

that help maintain cellular function but often at the cost of growth rate. Plants exposed to drought, salinity, or extreme temperatures adjust growth strategically rather than passively, and stress signaling can actively suppress anabolic activity and plant growth even before energy status collapses. For sword bean, this means that slower growth under adverse conditions should not be interpreted only as injury, but also as part of an adaptive reallocation of resources toward survival and stress resistance. A central adaptation mechanism is osmotic adjustment, in which plants accumulate solutes to maintain turgor and protect sensitive cellular processes during dehydration. Compatible solutes such as proline, soluble sugars, and other osmolytes help maintain water uptake, cell turgor, and redox balance, and across 26 studies in 12 crops osmotic adjustment was positively associated with yield under drought in 24 cases. This evidence supports the view that osmotic adjustment is not merely a survival response, but a trait with direct relevance to sustained growth and productivity under water-limited conditions.

Antioxidant defense is another key mechanism because abiotic stress commonly triggers oxidative damage through excess reactive oxygen species. Drought reduces CO₂ fixation through stomatal closure and is associated with increased ROS production, while major enzymatic antioxidants such as superoxide dismutase, catalase, ascorbate peroxidase, and glutathione reductase are central to restoring ROS homeostasis. In legumes broadly, oxidative burst, membrane instability, and metabolic disruption are early features of stress exposure, so stronger antioxidant capacity is likely to support more stable sword bean physiological performance under heat or drought (Furlan et al., 2021). Morphological escape and avoidance traits also contribute substantially to tolerance in stressed legumes. Early maturity, small leaves, deep rooting, strong remobilization under stress, and stomatal control can combine to improve drought resistance, while reduced leaf number and size, improved root system architecture, and stress-induced hormonal signaling are recognized as major tolerance traits in grain legumes (Khatun et al., 2021). Taken together, these mechanisms suggest that sword bean adaptation under different management practices will depend on combining water-conserving morphology, efficient physiological adjustment, and stress-mitigating field management to preserve growth under variable environments.

5 Effects of Cultivation Practices on Sword Bean Growth Performance

5.1 Influence of planting density and spatial arrangement

Planting density and spatial arrangement strongly influence legume growth by regulating canopy light interception, dry matter accumulation, and competition among neighboring plants (Musana et al., 2020). In soybean, higher density increased canopy light interception and dry matter accumulation and raised seed yield by 22.8%, while in common bean optimized density improved growth rate and yield by increasing light capture and reducing unnecessary competition. Uniform spatial arrangement is as important as plant number because it reduces plant-to-plant variability and improves population-level resource use (Xu et al., 2021). Soybean under uniform spacing increased seed yield by 9.5% and reduced variation in seed weight per plant by 71.5%, while faba bean evidence shows that very low density limits yield through too few plants and very high density reduces yield through pod abortion and barren stalks, indicating that sword bean should also have an optimum intermediate density rather than a simple “more plants is better” response.

Plant density also changes plant architecture, with dense stands often producing taller but less individually vigorous plants. In common bean, the highest density increased plant height, but biomass was greatest at 250,000 plants/ha and pod number per plant declined as density increased, while high-density stands can also raise risks of lodging, disease, and reduced photosynthetic efficiency under low within-canopy light (Musana et al., 2020). More detailed spacing studies show that within-row arrangement affects both vegetative growth and reproductive output. In common bean, intra-row spacing significantly altered leaf area, branch number, shoot dry weight, pods per plant, seeds per pod, and grain yield, and a 5 cm spacing gave the highest yields in the tested environments, showing that spatial precision can influence multiple components of crop performance at once (Bakure et al., 2025). For sword bean, which forms a vigorous canopy and climbing habit, these findings imply that spacing should be optimized not only for stand establishment but also for light penetration, branching pattern, and support of sustained biomass production.