5.4 Representative cultivars suitable for southern winter conditions

Studies conducted under various cool-season and off-season cultivation environments have identified several cultivars suitable for winter or protected production systems. Under spring and off-season cultivation conditions in Nepal, Ivory White F1 consistently produced the highest fleshy root yields and exhibited excellent quality characteristics in both net-house and shaded cultivation systems.

In addition, comparative trials conducted under winter protected cultivation conditions in Wuhan identified several Korean spring radish cultivars that demonstrated good yield and quality performance within autumn–winter protected production systems (Wan, 2010).

5.5 Comparative performance under open-field and protected cultivation conditions

Superior cold-tolerant cultivars are generally able to achieve higher and more stable yields than local check cultivars during cool-season or off-season cultivation while maintaining desirable quality characteristics.

Under shade-net and off-season production environments, Ivory White F1 produced fleshy root yields of approximately 31 $t \cdot ha^{-1}$ and outperformed other improved and hybrid cultivars in root length, root circumference, dry matter content, vitamin C content, and consumer acceptance (Dahal et al., 2020).

In winter open-field trials, compared with the commonly grown cultivar Mino Early, Okura increased yield by approximately 49%, while Miyasige increased yield by approximately 22%. Both cultivars maintained good root size and attractive external appearance (Shrestha et al., 2021).

6 Winter Production Cultivation Techniques

6.1 Optimal sowing time and planting density

By properly adjusting sowing time and planting density, radish can achieve stable production under low-temperature conditions. Model analyses and long-term simulation studies have shown that optimizing sowing dates together with proper irrigation and fertilization management can significantly improve radish yield and resource-use efficiency. This indicates that sowing time should be matched with local climatic conditions and should be selected to avoid severe low-temperature damage while ensuring sufficient accumulated temperature for fleshy root development (Zhang et al., 2021).

Experimental results under different seasonal conditions further demonstrated that direct seeding with a smaller plant spacing (approximately 10 cm) is favorable for aboveground vegetative growth, whereas a wider spacing (approximately 20 cm) significantly increases root diameter, root length, and individual root weight. These findings suggest a density trade-off between leaf growth and fleshy root yield (Hudu et al., 2025). Therefore, in winter production, sowing dates should be arranged according to local cold-wave patterns to avoid periods of extreme low temperatures. At the same time, an appropriate planting density should be adopted to ensure rapid canopy closure and improved ground coverage while providing sufficient space for root enlargement.

6.2 Soil preparation and nutrient management

Radish is highly responsive to soil fertility, and improper fertilization is one of the major reasons for low nutrient-use efficiency in radish production in China. The combined application of chemical fertilizers with organic and biofertilizers, such as farmyard manure, spent mushroom substrate, nitrogen-fixing bacteria (Azotobacter), and phosphate-solubilizing bacteria, can significantly increase the availability of nitrogen (N), phosphorus (P), and potassium (K) in the soil. This practice promotes fleshy root growth, increases yield, and improves soil health, showing much better results than the use of chemical fertilizers alone (Shilpa et al., 2023).

In recent years, the Nutrient Expert system and nutrient requirement models based on the QUEFTS framework have enabled the accurate estimation of balanced nitrogen, phosphorus, and potassium requirements according to the nutrient demand per unit yield. These tools provide scientific support for fertilization decisions under different soil and climate conditions, thereby improving yield and economic returns, enhancing nutrient-use efficiency, and reducing environmental risks associated with excess nitrogen and phosphorus accumulation (Zhang and Ullah, 2022).