have widespread applications in supplements, skincare products, and natural food colorants (Udchachon et al., 2021).

3.6 Breeding techniques and marigold released

Breeding programs in marigold have resulted in the development of diverse cultivars with improved flower yield, color intensity, plant architecture, and commercial adaptability. Different breeding approaches, including hybridization, selection, mutation breeding, and male-sterility-based breeding have contributed to the release of improved cultivars in India and other regions (Table 1). Hybrid cultivars generally provide advantages in yield and flower quality, whereas selection and mutation breeding have expanded genetic diversity for specific ornamental traits.

Table 1 Representative marigold cultivars developed through different breeding approaches and their major applications

Breeding approach	Representative cultivars	Main breeding objectives	Major advantages/applications
Hybridization	Arka Agni, Arka Bangara-2, Arka Ambara	Increased flower yield, larger flower size, improved uniformity	Commercial hybrid production
Selection breeding	Pusa Narangi Gainda, Pusa Basanti Gainda	Flower color, yield stability, plant type improvement	Open-pollinated cultivar development
Mutation breeding	Pusa Centenary	Creation of novel variation	Development of unique flower traits
Male sterility-based breeding	IIHR/IARI male sterile lines	Efficient hybrid seed production	Reduced emasculation labor

3.7 Integrated post-harvest technology

Post-harvest management is a critical component of marigold production because flowers are highly perishable and rapidly lose their commercial value after harvest. Recent advances in cold chain management, value addition, and processing technologies have significantly improved flower quality, shelf life, and industrial utilization. Low-temperature storage combined with high relative humidity effectively reduces respiration rate, ethylene production, moisture loss, and microbial deterioration, thereby maintaining flower freshness and extending marketability. Studies have demonstrated that storing marigold flowers at 4 °C with approximately 95% relative humidity can extend shelf life to about 8 days, compared with only 3 days under ambient conditions, while preserving flower colour, firmness, and overall quality (Dalavi et al., 2025). Such cold-chain technologies are particularly beneficial for long-distance transportation and export marketing.

In addition to fresh flower marketing, recent technological advances have enhanced the industrial utilization of marigold through value-added processing. Advanced chromatographic techniques enable the extraction of high-purity lutein (up to 97.1%), which is widely used in pharmaceutical products, nutraceuticals, poultry feed, cosmetics, and natural food colourants. Likewise, solid-state fermentation of fresh flowers with calcium lactate prior to drying has been reported to improve β-carotene retention and increase the recovery of high-quality value-added powders suitable for commercial processing (Hayat, 2024). These post-harvest innovations not only minimize economic losses but also diversify the industrial applications of marigold, thereby increasing its commercial profitability.

3.8 Advancement in cultivation practices

Modern cultivation practices have considerably improved marigold productivity through the optimization of plant architecture, resource utilization, irrigation management, and environmental control. Among these practices, pinching remains one of the most effective cultural operations for regulating plant growth and flowering. Pinching suppresses apical dominance by reducing auxin accumulation at the shoot apex, thereby stimulating lateral bud development, increasing branch formation, and improving assimilate distribution towards reproductive organs. Early pinching at 14 days after transplanting promotes earlier flowering, whereas delayed pinching at approximately 28 days after transplanting generally produces greater plant height, more branches, and a higher number of flowers, ultimately resulting in superior flower yield.