

Figure 4 Schematic representation of tissue culture and micropropagation techniques used for marigold improvement

Despite its considerable advantages, commercial application of tissue culture in marigold remains constrained by several factors. Large-scale micropropagation requires specialized laboratory facilities, skilled personnel, and relatively high production costs, limiting its adoption by commercial nurseries. In addition, successful acclimatization of regenerated plantlets under field conditions remains a major challenge, and prolonged in vitro culture may occasionally induce somaclonal variation that affects genetic uniformity. Consequently, further optimization of propagation protocols and cost-effective production systems is required before tissue culture can be widely adopted for commercial-scale marigold production.

3.5 Achievements in marigold breeding

The growing needs of the ornamental, industrial, and religious sectors necessitate the development of highly productive cultivars. To address this, modern research has produced superior hybrids specifically 'Arka Abhi', 'Arka Bhanu', and 'Arka Vibha' which demonstrate remarkably higher flower production. Beyond simple yield increases, these new varieties offer practical advantages like increased durability during transport and a longer shelf life, which ranges from 8 to 9 days. These hybrids have shown potential for commercial cultivation in various agro-climatic zones, enhancing farmer incomes and market availability (Venkatesan and Ramesh Kumar, 2025).

Commercial marigold varieties now have better tolerance to these risks due to breeding operations that have successfully included resistance genes from wild cultivars (Babaei et al., 2021). Abiotic stresses, such as drought, salinity, and heavy metal contamination, also adversely affect marigold growth and essential oil quality. Elevated levels of these stresses can result in the production of reactive oxygen species (ROS), which are harmful to plant cells. Research has shown that drought-responsive genes play a crucial role in regulating important physiological and biochemical processes, supporting the development of drought-tolerant hybrids (Kumar et al., 2023). In a similar way, salinity-tolerant cultivars are being improved by focusing on traits such as osmotic regulation and ion balance, which help maintain productivity under saline conditions (Ma et al., 2020). Advanced biotechnological approaches, including CRISPR-Cas9 and transcriptomic analysis, are increasingly being used to enhance stress tolerance in plants through precise genome editing and in-depth study of stress-response mechanisms. These technologies have enabled the discovery of key genes involved in abiotic stress resistance, accelerating the development of improved resilient varieties (Xu et al., 2020).

Quality traits such as vibrant color, longer vase life, and higher carotenoid content have been prioritized in recent breeding efforts. Varieties like ‘Arka Shubha’, known for its high carotenoid content, have been developed with industrial applications in mind. These varieties offer high yields of carotenoids, which are important for use in the pharmaceutical, food, and cosmetic industries. It is found that ‘Arka Shubha’ produced significantly higher levels of lutein and zeaxanthin, which are valuable carotenoids known for their antioxidant properties. These carotenoids