

performance. Overall, the biological basis of branch formation in Hangbaiju is a coordinated system in which vegetative vigor, release from apical dominance, and conversion of lateral shoots into flower-bearing branches jointly determine yield. This is why different pinching treatments can produce large differences in flower production: they intervene directly in the developmental network that links shoot architecture to reproductive output.

3 Cultivation and Regulatory Mechanisms of Different Topping Methods

3.1 Effects of single topping on plant architecture

Single topping primarily alters plant architecture by removing the terminal bud, weakening apical dominance, and redirecting growth toward lateral shoots. In potted chrysanthemum, one terminal-bud pinching reduced final plant height relative to the unpinched control while increasing leaf number, branch number, and flowers per plant, showing that a single intervention can already shift plants from vertical growth to a more compact and productive canopy. A similar architectural response was recorded in *Chrysanthemum morifolium* cv. Ratlam Selection, where pinching at 30 days after transplanting produced the maximum number of branches and the greatest plant spread among the tested pinching times.

Single topping also affects reproductive rhythm by trading earlier flowering for improved lateral development. In annual chrysanthemum, no pinching gave the largest flowers and earliest bud appearance, whereas single pinching improved canopy spread and still maintained favorable flower characters compared with more intensive pinching. Another factorial study found that single pinching at 15 days after transplanting gave the highest flower weight and earliest 50% flowering, while single pinching at 30 days ranked next and produced broader plant spread, indicating that one well-timed topping can balance architecture and yield without the stronger flowering delay associated with repeated pinching (Mohanty et al., 2025).

3.2 Effects of multiple topping and hierarchical pruning

Multiple topping strengthens the branching response by repeatedly interrupting apical dominance, thereby increasing the number of active lateral growing points and expanding canopy spread. In *Chrysanthemum indicum*, three pinching events produced the highest branch number, leaf number, plant spread, and flower number, while unpinched plants remained the tallest and least branched (Ehsanullah et al., 2021). In annual chrysanthemum, double pinching likewise produced the shortest plants but the greatest numbers of leaves, primary branches, and flowers per plant, supporting the general rule that repeated topping shifts assimilate use away from main-stem elongation and toward branch proliferation.

Hierarchical pruning effects depend not only on pinching frequency but also on which node positions are retained after each cut. In garland chrysanthemum, new-shoot emergence after the first pinching was higher than after the second, and lateral-shoot development varied systematically with node position (Matsunaga and Sasaki, 2026). Shoots arising from the first and second nodes of the main stem showed stronger subsequent regeneration, whereas regrowth from lower nodes on upper first-order laterals was weaker, indicating that hierarchical pruning should retain node positions with higher regenerative capacity rather than treating all lateral shoots as equivalent.

3.3 Interactive effects of topping intensity and timing

The effect of topping intensity depends strongly on timing, because earlier and later pinching modify different developmental phases of the crop. In garland chrysanthemum, pinching in the nursery at 20 days after sowing produced the highest branch number, plant spread, and stem girth, whereas non-pinched plants stayed consistently taller, showing that early topping can be more effective for branch induction than delayed intervention. In *C. morifolium* cv. Ratlam Selection, pinching at 30 days after transplanting outperformed pinching at 45 days for branch number and plant spread, while no pinching still led to earlier bud initiation and 50% flower opening, which highlights the trade-off between structural improvement and earliness.

Increasing topping intensity can further raise flower number, but delayed or repeated pinching often postpones flowering and may reduce individual-flower traits. In annual chrysanthemum, double pinching at 15 and 30 days gave the highest flower number, but it also significantly delayed flowering and reduced individual flower size.