At present, MAS technology has been successfully applied in radish disease-resistance breeding. Using 275 core radish germplasm accessions collected from 30 provinces in China as well as Russia, Germany, South Korea, and other countries, Ma et al. (2024) conducted artificial inoculation with Race 4, the dominant physiological race of Plasmodiophora brassicae in China. Disease resistance levels were evaluated using the disease index (DI). Significant differences in clubroot resistance were observed among the germplasm resources. Six highly resistant accessions and 50 resistant accessions were identified. Some materials originating from Sichuan Province, Russia, and Germany showed stable and high levels of resistance (Figure 1). The study further analyzed the geographic distribution and horticultural characteristics of these resistant germplasms and found that resistant resources were relatively abundant in southern regions. In addition, the highly resistant materials exhibited considerable genetic diversity in leaf type, fleshy root shape, and root color. Previously reported clubroot-resistant SSR molecular markers were then used to evaluate the highly resistant materials. The results indicated that these accessions possessed genetic characteristics different from those of known resistant materials, suggesting that they may carry novel resistance genes. Finally, several highly resistant accessions were crossed with elite cultivated varieties, resulting in a number of hybrid progenies with breeding potential.

At the same time, genome-wide association studies (GWAS) and transcriptome analyses have identified several important genes and transcription factors involved in cold tolerance and fleshy root development, including RsERF40 and the RsWRKY40-RsSPS1-CBF regulatory module. These findings provide potential targets for improving cold tolerance through MAS and genomic selection while maintaining normal fleshy root growth (Li et al., 2023b).

Figure 1 Phenotypic comparison between high-resistance and high-sensitivity seedlings. (a-f) Highly resistant (HR); (g-i) highly susceptible (HS). Bar scale = 1 cm (Adopted from Ma et al., 2024)

4.5 Major achievements and limitations of breeding research

Substantial progress has been achieved in radish breeding with respect to yield, quality, disease resistance, and environmental adaptability. In some breeding programs, more than half of the released cultivars have become F_1 hybrids developed using CMS technology and molecularly identified core germplasm resources. Among these achievements, clubroot resistance breeding is considered a successful example. Through the integration of diverse germplasm resources, phenotypic screening, and molecular marker technologies, breeders have not only enriched the resistance gene pool but also developed several new disease-resistant cultivars.