Given the important role of rain shelters in reducing cracking risk, while also potentially affecting fruit quality, it is necessary to systematically evaluate their overall effects in cherry production. In this study, rain-protected cultivation is analyzed as an integrated system to assess its effects under field conditions on: (i) the incidence and severity of rain-induced fruit cracking, and (ii) key quality traits such as skin color, fruit firmness, and sugar accumulation. By linking cracking responses with fruit quality variations across different canopy positions and seasonal conditions, this study aims to clarify the trade-offs of rain-protected cultivation and identify conditions that can both reduce cracking risk and maintain or improve commercial quality, thus providing a theoretical basis and practical guidance for more sustainable and profitable sweet cherry production in rainy regions.

2 Biological Characteristics of Cherries Related to Cracking and Quality

2.1 Fruit skin structure and cracking sensitivity

The cherry fruit skin (composed of cuticle + epidermis + hypodermis) is the primary load-bearing structure. It experiences high mechanical tension and has limited elastic extensibility, so additional expansion can easily lead to tissue rupture (Winkler et al., 2016). A thinner cuticle and more severe microcracks increase the fruit's sensitivity to rain-induced cracking because these factors weaken the barrier function of the skin, allowing water to enter more easily into localized areas. Local rupture of flesh cells beneath the epidermis, followed by crack propagation in a "zipper-like" manner, further indicates that fruit skin with low mechanical strength and insufficient elasticity plays a key role in cracking sensitivity (Knoche et al., 2025). When the skin barrier is damaged, water can rapidly enter through the fruit surface and the pedicel region, increasing local mechanical stress in the skin.

2.2 Water uptake pathways in cherry fruit

Under rainfall or prolonged surface wetness, water can be directly absorbed through the fruit skin, especially in the presence of microcracks or water-accumulating areas (such as the pedicel cavity and stylar end), where surface wetness duration is extended (Santos et al., 2023). This surface water uptake pathway is a major driving factor of fruit cracking, and its extent is closely related to the duration of surface wetness and the wetted area.

At the whole-plant level, when soil moisture is high, water is transported upward through the xylem and phloem, affecting the water status of the fruit and potentially interacting with surface water uptake. However, recent studies emphasize the importance of local processes in the fruit skin rather than only the role of overall turgor pressure (Aydın et al., 2025).

2.3 Characteristics of quality formation

The color formation of sweet cherries is mainly driven by the accumulation of anthocyanins, and anthocyanin synthesis is strongly regulated by light. Insufficient light (such as shading or low-light stress) reduces anthocyanin content, thereby affecting the development of red coloration in the fruit (Tang et al., 2023). Soluble sugars (such as fructose, sucrose, and related sugars) accumulate rapidly during ripening, and their levels are closely related to leaf photosynthesis and carbon assimilation. Shading reduces the photosynthetic capacity of leaves, thereby decreasing sugar accumulation in the fruit and affecting overall quality.

3 Cherry Canopy Training Systems and Their Structural Characteristics

3.1 Common cherry training systems

Modern cherry orchards are increasingly relying on high-density training systems to regulate tree vigor, improve light distribution and fruit quality, and facilitate labor-intensive operations such as pruning, harvesting, and the installation of rain covers or protective nets. Among these systems, Kym Green Bush (KGB), Upright Fruiting Offshoots (UFO), central leader and tall spindle systems, and the Spanish bush system represent different canopy structure types, which significantly affect fruit distribution and the microclimate within the fruiting zone (Long et al., 2015).

The KGB system is a multi-leader, bush-like structure composed of several upright and relatively short leaders emerging from low on the trunk, forming a compact canopy suitable for ground-based operations (Lang et al., 2019). Due to higher planting density and multiple leaders, KGB orchards usually have larger canopy volume and