internode length and leaf distribution jointly regulate both canopy structure and microclimate, making them critical determinants of stable yield formation.

2.3 Balance between vegetative and reproductive growth

Maintaining a dynamic balance between vegetative and reproductive growth is fundamental for achieving high and stable yields in protected tomato production. Vegetative growth, including stem and leaf development, leaf area expansion, and root vitality, provides the basis for assimilate production. Reproductive growth, encompassing flower differentiation, pollination, fruit set, and fruit enlargement, directly determines yield formation. Excessive vegetative growth may result in continuous allocation of assimilates to stems and leaves, suppressing flower differentiation and reducing fruit set stability. Conversely, excessive reproductive load can lead to insufficient leaf area, reduced root activity, and premature senescence, ultimately limiting sustained fruit production. Therefore, vigorous growth alone does not guarantee high yield; rather, the key determinant is the maintenance of balanced "source-sink" relationships across growth stages.

Semi-determinate tomatoes exhibit a moderately extended vegetative phase compared with determinate types, while avoiding excessive vegetative growth typical of indeterminate types. This growth habit facilitates coordination between leaf capacity and fruit demand, improving yield-related traits and water use efficiency. These findings suggest that optimal plant types are characterized by a coordinated structural-functional state combining moderately sustained growth with stable reproductive translocation. Light regulation further influences biomass partitioning. Supplemental LED lighting generally increases total biomass and fruit yield, while specific spectral combinations can enhance dry matter allocation to fruits. By regulating leaf thickness, internode elongation, and plant morphology, light quality reshapes the balance between vegetative and reproductive growth. Thus, this balance should be regarded as a dynamic trait jointly shaped by genotype, growth habit, and environmental regulation.

Under stress conditions, this balance becomes even more critical. High temperatures not only affect photosynthesis and vegetative growth but also directly impair pollen viability, stigma development, and fruit set, leading to yield loss even when vegetative growth appears vigorous. Reproductive traits such as flower number, pollen performance, and fruit set rate show closer relationships with final yield than many vegetative indicators (Graci and Barone, 2024). Similarly, under water stress, genotypic differences in vegetative performance do not necessarily translate into stable yields if reproductive development is compromised. Some genotypes maintain strong vegetative growth under stress but still exhibit significant yield reduction due to impaired fruit formation. This highlights that stable assimilate allocation to fruits during later growth stages is a key determinant of yield stability.

3 Traits Related to Flowering and Fruit Set in Protected Tomato Production

3.1 Fundamental role of inflorescence number and flower number in yield formation

The number of inflorescences and the number of flowers directly determine the potential number of fruits in protected tomato production and are among the most fundamental quantitative traits underlying yield formation. In greenhouse tomatoes, the number of marketable fruits per unit area largely depends on how many inflorescences each plant can produce and how many fully functional flowers each inflorescence can ultimately form and retain. Analyses of yield components in indeterminate tomato materials have shown that the number of flowers per inflorescence and the number of successfully fruit-set flowers are significantly positively correlated with fruit number and total yield, and these traits often determine yield potential more directly than plant size alone. The path analysis conducted by Ramana et al. (2025) also demonstrated that both flower number and fruit number have significant direct positive effects on yield. These findings indicate that achieving high and stable yields in protected tomato production depends not only on vigorous vegetative growth, but also on the effective transition from vegetative to reproductive growth, namely, the formation of a sufficient number of high-quality inflorescences and flowers.