However, some cultivated populations still face problems related to relatively narrow genetic backgrounds and ongoing genetic erosion. In terms of cold-tolerance breeding, although the molecular regulatory mechanisms and key regulatory genes are being gradually clarified, relatively few cold-tolerant winter radish cultivars have been widely adopted in production. This is mainly due to the incomplete development of molecular markers associated with cold tolerance, the complex quantitative inheritance of cold-tolerance traits, and the lack of high-quality phenotypic data collected across multiple environments (Chang-Brahim et al., 2024; Ray et al., 2025).

5 Characteristics of Major Cold-Tolerant Radish Cultivars

5.1 Criteria for cold tolerance evaluation

The evaluation of cold tolerance in radish cultivars usually considers their survival ability under low-temperature conditions, production stability, and the ability to maintain agronomic and quality traits. Key evaluation indicators include stable seed germination and plant establishment under unfavorable low-temperature environments, reduced bolting and disease incidence, and the ability to produce marketable fleshy roots during cool seasons, under protected cultivation, or in low-temperature regions. In addition, yield stability (fleshy root yield per unit area and proportion of marketable roots), as well as the maintenance of root morphology, storage performance, and sensory quality, are widely used as important indicators for assessing cultivar adaptation to winter or off-season cultivation environments.

5.2 Morphological and agronomic traits

Cold-tolerant or winter-adapted radish cultivars generally show vigorous vegetative growth and strong fleshy root development under cool environmental conditions. Studies conducted across different ecological environments have shown that plant height, leaf number, leaf area, root length, root diameter, and individual root weight are important agronomic traits for selecting superior cultivars (Singh et al., 2021; Lahari and Tripathi, 2023; Thakur et al., 2023).

For example, under cool or protected cultivation conditions, the cultivars Ivory White F1 and Okura can achieve fleshy root yields of approximately 30~54 $t \cdot ha^{-1}$, while also producing longer roots and larger root diameters (Shrestha et al., 2021).

The Chinese radish cultivar Serdtse Podmoskovya, developed in Russia, is characterized by a medium growth period (65~75 d), a high marketable root rate (81%~89%), and a relatively large individual root weight (281~533 g). It has shown good production performance under both open-field and protected cultivation conditions (Stepanov, 2023). Genetic diversity analyses have further demonstrated that radish germplasm resources exhibit extensive variation in growth duration, root shape (ranging from round to cylindrical), and biomass allocation patterns.

5.3 Quality characteristics (flavor, texture, and nutritional composition)

Cold-tolerant radish cultivars intended for winter markets must not only possess strong environmental adaptability but also meet consumer expectations for quality. Important quality traits include uniform root shape and size, smooth skin, crisp and tender flesh, and a moderate pungent flavor.

Under shade-net or off-season cultivation conditions, the hybrid cultivars Ivory White F1 and Mino Early Long White F1 showed relatively high root dry matter content (approximately 7.6%), high ascorbic acid content (approximately 19.5 mg/100 g), and high total soluble solids content (approximately 6 °Brix). These cultivars also received favorable consumer ratings for pungency and overall flavor (Dahal et al., 2020).

The cultivar Serdtse Podmoskovya produces white, juicy fleshy roots with a mildly pungent taste. Under winter production conditions, its dry matter content ranges from 6.3% to 11.0%, total sugar content from 2.6% to 3.2%, and ascorbic acid content is approximately 19~20 mg% (Stepanov, 2023). Late-maturing, large-root winter cultivars generally contain higher levels of dry matter and vitamin C, whereas early-maturing, small-root cultivars tend to have lower dry matter content but still maintain desirable ascorbic acid levels (Kurina et al., 2021).