

Under optimized management, the commercial fruit rate has increased, the fruit storage capacity has improved, and the incidence of pests and diseases has decreased. After the introduction of superior varieties and efficient management, both the appearance and internal quality of the fruits have improved, and the market acceptance has significantly increased. In some orchards, the commercial fruit rate exceeds 90%, and the economic benefits have significantly increased (Du, 2001; Tan et al., 2012). In addition, the development of the medicinal value of fruits has also expanded the industrial chain and increased the added value (Huang et al., 2025).

8 Challenges and Research Gaps

8.1 Lack of long-term comparative data across cultivation models

At present, research on different cultivation and management models of Changshan Huyou (such as organic, intensive, conventional, intelligent, etc.) is mostly short-term experiments or regional cases. Most studies only last for one quarter or 2 to 3 years, lacking systematic, long-term and multi-point comparative data. This leaves us with limited understanding of the sustained effects of management measures, interannual fluctuations, and their interactions with environmental factors such as climate and soil (Tan et al., 2012; Ren et al., 2020; Zhang et al., 2020; Li and Tao, 2023; Luo et al., 2023). For instance, some experiments have shown that optimizing dense planting, fertilization and water management can significantly increase yield and commercial traits. However, due to the short cycle, it is impossible to reflect the long-term cumulative effect and it is also difficult to assess the long-term changes in the orchard ecosystem.

8.2 Trade-offs between yield maximization and quality traits

In production, there is often a contradiction between “high yield” and “good quality”. For instance, intensive high-density planting and high nitrogen fertilizer input can increase the yield per unit area, but the fruits tend to be too large, the sugar-acid ratio decreases, the flavor becomes weak, and the risk of pests and diseases may also increase (Ren et al., 2020; Chen et al., 2023). In contrast, organic or ecological management can improve fruit quality and safety, but the increase in yield is limited and the management cost is higher. How to find the balance point between output and commercial traits under different modes is a difficult problem in current research and production. In addition, there are often complex interactions among varieties, environment and management measures, which makes the trade-off between yield and quality even more complicated (Zhang et al., 2020; Li and Tao, 2022; Li and Tao, 2023).

8.3 Insufficient region-specific optimization strategies

The ecological conditions in the main production areas of Changshan Huyou vary greatly, with different climates, soils and terrains. The responses of different regions to management models also differ significantly. However, most of the existing research focuses on a single region or unified management standards, lacking localized optimization plans for different ecological zones. For instance, there are significant differences in demands such as water and fertilizer management, pest and disease control, and fruit ripening regulation between the humid southern region and the subtropical northern region. A unified model is difficult to take into account the actual situation (Tan et al., 2012). In the context of frequent extreme climate events (such as high temperatures, heavy rain, and droughts), it is even more urgent to develop and promote adaptable regional management measures (Huang et al., 2020; Zhang et al., 2020; Yan et al., 2021; Li and Tao, 2023). At present, research on management optimization for different ecological zones, screening of adaptive varieties, and the synergy between management and varieties is still insufficient.

9 Future Perspectives

9.1 Application of smart agriculture and digital technologies in Huyou orchards

With the development of the Internet of Things, remote sensing, artificial intelligence and big data, smart agriculture is becoming an important method to increase the yield and quality of citrus fruits, including Changshan Huyou. Deep learning models can combine various types of data and perform well in aspects such as yield prediction, pest and disease monitoring, precise irrigation and fertilization. They can handle the complex relationships among the environment, plants and management, significantly improving prediction accuracy and management efficiency (Li et al., 2022a; Sun et al., 2022; Lu et al., 2024). Remote sensing and satellite data