Deep plowing and careful seedbed preparation before sowing are beneficial for uniform seed emergence and early root development. These practices are particularly important for successful crop establishment under winter low-temperature conditions.

6.3 Irrigation strategies under low-temperature conditions

During winter radish production, evapotranspiration is generally low. However, maintaining suitable soil moisture remains a key factor for normal plant growth and nutrient uptake. Optimized irrigation management can reduce irrigation water use by approximately one-third to one-half while maintaining or even increasing yield, and it can also significantly decrease the risk of nitrate leaching (Gan et al., 2023).

Drip irrigation experiments have shown that maintaining moderate soil water potential (generally around 7~12 kPa) under suitable mulching conditions results in the best fleshy root growth, fresh weight accumulation, and economic returns. Both water deficit and excessive moisture can reduce production performance (Santos et al., 2022). Under protected cultivation conditions, moderate deficit irrigation combined with appropriate nitrogen application can maintain yield while improving nitrogen-use efficiency and reducing environmental impacts.

During winter irrigation, prolonged soil saturation should be avoided to prevent root injury under low-temperature conditions. In addition, irrigation should preferably be carried out during the warmer periods of the day to minimize cold damage to root growth.

6.4 Application of protected cultivation measures (mulching, tunnels, and greenhouses)

Protected cultivation is an important approach for reducing low-temperature stress and ensuring safe radish production during winter. Plastic mulches of different colors can increase rhizosphere temperature and soil heat accumulation. Transparent plastic mulch usually provides the strongest warming effect and can significantly increase root length, root diameter, and root weight while effectively reducing premature bolting caused by temperatures below 10 ℃ during early spring (Lee and Park, 2020).

Black plastic mulch and nonwoven fabric covers can also improve plant growth and yield. Under suitable soil moisture tension conditions, black plastic mulch generally provides higher production efficiency and economic benefits than bare-soil cultivation. In addition, organic mulches and crop residues, such as straw and by-products from Brazilian palm processing, can improve the soil moisture and temperature environment, thereby enhancing radish growth and productivity under protected cultivation systems (Gomes et al., 2020).

Low tunnels, high tunnels, and combined low-tunnel plus high-tunnel systems can significantly increase vegetable yields during cool seasons and can maintain stable production even under freezing conditions (Shiwakoti et al., 2018). For radish production, polyethylene low tunnels can improve leaf nutrient status, increase dry matter accumulation, and enhance fleshy root yield. When combined with foliar silicon application, the effects on cold tolerance and yield improvement become even more pronounced (Alhasnawi and Al-Bayati, 2023; Al-Bayati and Alhasnawi, 2025).

In seed production systems, winter greenhouses are commonly equipped with heated or insulated seedbeds and plastic covering facilities for elite plant propagation, ensuring early transplanting and protection from frost damage.

6.5 Integrated pest and disease management in winter

Winter production does not completely eliminate pest and disease problems; instead, it changes the timing and types of pests and diseases that occur. In radish seed production, protected facilities such as greenhouses and plastic tunnels still require strict weed, pest, and disease management, and pesticides should be used in accordance with relevant national regulations and approved pesticide lists.

In both open-field and protected winter cultivation systems, mulches and cover crops can serve as important components of integrated management strategies. Dead mulches not only suppress weed growth but also regulate soil moisture and temperature, thereby improving crop performance. In addition, winter cover crops dominated by