frost, it is not necessarily the place where the cold air is the strongest; instead, it is often the location where the cold air cannot escape. Cold air flows like water towards lower areas at night and stops when it encounters depressions. During radiation frost weather, the top or upper part of the slope, due to smooth cold discharge, sometimes has a higher temperature. On the contrary, once there are terrain or obstacles blocking the passage, the cold air accumulates at the rear, and the damage is even more severe (Whiteman et al., 2018). Research on the microclimate of hillsides also mentions that low-lying areas such as valleys are more likely to form cold air convergence and inversion phenomena, with more significant diurnal and seasonal temperature differences (Lundquist et al., 2020).

The terrain position itself can explain many temperature variations. Looking at the loquat orchard, management should not simply be understood as "the south slope is warm and the north slope is cold"; the cold discharge path should also be considered. Instead of only comparing slope directions, it is better to prioritize identifying units prone to accumulating cold, such as the foot of the slope and depressions, to avoid them in advance, which often can reduce the occurrence of frost (Figure 2) (Dobos et al., 2025).

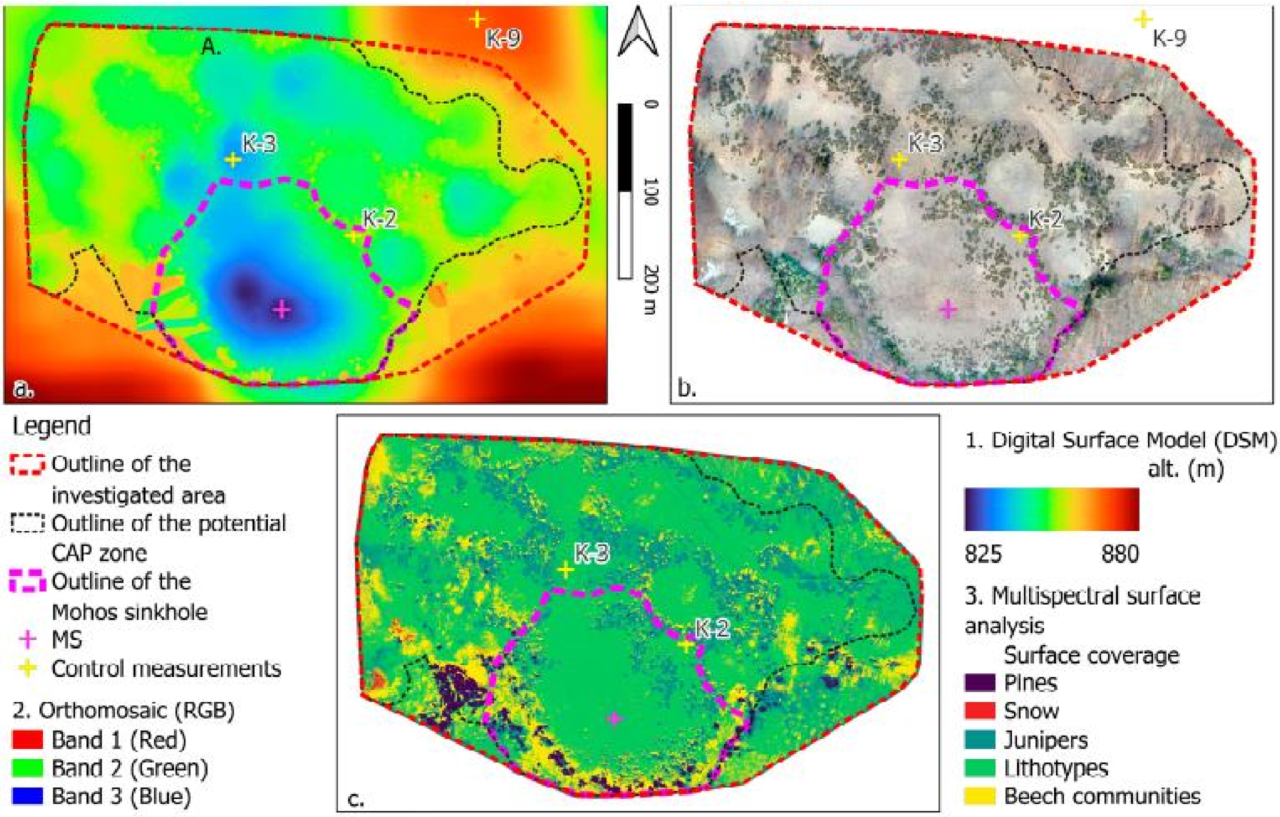


Figure 2 High resolution (2.4 cm) digital surface model of the Mohos sinkhole and its environment. (b) High resolution (2.4 cm) orthomosaic (RGB) of the Mohos sinkhole and its environment. (c) Classified land cover image of the Mohos sinkhole and its environment. This complex figure shows that the heterogeneity of the study area within the major properties generates a CAP phenomenon (Adopted from Dobos et al., 2025)

## 5 Effects of Different Slope Directions on the Degree of Flowering Period Frost Damage

### 5.1 Comparison of flower organ damage rate and frost damage grade

When discussing the severity of frost damage, it is necessary to return to a unified grading standard. According to the current regulations, the flowering period mainly depends on the decrease in the daily minimum temperature and is determined by the flower frost damage rate $P_1$: if the temperature drops below -4 ℃ and the damage rate exceeds 30%, it has entered the moderate or above level; if it is below -6 ℃ and the $P_1$ exceeds 90%, it belongs to extremely severe (Sun et al., 2022).

The significance of slope direction lies in changing the probability of the orchard reaching these temperature thresholds. Sunny slopes receive more sunlight during the day and have better heat storage conditions, theoretically making it less likely to fall below the lower threshold line; shady slopes warm up slowly at night and get colder quickly, making them more likely to increase the frost damage grade. However, the grading results are not determined solely by the slope direction. If a sunny slope happens to be in a depression where cold air is blocked and accumulates, cold air gathering within the orchard scale can also result in a higher $P_1$ and severe frost damage (Lundquist et al., 2020). This "seeming sunny but suffering severe damage" situation is often the result of cold air exerting its influence within the orchard scale.

### 5.2 The impact of freezing damage on fruit set rate and initial yield formation

Whether the flowering period is affected by freezing ultimately comes down to the "threshold" of fruit set rate. The definition of freezing damage during the flowering period in the standards already clearly states the consequences: Low temperatures cause flowers to wither and fall off, directly leading to a decrease in fruit set rate and fruit set quantity (Zhao et al., 2021). From the perspective of other fruit trees, this transmission relationship is more intuitive - the severity of frost damage during the flowering period varies each year, but once it affects the critical stage, both yield and quality will fluctuate accordingly (Vitasse et al., 2018).

Therefore, many studies will identify high-risk areas in advance through topography and microclimate. The situation for loquat is even more complex. Its flowers and young fruits need to survive multiple rounds of cold air during the winter. If a single low temperature has already reduced the effective number of flowers, even if the temperature rises later, the young fruits will only develop "on the remaining basis" and it is difficult to make up for the previous losses. As a result, the initial yield base is often low, and the space for thinning and adjustment also becomes smaller in the subsequent stages.

### 5.3 Analysis of physiological indicators related to cold resistance

Whether a persimmon variety is resistant to cold is not solely determined by its inherent nature; the long-term temperature conditions in the orchard can also lead to differences. During low-temperature treatment, the cell membranes of flowers and fruits are prone to damage, and reactive oxygen species-related reactions, MDA and proline levels increase, while antioxidant enzymes are activated (Liu et al., 2019). Moreover, cold resistance is generally stronger in flower buds, followed by flowers, and weakest in young fruits. Genetic evidence also provides clues.

For instance, some candidate genes for cold resistance are associated with reduced electrolyte leakage and enhanced antioxidant capacity, indicating that "antioxidation + membrane stability" is crucial (Yang et al., 2022). Thinking further up the slope becomes somewhat counterintuitive: sunny slopes are warmer in winter, and cold acclimation may not be sufficient. When a cold wave strikes, the same variety may be more prone to membrane damage; on the shady slope, it is colder, but if the temperature drop is gradual, the tree may be better able to adapt. This inference can only be confirmed through synchronous monitoring of electrolyte leakage, tissue browning, etc.

## 6 Impact of Different Slope Directions on Yield Stability

### 6.1 Analysis of yield differences and their constituent factors

There is no simple linear relationship between slope direction and yield. Instead, multiple paths often work together. First, if the flowering period or the early fruiting stage is affected by freezing, the effective number of flowers and fruits will decrease; then, the low-temperature stress may also slow down fruit growth and affect the proportion of fruits reaching the commercial standard (Zhao et al., 2021); in addition, management measures such as irrigation, covering, and pruning vary in effectiveness on different slope directions. Some areas are more labor-saving, while others achieve twice the result with half the effort. Some practices at the production level are actually "offsetting" the adverse effects of slope direction.

For example, choosing suitable slopes, planning small plots and terraces, and arranging row directions as mostly north-south are essentially improving the microclimate and enhancing management efficiency. From a risk perspective, some studies have pointed out that the risk of disaster is often the dominant factor among comprehensive risks (Li et al., 2021). This means that in small climate units where freezing is more likely to occur, even if the variety and management are the same, the yield may overall decrease due to several cold damages in extreme low-temperature years. Therefore, rather than saying a certain slope is "more productive", it is better to understand that in extreme low-temperature years, the extent of losses varies.

### 6.2 Inter-annual yield fluctuations and stability coefficient

When discussing yield stability, we cannot merely focus on whether the average yield is high or not; we also need to consider how significant the fluctuations are. Relevant data also remind us that when recommending a certain layout or measure, both the average level and the stability of performance should be taken into account, because stable production does not necessarily mean the highest yield, but too much fluctuation is also a risk. In agricultural research, variance or coefficient of variation are commonly used to describe such fluctuations, and some people use the sustainable yield index (SYI) for comprehensive judgment (Bandyopadhyay et al., 2019). Long-term location experiments have shown that SYI is often positively correlated with the average yield, but negatively correlated with the yield coefficient of variation (Singh et al., 2018).

In other words, reducing fluctuations is itself valuable. Applying this thinking to slope orientation comparisons, the single yield data of the same slope orientation over multiple years can be plotted as a sequence. The standard deviation or degree of variation can be used as the core indicator, and then we can examine whether there is a relationship between it and the frequency of reaching the frost damage threshold during the flowering and fruiting periods. In this way, the so-called "slope orientation effect" is no longer just an abstract judgment but can be transformed into quantifiable differences in stability.

### 6.3 The impact of slope orientation on fruit quality and economic benefits

The economic benefits of an orchard do not solely depend on the quantity of production. The difference in light and heat brought about by the slope orientation does indeed affect the speed of ripening and the accumulation of sugar and acid (Zhou et al., 2020). However, in the production of loquat, the more common turning point often occurs after a frost event - the proportion of marketable fruits decreases, the harvest batches are disrupted, and the income suffers accordingly. In regions with a concentrated planting area and production volume like Fujian, once a certain type of site conditions increases the probability of frost damage, the impact is not only limited to a single orchard but will be magnified to the level of regional product quantity and market price (Wang et al., 2021).

Recent service practices are also moving towards a more detailed approach, for example, using -3 ℃ as a key threshold, combining 100-meter-level forecasts to divide risk areas, and prioritizing the allocation of anti-freezing manpower and materials to high-risk grids. The aim is to improve the input-output ratio. Therefore, when discussing "slope orientation and benefits", one cannot simply rely on experience to say which side is better. Instead, it should be evaluated together with quantitative factors such as the frequency of threshold triggering, the area of risk zones, and the degree of intervention.

## 7 Case Study: Comparative Analysis of Frost Damage Inloquat Orchards with Different Slopes in Typical Cold Years

### 7.1 Background of extreme cold events

The severe cold, rain, snow, and ice storm in early 2008 was still vividly remembered by many people. It affected a wide area and lasted for a long time. Not only transportation and power systems were impacted, but agriculture also suffered significant losses. In some areas, the ice freeze lasted for several consecutive days, and the cold period almost reached the historical extreme (Wang et al., 2019). Such a prolonged "cold without abating" weather was particularly unfriendly to the fruit and flower crops that were overwintering.

For loquat, which is located at the northern edge of cultivation or has already limited heat conditions, the problem was not just the difference in temperature once or twice, but rather the repeated freezing and thawing, combined with the tree body losing water. This would easily cause damage to the flowers and fruits and might also affect the tree's recovery the following year (Guo et al., 2020). Due to the extreme nature of the scenario, such events actually provided a testing window: Under the same cold wave background, whether slope and micro-topography were amplifying the risk or playing a buffering role to a certain extent.

### 7.2 Comparison of frost damage occurrence on different slopes

In the investigation conducted after that severe cold and snowstorm, researchers visited various locations and found that what actually reduced the yield was usually the continuous low temperatures combined with later freezing and frost (Wang et al., 2019). Moreover, the degree of damage varied significantly on different terrains. Although no strict comparative tests were conducted based on slope direction at that time, under the same cold wave, some plots suffered severe losses while others were relatively less affected. This difference itself indicates that the terrain plays a role. The mechanism by which cold air sinks along the slope, accumulates in low-lying areas, and fails to drain properly to form "cold pools" can also explain this phenomenon (Lundquist et al., 2020).

If we apply the current frost damage classification standards, the flowering stage grade is directly linked to the daily minimum temperature. As long as the slope direction or position causes a difference in the actual Tmin, some plots in the same area may fall into a lighter grade, while others may move into a heavier grade. Subsequently, the fruit set rate and yield will naturally differentiate. The warning given by extreme years is quite simple: Slope direction does not act alone; it needs to be considered together with the cold drainage structure of the micro-topography. The key lies in whether it has exceeded that temperature threshold.

### 7.3 Case insights and practical significance in production

The more extreme the year is, the more obvious the differences between the garden plots become, and it is easier to determine whether the initial site selection for the orchard was reliable. When a disaster strikes, the first step is often not to apply a one-size-fits-all approach to the entire orchard, but to identify the low-lying "cold spots" first (Lundquist et al., 2020). The technical materials mention that one can use topographic maps, temperature monitoring, and even smoke observation to track the flow of cold air, to see where the cold air drainage is blocked, and then clear the obstacles.

These practices are also applicable in mountain pear orchards. Looking further back, in the planning stage, the slope direction, drainage system, road layout, and terraced field layout should all be considered together. Relevant standards have requirements for slope orchard establishment, area division, and machine operation channels (FAO, 2019). Essentially, this is to make the terrain more controllable and to respond to disasters more efficiently. At the service level, more detailed forecasting support is needed. The grids should be refined and risk zoning maps should be made. Before the cold wave arrives, human resources and materials should be moved to the key areas to achieve targeted handling, rather than applying force evenly.

## 8 Discussion and Conclusion

When considering the previous clues together, the influence of slope orientation on frost damage during the flowering period is roughly the result of several forces overlapping. Firstly, the difference in light exposure leads to different energy starting points, with sunny slopes being more likely to accumulate heat during the day and having a different "base" for cooling at night; further down, it is the issue of how the cold air moves. Whether it flows smoothly or not, whether the slope foot or depression will form a cold pool, often directly determines which temperature range the lowest temperature falls into at night; in addition, long-term differences in microclimate may also affect the cold acclimation state of the tree, causing the same variety to respond differently to the same cold wave in different slope orientations. According to the current classification standard, whether during the flowering period or the fruiting stage, it is when the lowest temperature (plus duration) crosses a certain threshold that the damage rate rises rapidly. And precisely because of this, even a few degrees of difference brought by slope orientation, as long as it stays near the critical line, may cause the frost damage level to jump. Therefore, treating the slope orientation seriously during the orchard establishment stage is essentially adjusting the risk pattern, rather than merely pursuing a higher average temperature.

It should be noted that this analysis is largely based on the integration of public literature and current standards, and no long-term, homogeneous slope comparison experiments were conducted in a specific production area. Therefore, it is impossible to provide a quantitative coefficient such as "how much higher the south slope is compared to the north slope in terms of yield in a certain area". Additionally, slope orientation is often intertwined with factors such as variety, tree age, pruning, mulching, and irrigation. If the management of the sample plots is not uniform and there is insufficient repetition, it is easy to attribute management differences to topographical effects. In the future, several directions can be refined: First, place slope orientation, slope position, and cold drainage structure in the same stratified framework, and conduct continuous long-term monitoring around the lowest temperature and frost damage classification; Second, analyze physiological indicators such as electrolyte leakage, MDA, and antioxidant enzymes together with frost damage grades and fruit set rates to explain why "the same temperature leads to different damages"; Third, combine DEM for more precise forecasting and risk zoning, so that slope orientation information can serve both site selection for orchard establishment and also be used for pre-disaster warning and post-disaster assessment.

At the production level, there are several not-too-complicated measures that are best considered before establishing the orchard. The first step is not to rush to compare the south slope with the north slope, but to avoid the areas where cold air is prone to accumulate. Avoiding low-lying areas at the foot of the slope and terrain that is difficult for cold air to escape should be prioritized; if the land has already been determined, measures such as clearing obstacles on the downhill side and reserving cold air discharge channels can be taken to allow the cold air to have a way out. Secondly, regarding the selection of slope orientation, "preferring sunny areas for subtropical tree species" can be taken as the basic strategy, but do not ignore the risks brought by the earlier onset of phenology. Sunny slopes have better winter heat conditions and have a lower probability of crossing the low temperature threshold. However, if local cold waves often occur in late periods, be cautious of early flower exposure and incorporate this risk into the variety selection and flower and fruit management plans. Thirdly, integrate engineering and management into a standardized framework. Refer to relevant norms to control the slope gradient, make proper divisions of terraces and districts, and reasonably determine the row direction (such as north-south). This not only facilitates mechanical operations but also facilitates emergency response; at the same time, using the current frost damage classification threshold as the basis for park warning, the frost prevention decision can be shifted from experience-based judgment to rule-based decisions.

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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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