leaf area per unit land, which helps improve light interception. However, if branches are not renewed regularly, internal shading can easily occur (Yuri et al., 2021). The KGB system generally shows high yield per unit area and good harvesting efficiency, as most fruits are distributed within easy reach from the ground (Soysal et al., 2025).

The UFO system trains a trunk-like structure horizontally along a trellis, with multiple vertical fruiting shoots evenly distributed along it, forming a planar "fruiting wall" (Law and Lang, 2016). This narrow two-dimensional canopy captures light efficiently, simplifies pruning and renewal of fruiting shoots, and concentrates fruit along vertical axes that are easy to manage. Individual trees in the UFO system are relatively small, but the density of fruiting shoots per unit area is high, which helps achieve early fruiting, stable yield, and high harvesting efficiency, especially when most fruits can be picked from the ground (Ampatzidis and Whiting, 2013).

Central leader and tall spindle systems (including forms such as Vogel Central Leader and Tall Spindle Axe) are conical three-dimensional canopy structures characterized by a single trunk with multiple lateral fruiting branches distributed along it (Lang et al., 2019; Stone et al., 2022). These systems can develop larger trees with greater canopy volume and can produce fruits with good size and firmness, especially when lateral branches are properly spaced to avoid shading (Karakaya et al., 2022). Tall spindle variants are more slender and allow higher planting density, but the fruiting zone often extends beyond ground operation height, requiring ladders for management, and light distribution within the lower canopy is often less uniform (Rabcewicz et al., 2017).

The Spanish bush system is a multi-leader, low-trunk structure, where several main scaffold branches originate near the ground, distributing fruiting shoots within a relatively open canopy of moderate height (Long et al., 2015). When canopy density is properly controlled, this system can produce large fruits with high firmness and good coloration. Compared with tall central leader trees, its bush-like structure improves operational accessibility, although fruits may still be distributed deeper within the canopy (Karakaya et al., 2022).

3.2 Structural characteristics affecting cherry fruit environment

Among the different training systems mentioned above, fruit distribution, canopy permeability, and fruiting zone height are key structural traits that determine the fruit microenvironment, thereby influencing cracking risk and fruit quality. Structures dominated by vertical leaders (such as UFO upright shoots, KGB small leaders, and tall spindle trunks) tend to concentrate fruits along vertical axes, while systems dominated by lateral branches (such as central leader systems with long scaffold branches and Spanish bush systems) distribute fruits more on horizontal or inclined branches away from the trunk (Lang et al., 2019). Planar structures like UFO concentrate fruits within a narrow band close to the trellis, which is beneficial for uniform light exposure and rain cover installation; in contrast, multi-leader bush systems (such as KGB and Spanish bush) create a more three-dimensional fruiting space, which can easily lead to differences in light, temperature, and humidity within the canopy (Ampatzidis and Whiting, 2013).

Canopy openness and compactness also have important effects on the fruit environment. Open or planar canopies, with less leaf overlap, allow better light penetration, improve photosynthetic uniformity, and thus enhance fruit coloration and soluble solids content; in contrast, dense and compact canopies tend to cause shading, reduce internal light levels, and suppress fruit quality and dry matter accumulation (Gonçalves et al., 2008). Large, dense, and vertically structured trees usually have greater shaded leaf area, which can result in poor fruit coloration and lower soluble solids content (SSC) and acidity. On the other hand, smaller or structurally optimized canopies reduce ineffective shading and improve fruit quality throughout the canopy (Zhang et al., 2025).

In addition, the height and accessibility of the fruiting zone not only affect management operations but also alter the microclimate around the fruit. "Ground-operated" systems such as KGB and UFO place most fruits within reach from the ground, which improves harvesting efficiency and allows more uniform coverage of rain shelters and protective nets over the fruiting area (Law and Lang, 2016). In contrast, in central leader and tall spindle systems, many fruits are located higher in the canopy, where different heights experience variations in wind, radiation, and rainfall exposure, and where the installation and management of protective structures become more complex (Rabcewicz et al., 2017). Therefore, the interaction between training structure and rain protection design